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

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ABSTRACT

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).

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.

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 1980-2018 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), southern bluefin tuna (SBT), sharks (SKX) 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 42 clusters for taking the mixture of fishing operations into account (P_2^7 which means 2 species can be chosen with priority from 7 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, 2019).

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, $\varepsilon \sim$ 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. Cluster analysis

For Area 1 (NW), 4 clusters were selected (Fig. 2). Cluster 1 was the operations consisted of yellowfin tuna, cluster 2 was the operations for bigeye, cluster 3 was for mixed species and cluster 4 was for albacore (Fig. 3). The operations of cluster 4 mainly concentrated subtropical and temperate waters before 1990s and NHBF were about 10 hooks; operations of cluster 2 and 3 concentrated in tropical waters after 1990s and NHBF increased to about 15 hooks (Fig. 4). The proportion of albacore catches of cluster 4 were obviously higher than those of other clusters (Fig. 5). The historical trends of catches by species are shown in Fig. 6 and the trends of albacore catch and fishing effort by clusters are also shown in Fig. 7. The proportion of albacore catches of cluster 4 revealed a decreasing trend in recent years.

For Area 2 (NE), 3 clusters were selected (Fig. 8). Cluster 1 was the operations for albacore, cluster 2 and 3 consisted of more operations for bigeye tuna, but cluster 3 were mainly for bigeye tuna and cluster 2 consisted of more yellowfin tuna and other species (Fig. 9). The operations of cluster 1 mainly concentrated subtropical and temperate waters before 1990s and NHBF were about 10 hooks; operations of cluster 2 and 3 concentrated in tropical waters since early 2000s and NHBF were about 15 hooks; operations widely distributed with NHBF larger than 10 hooks for cluster 2 (Fig. 10). The proportion of albacore catches of cluster 1 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. In this area, most of the catches of albacore were grouped into cluster 1 but the catches have substantially decreased in recent years.

For Area 3 (SW), 3 clusters were selected (Fig. 14). The operations of cluster 3 were mainly for albacore, cluster 2 was the operations for other species, and cluster 1 contained the operations for albacore, bigeye tuna, yellowfin tuna and swordfish (Fig. 15). Cluster 3 mainly consisted of the operations before 1990s; operations of cluster 1 were mainly from 1990s to early 2000s; most operations of cluster 2 concentrated in the southwest waters after the mid-2000s; NHBF were mainly 10 hooks for clusters 1 and 3, and NHBF were about 10-15 hooks for cluster 2 (Fig. 16). The proportion of albacore catches of cluster 3 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. Most of the catches of albacore were made by the operations of cluster 3 but the proportion of albacore catches 3 slightly increased with the fishing effort for cluster 2 in recent years.

For Area 4 (SE), 4 clusters were selected (Fig. 20). Clusters 1 and 2 contained the operations mainly for albacore, cluster 3 were the operations for the bigeye tuna but they also had some operations for yellowfin tuna and swordfish, cluster 1 were the operations for other species but most clusters also contained some operations for other species except for cluster 2 (Fig. 21). The operations of cluster 1 mainly occurred after the early 2000s; most of operations were made before the mid-2000s for other clusters; the operations of cluster 4 were mainly from the second half year for SBT; the differences in the characteristics of the operations were not significant for other factors (Fig. 22). 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. 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. 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.

3.2. CPUE standardization

The clusters contained very few catches of albacore were excluded when doing the CPUE standardizations. Cluster 2 was excluded for Area 1 (NW), clusters 1 and 3 were excluded for Area 3 (SW), and cluster 3 was excluded for Area 4 (SE). Although most of the albacore catches were grouped into cluster 1 in Area 3 (NE), all clusters were used for further analysis because very few albacore catches occurred the after early 2000s even the cluster 1.

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. 26-29, 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. 30 and 31. 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. Comparing to the results of Wang (2019), unreasonable high values of the standardized CPUE were not occurred in Area

2 (NE) when all of the data were used in CPUE standardizations. In addition, the 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 when Wang (2019) excluded the data of some clusters to conduct the CPUE standardizations.

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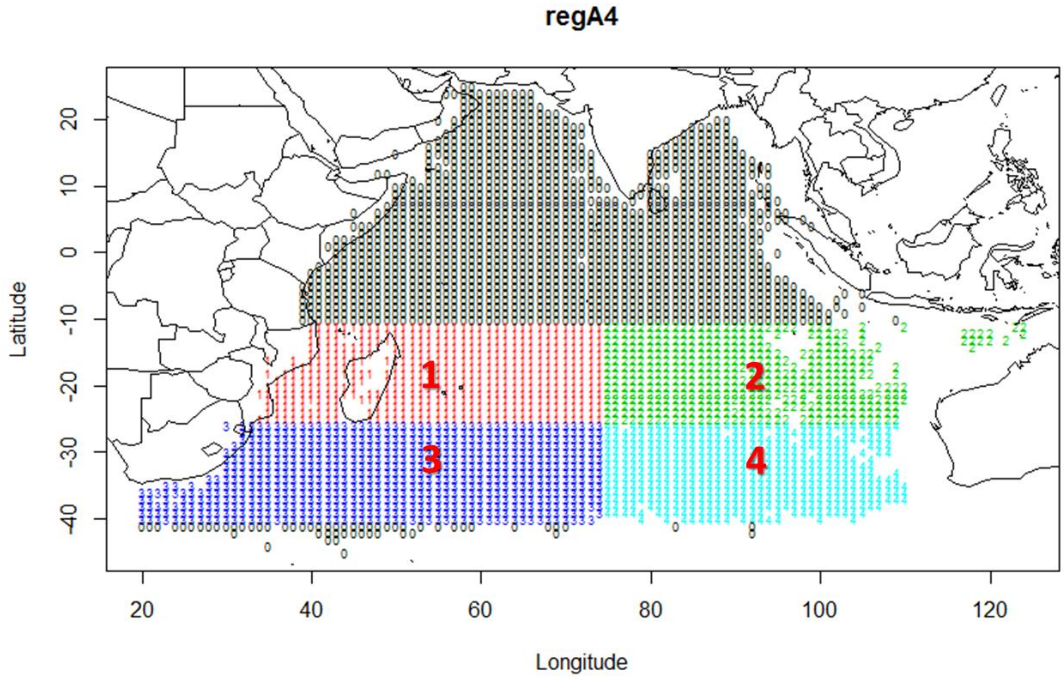


Fig. 1. Area stratification for albacore in the Indian Ocean.

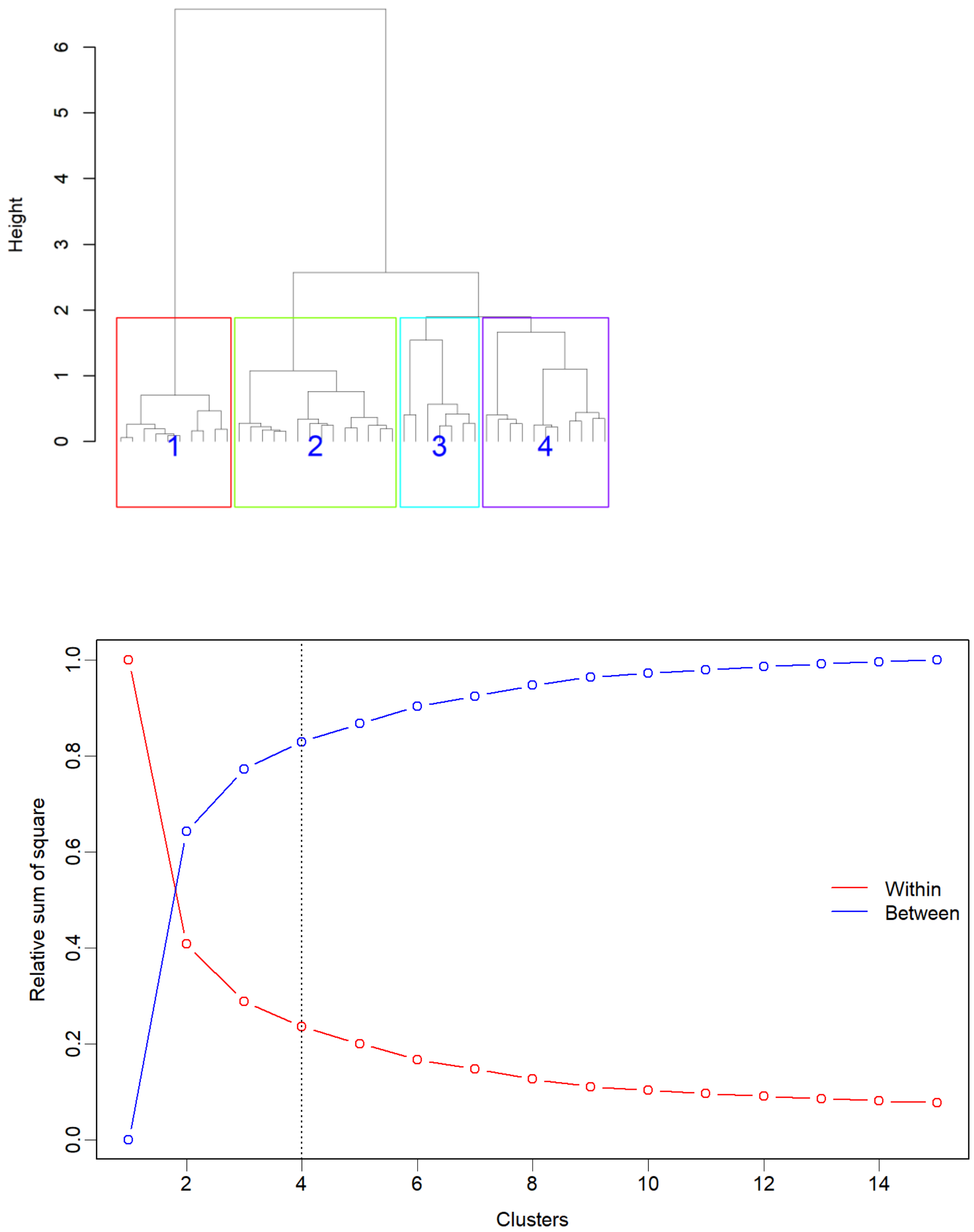


Fig. 8. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

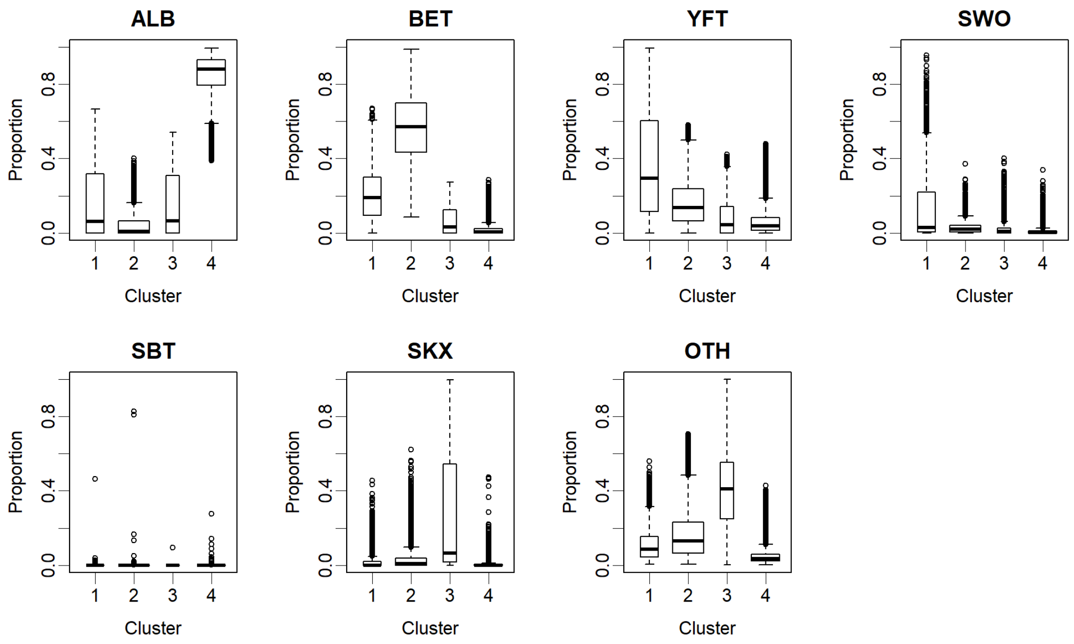


Fig. 9. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

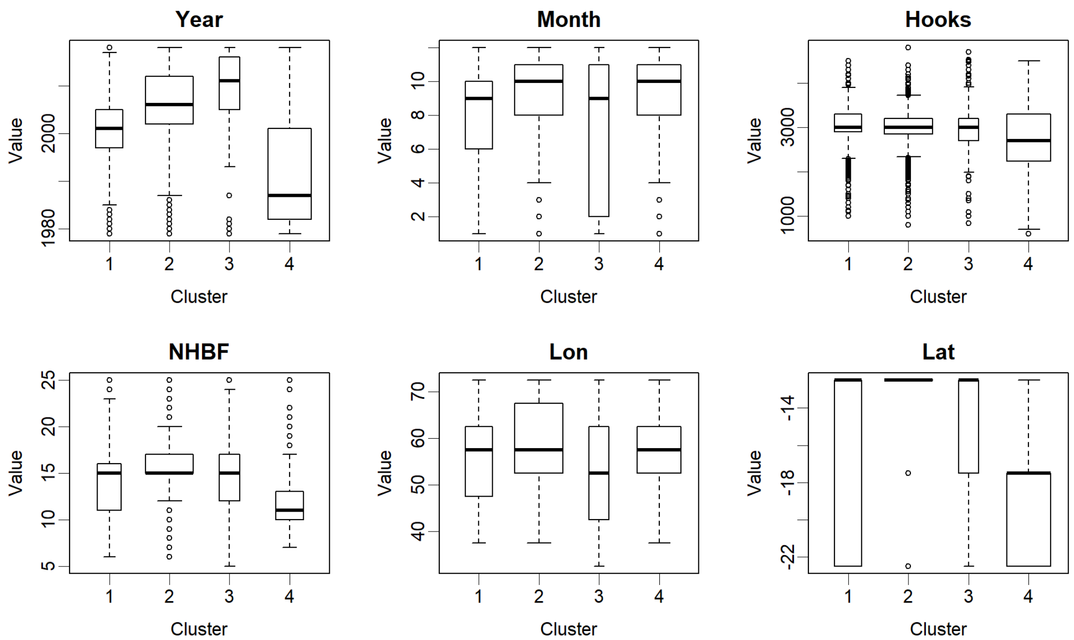


Fig. 10. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

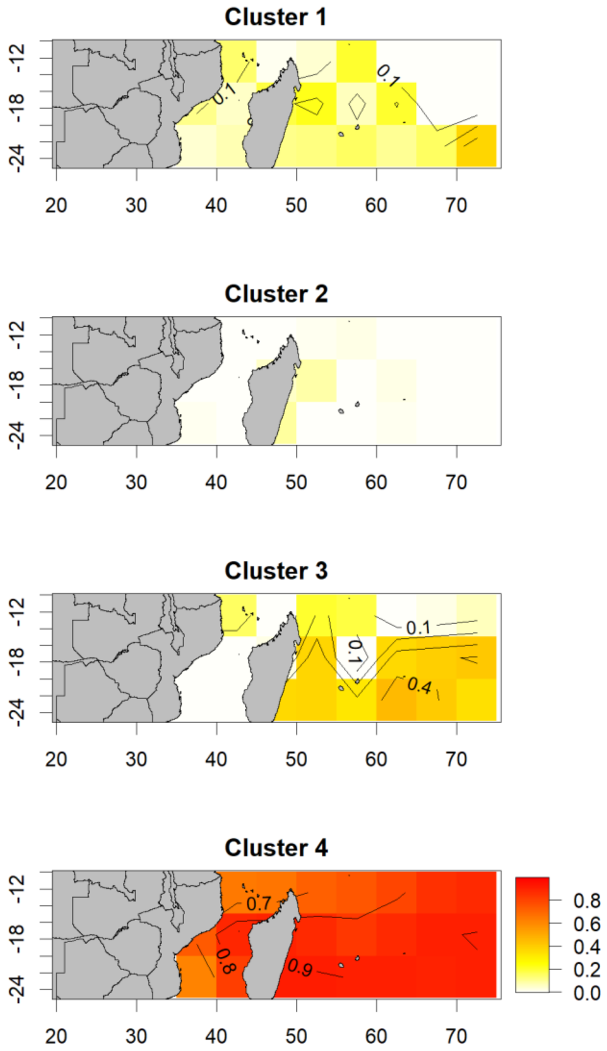


Fig. 11. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean. Yellow is high catch and red is low catch.

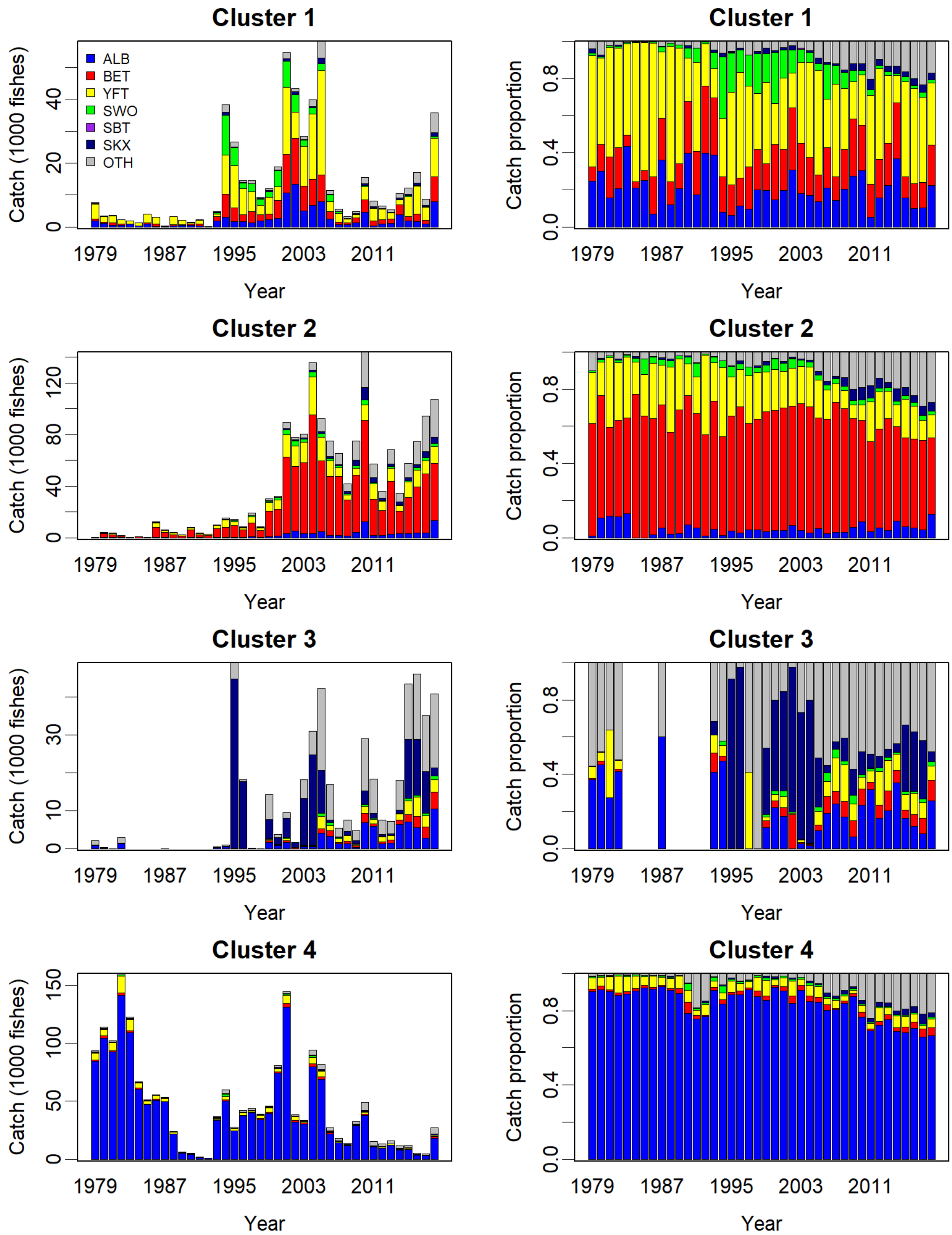


Fig. 12. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

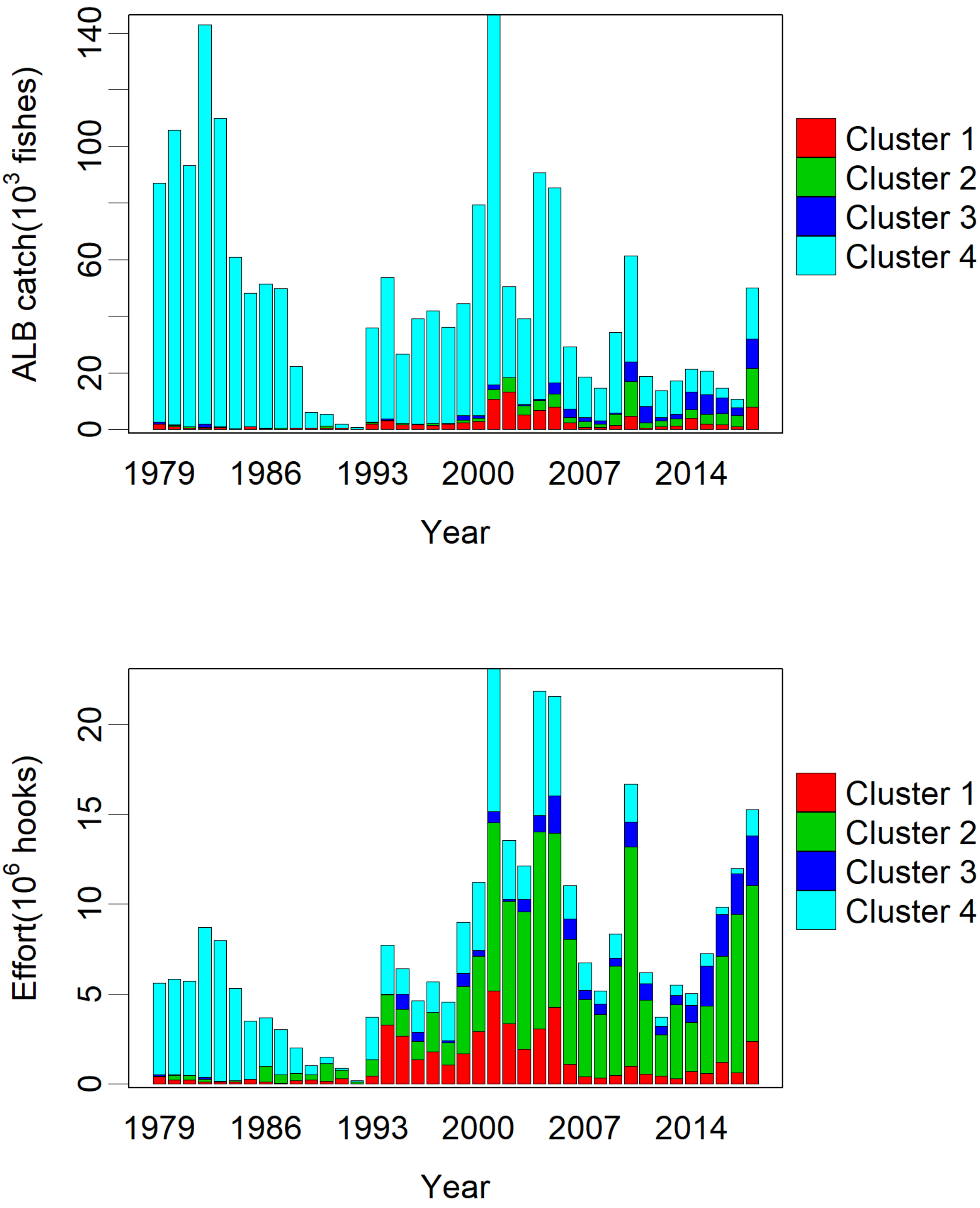


Fig. 13. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

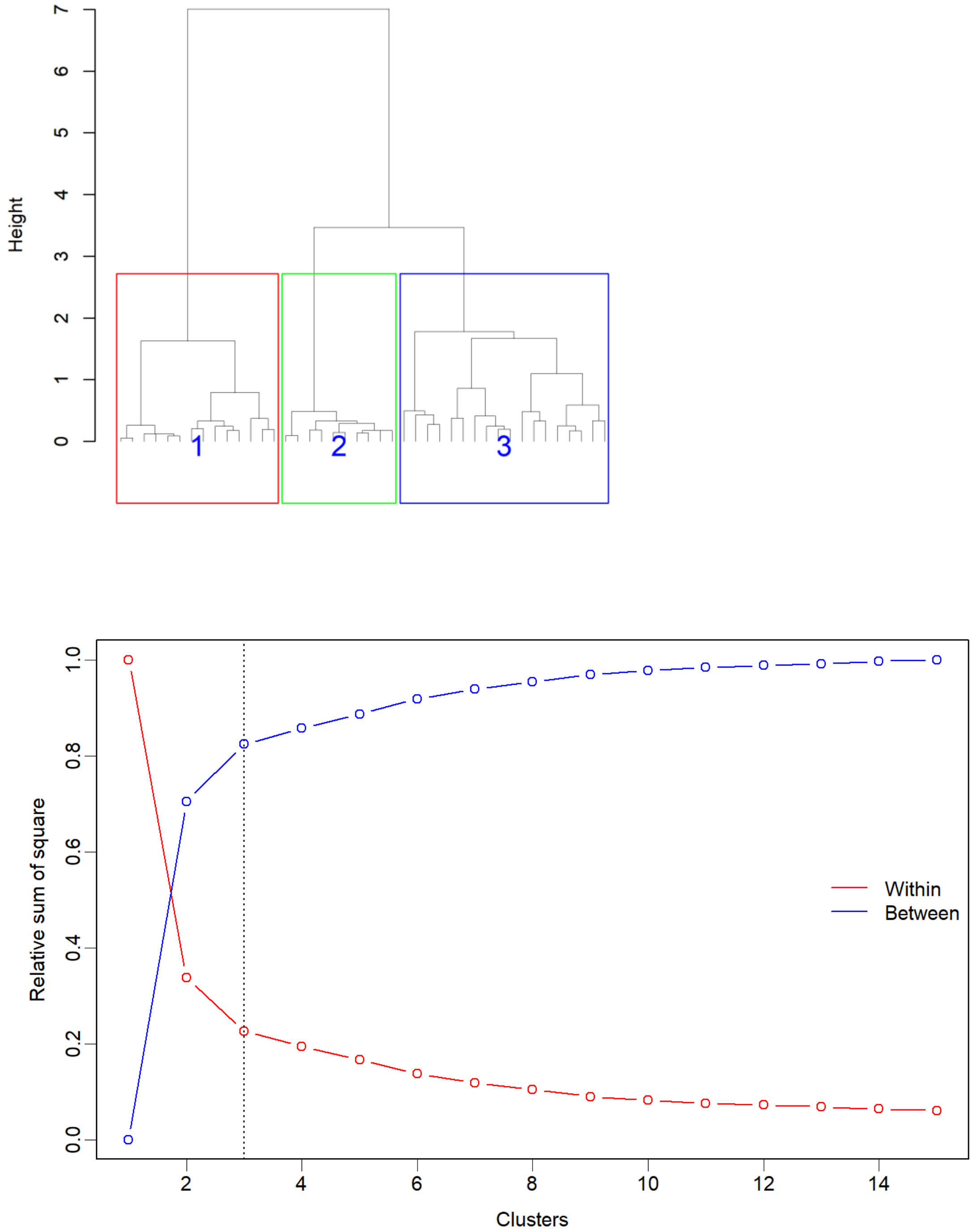


Fig. 14. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

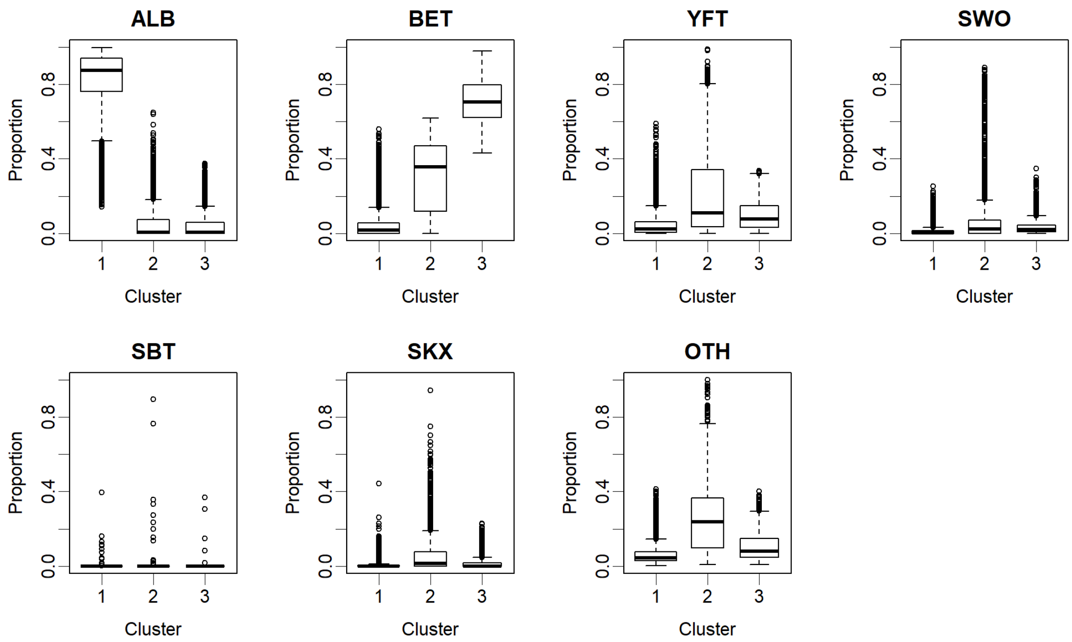


Fig. 15. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

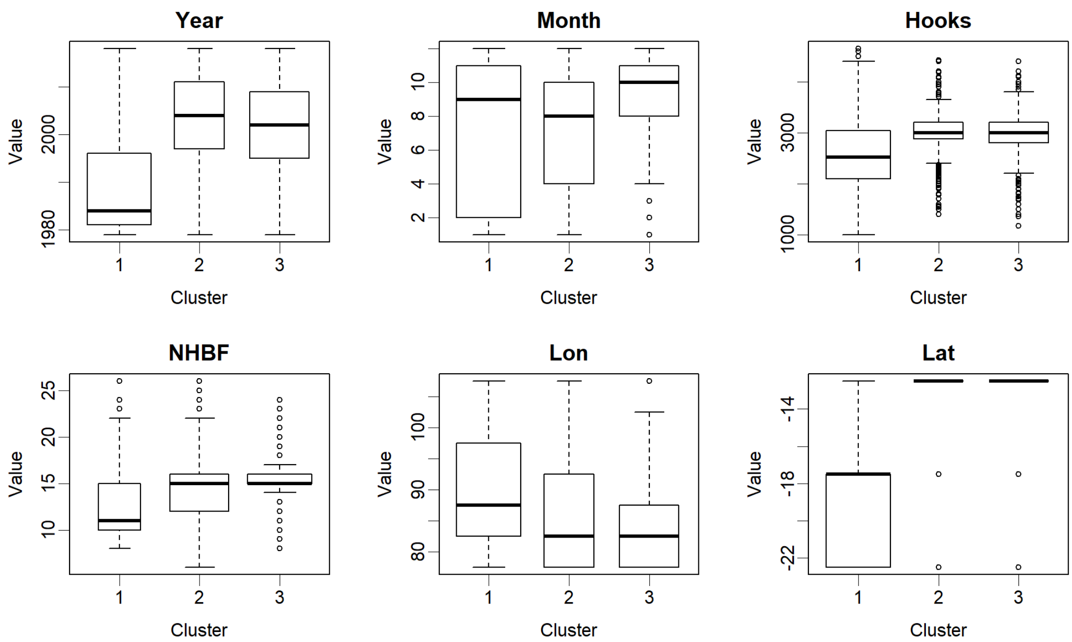


Fig. 16. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

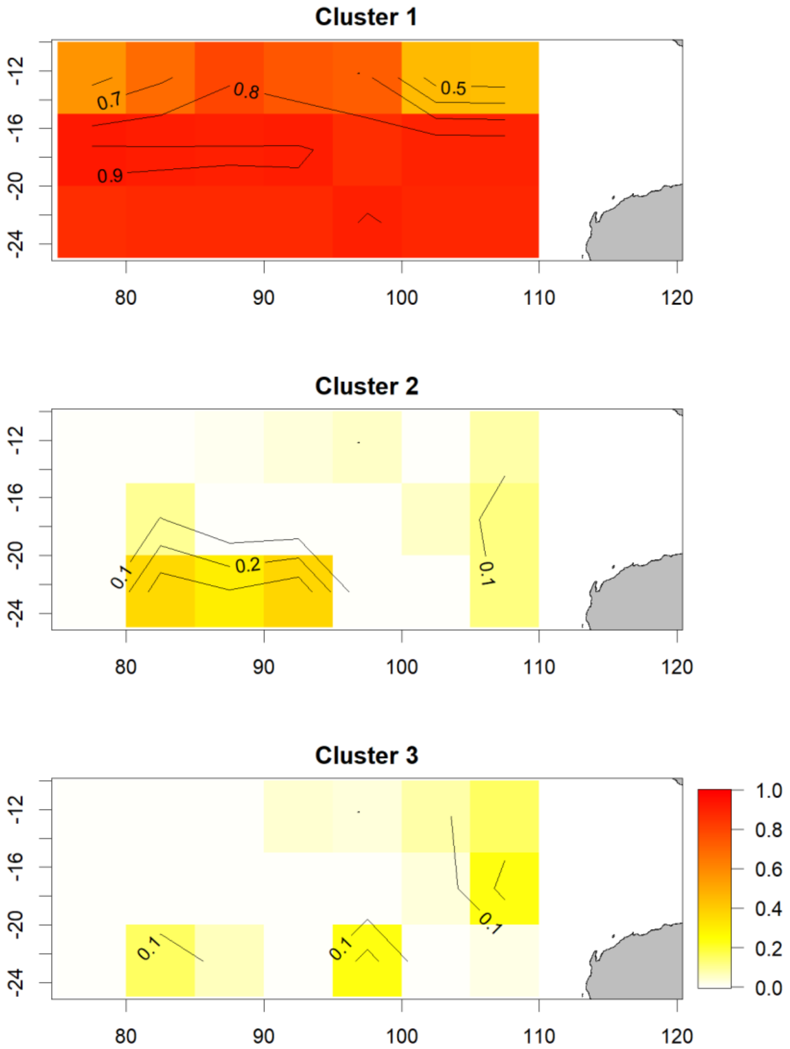


Fig. 17. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean. Yellow is high catch and red is low catch.

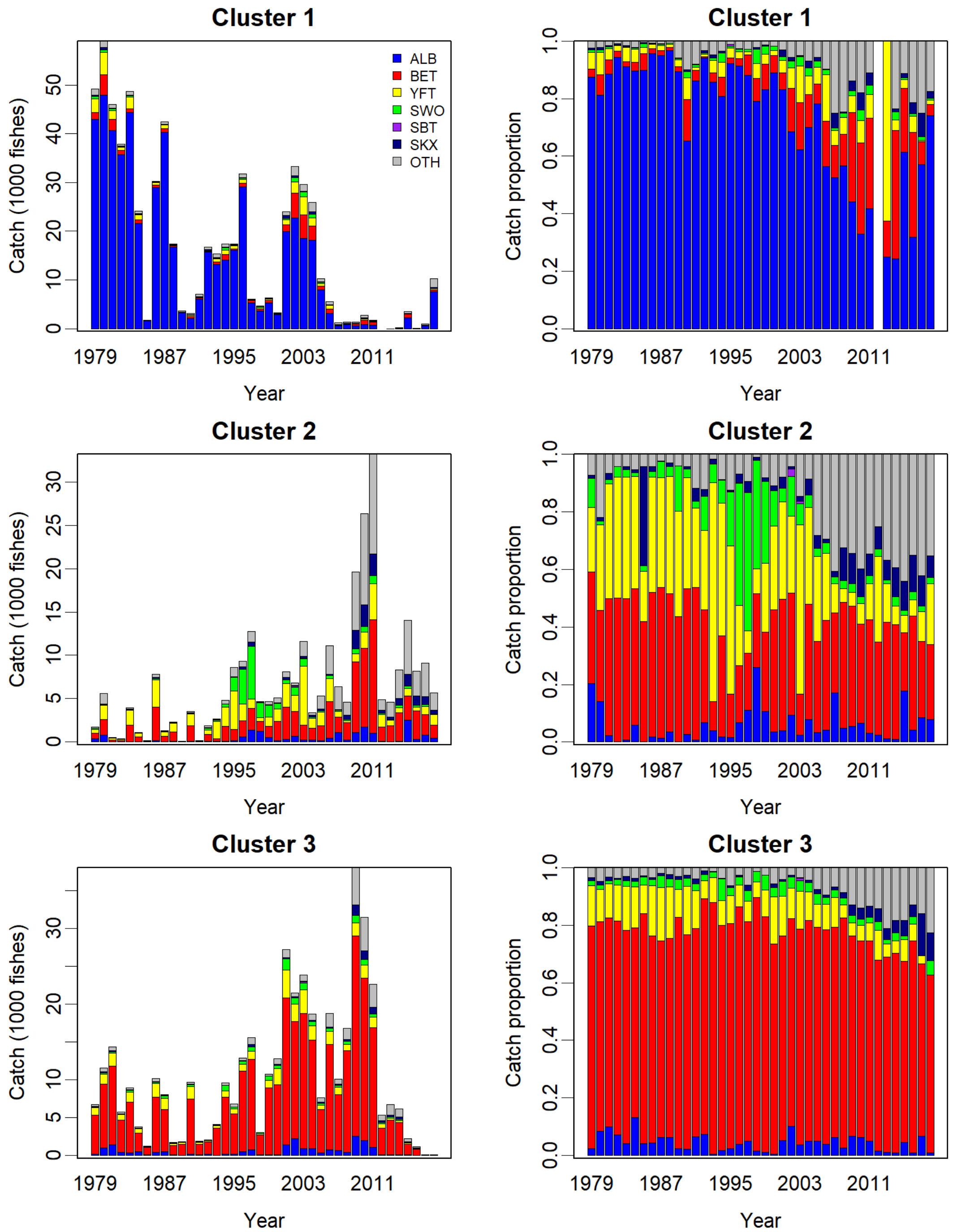
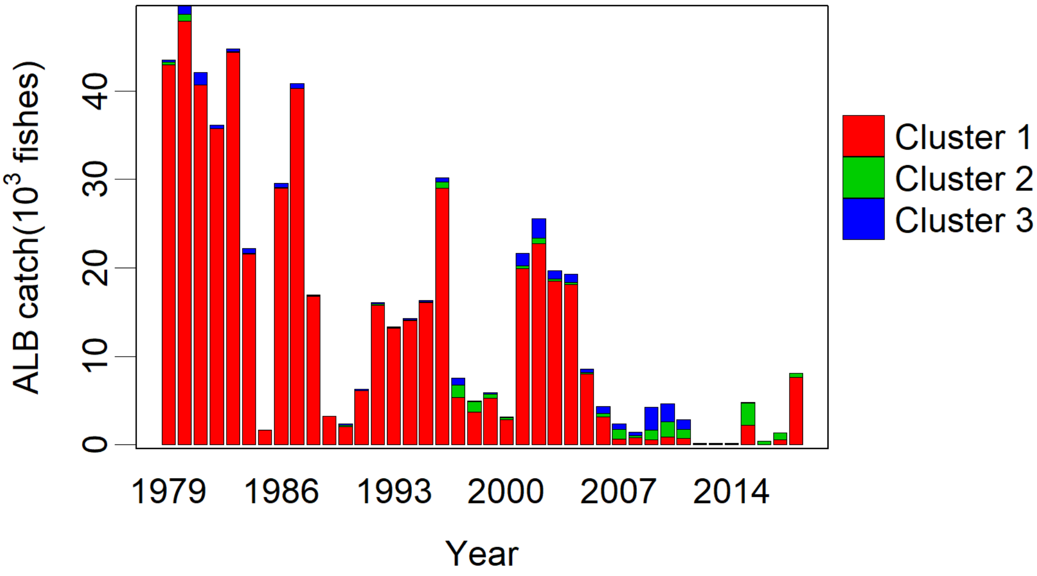


Fig. 18. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.



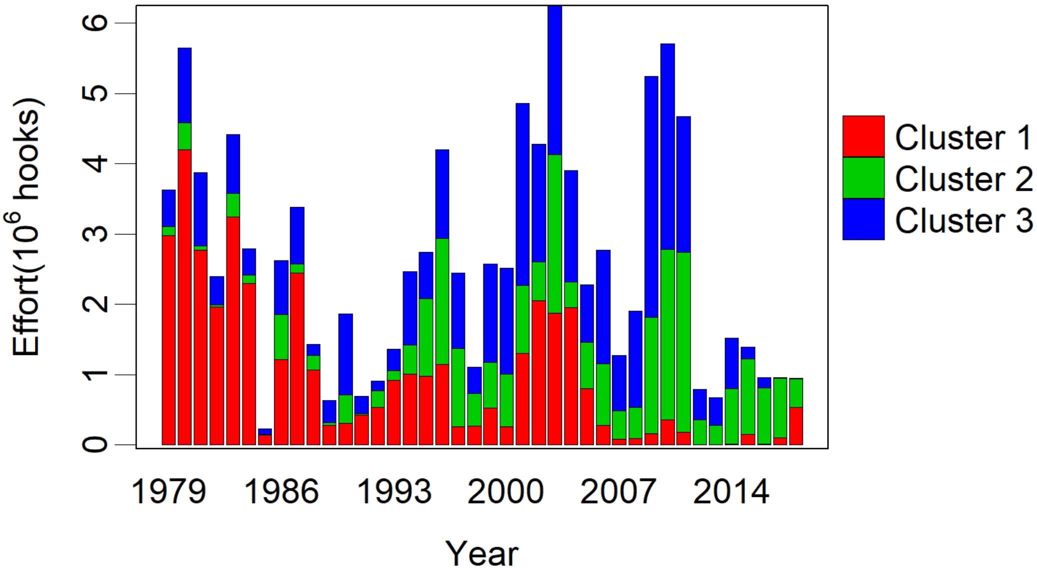


Fig. 19. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

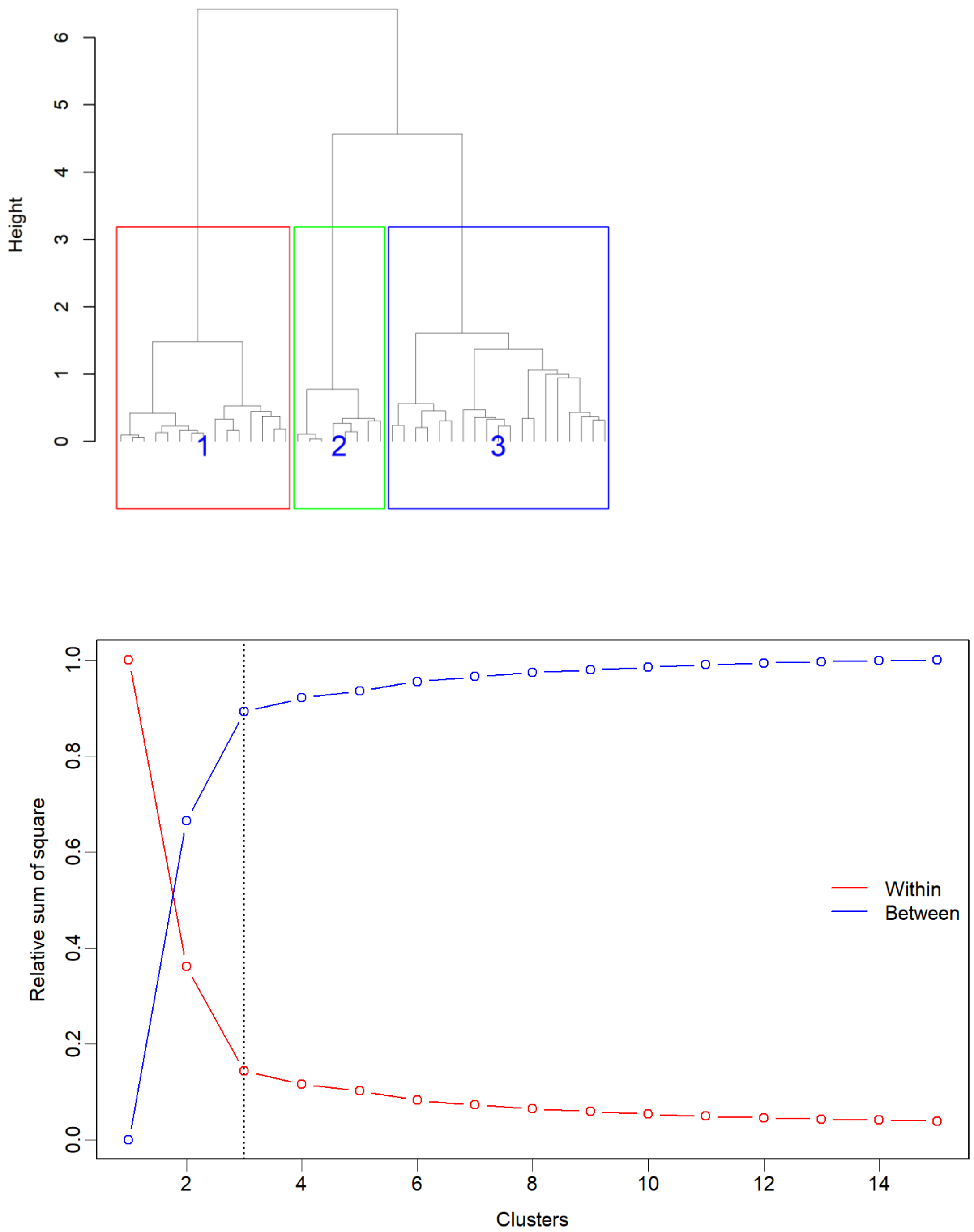


Fig. 20. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

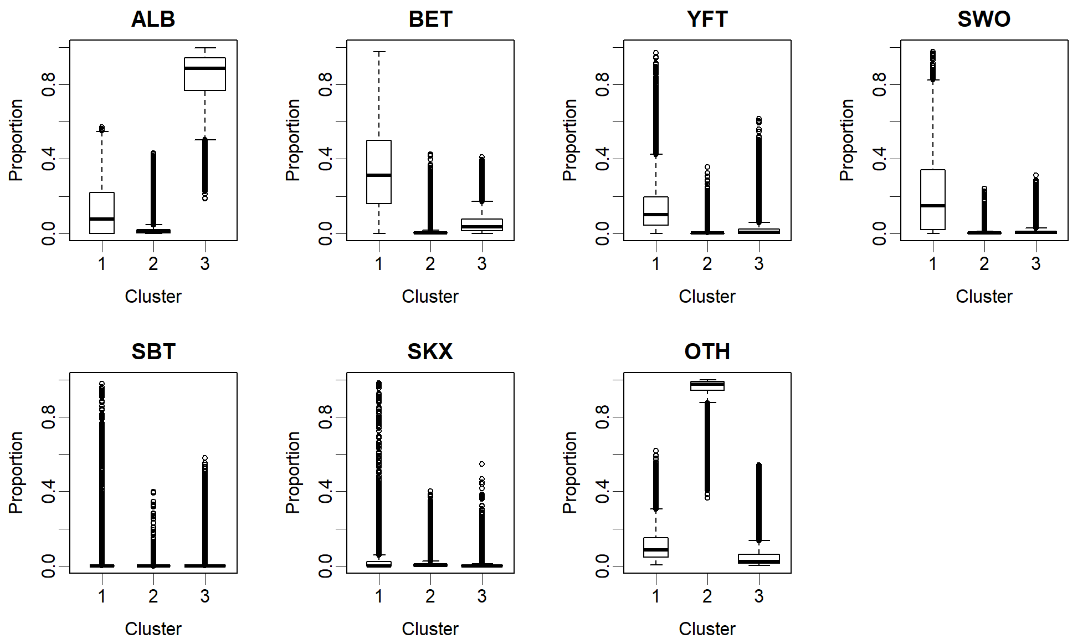


Fig. 21. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

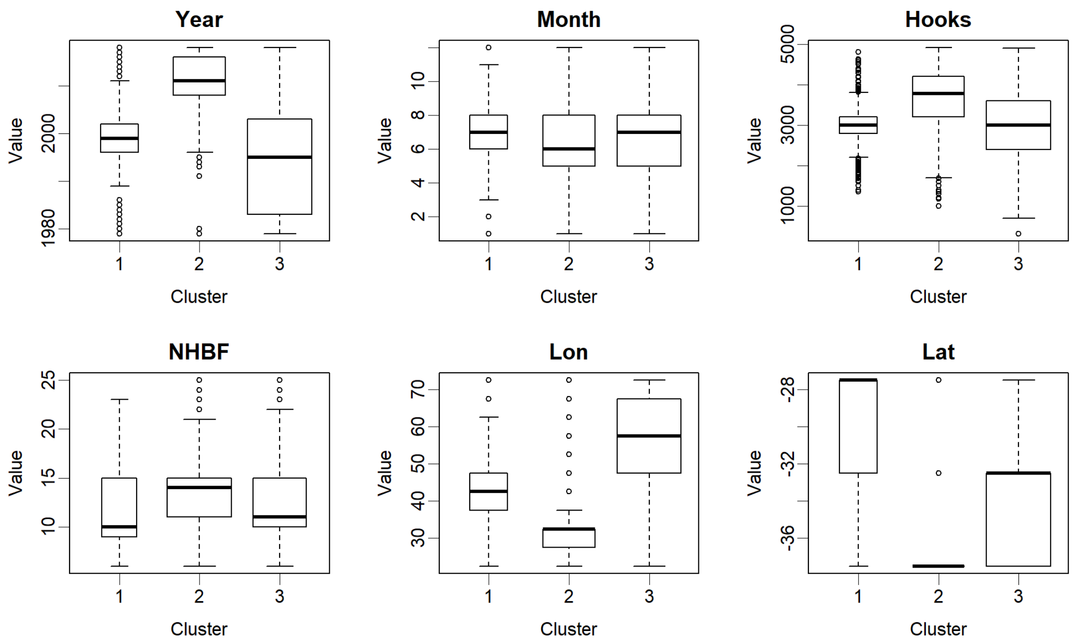


Fig. 22. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

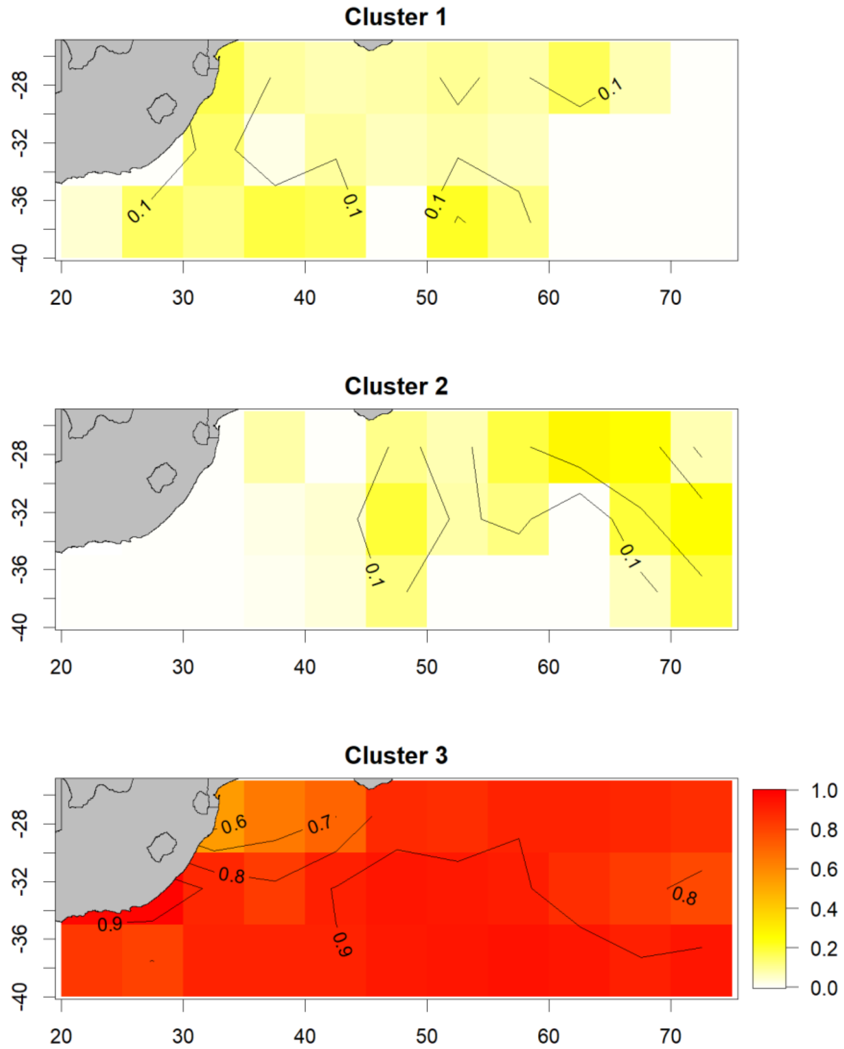


Fig. 23. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean. Yellow is high catch and red is low catch.

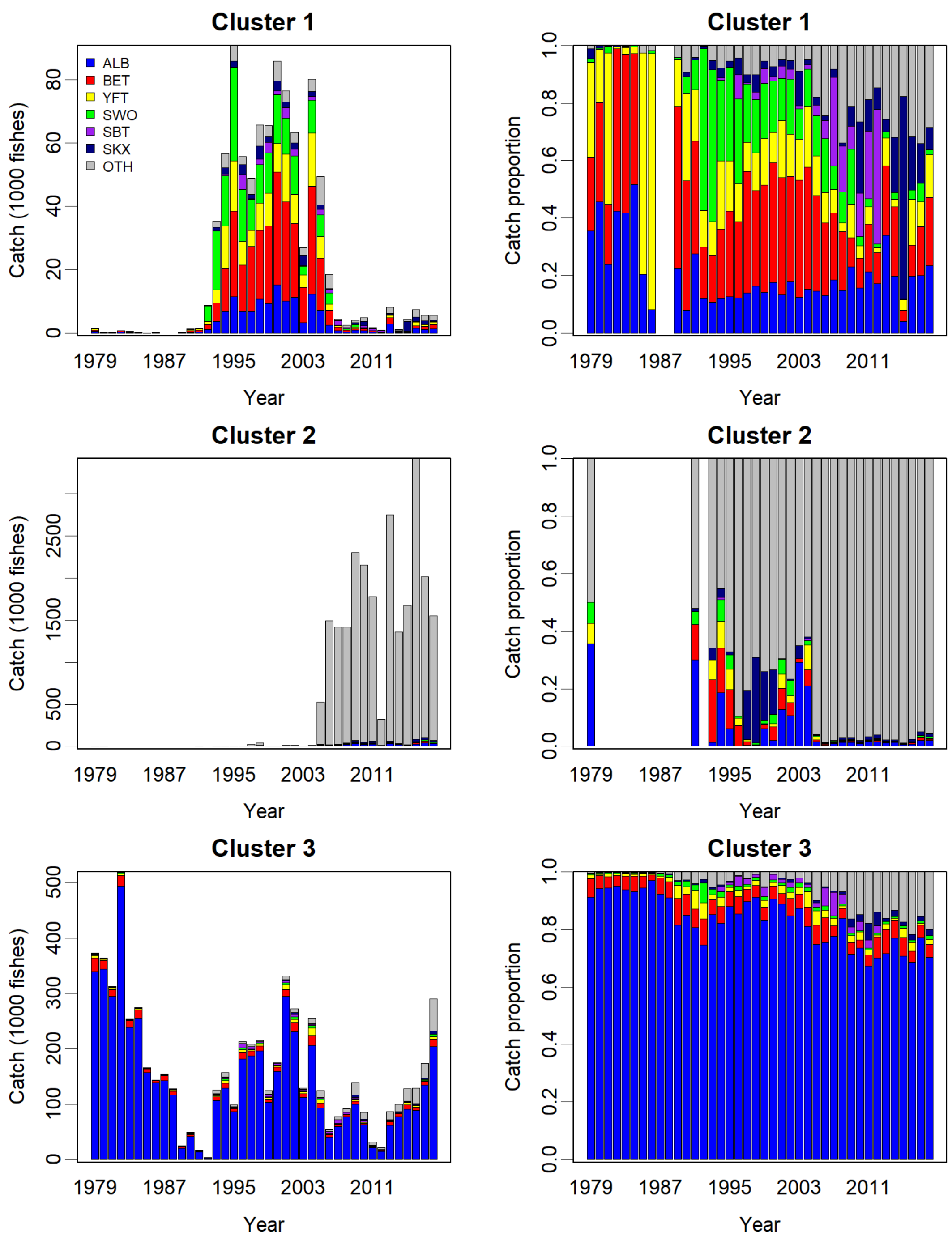


Fig. 24. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

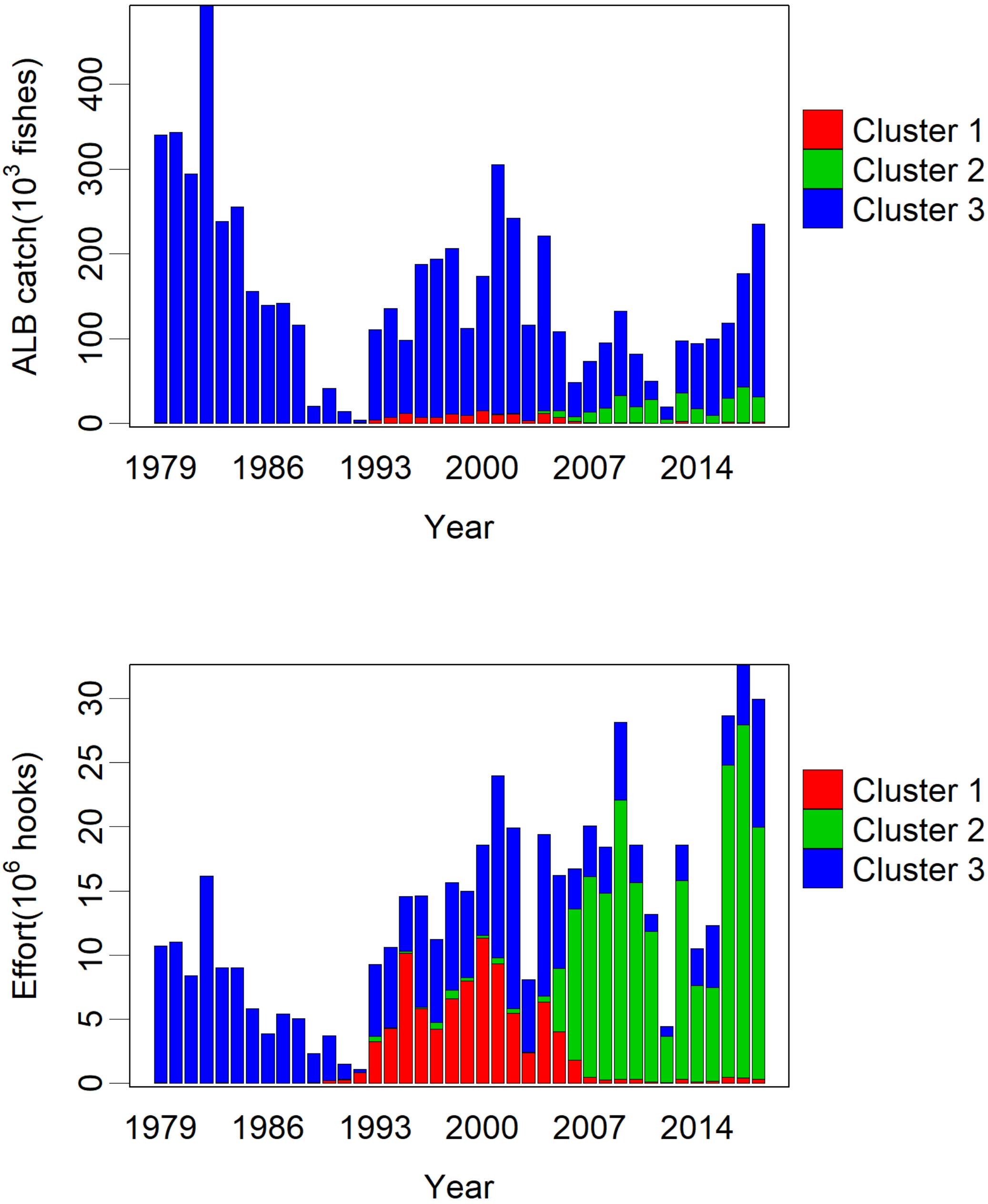


Fig. 25. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

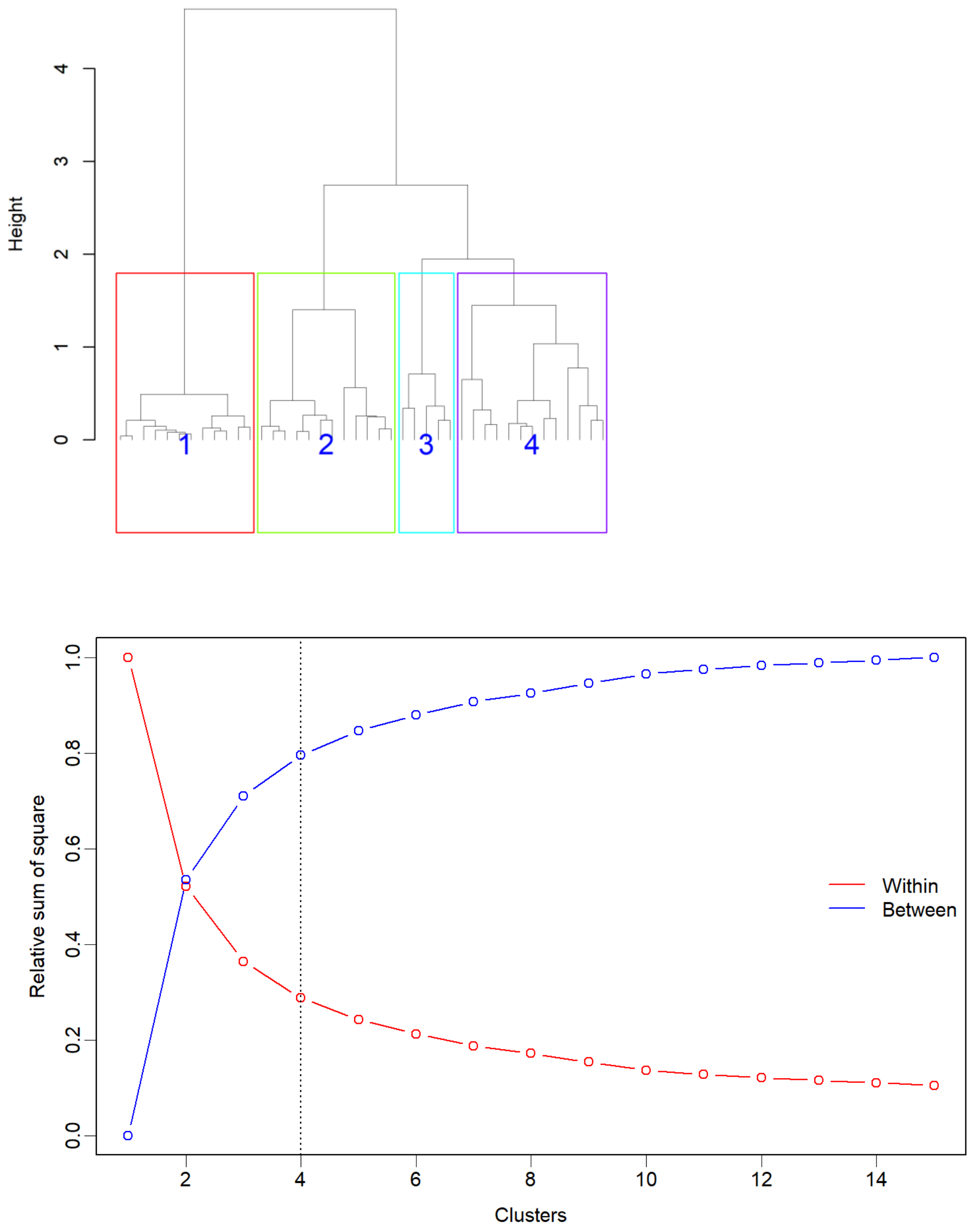


Fig. 26. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

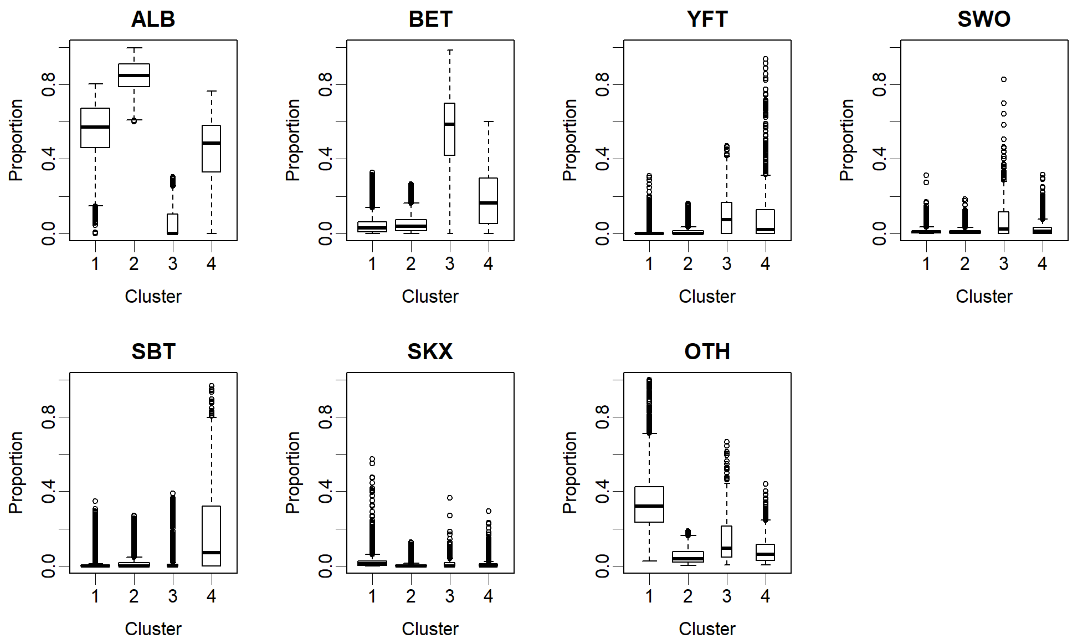


Fig. 27. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

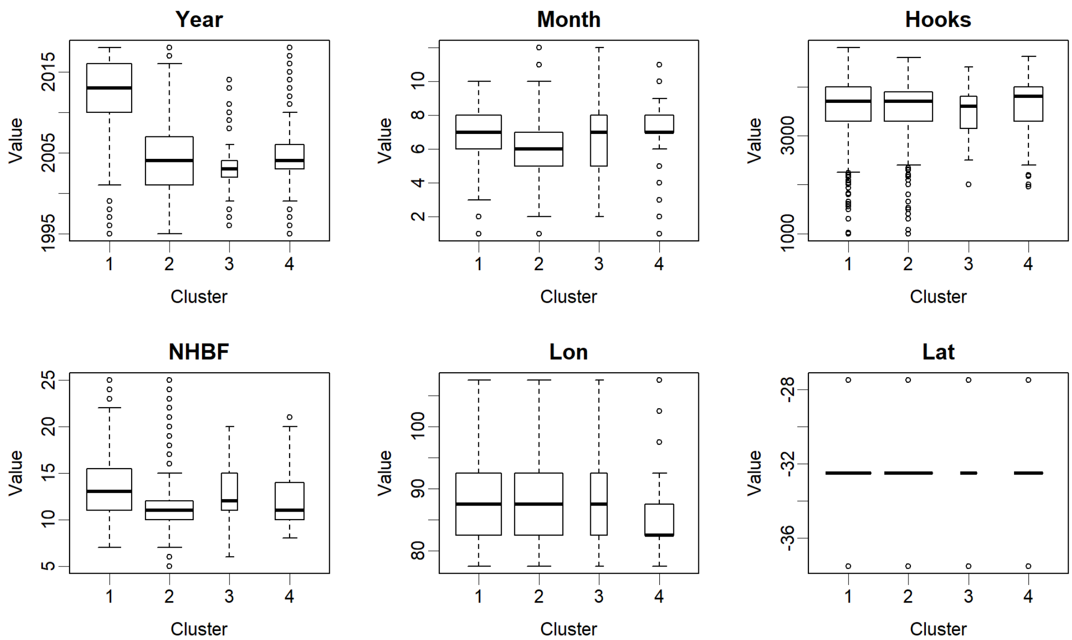


Fig. 28. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

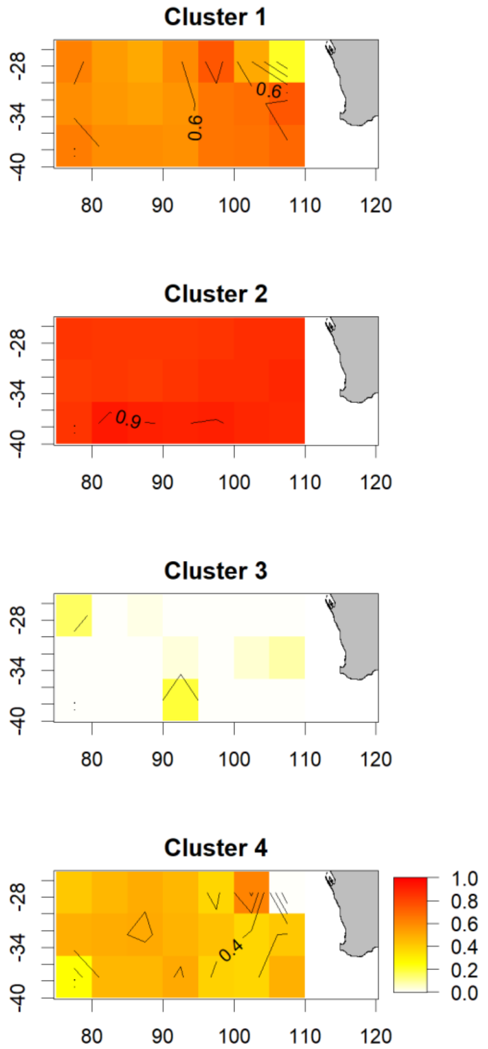


Fig. 29. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean. Yellow is high catch and red is low catch.

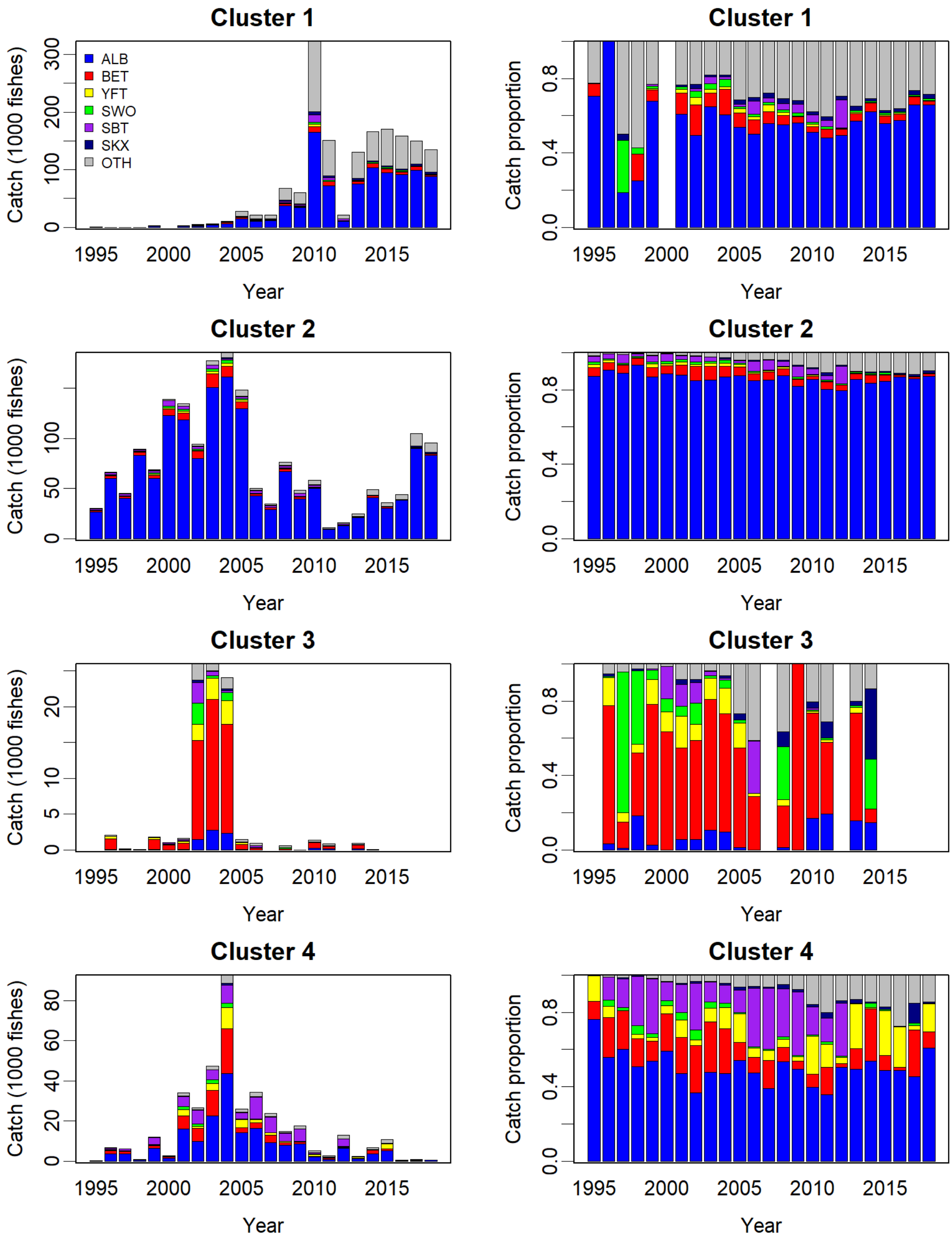


Fig. 30. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

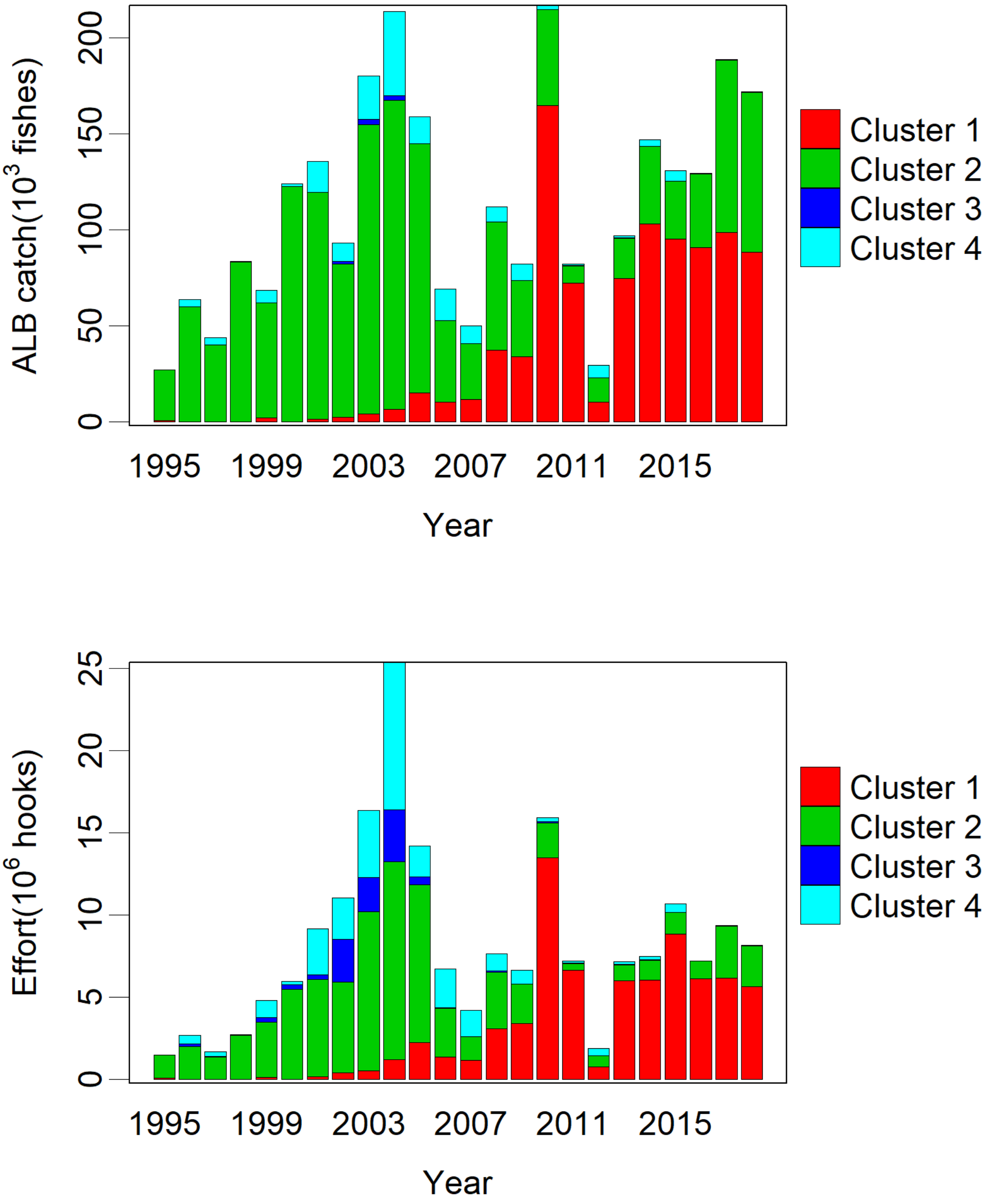


Fig. 31. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

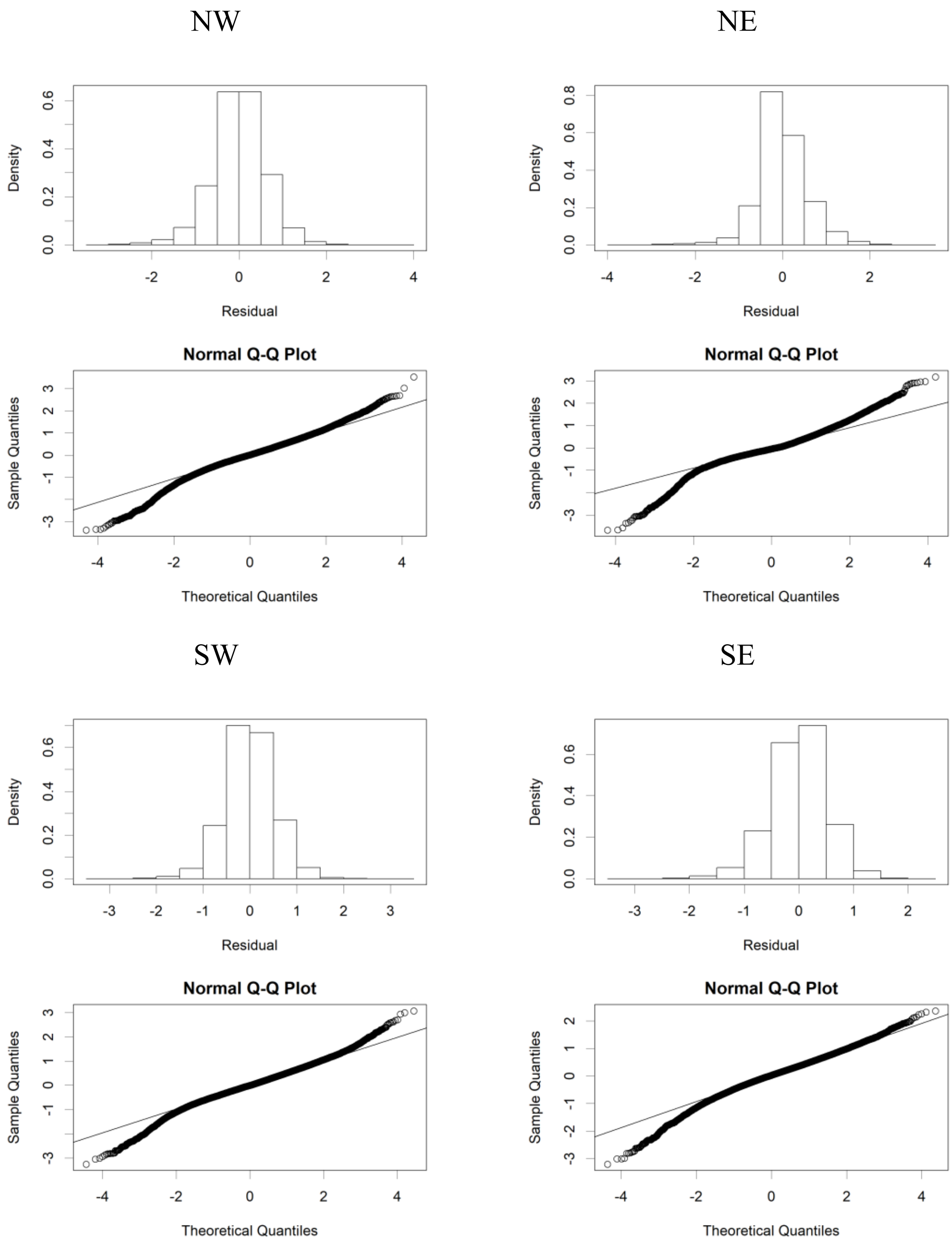


Fig. 32. Histogram and Quantile-Quantile plots obtained from the year-quarter GLM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

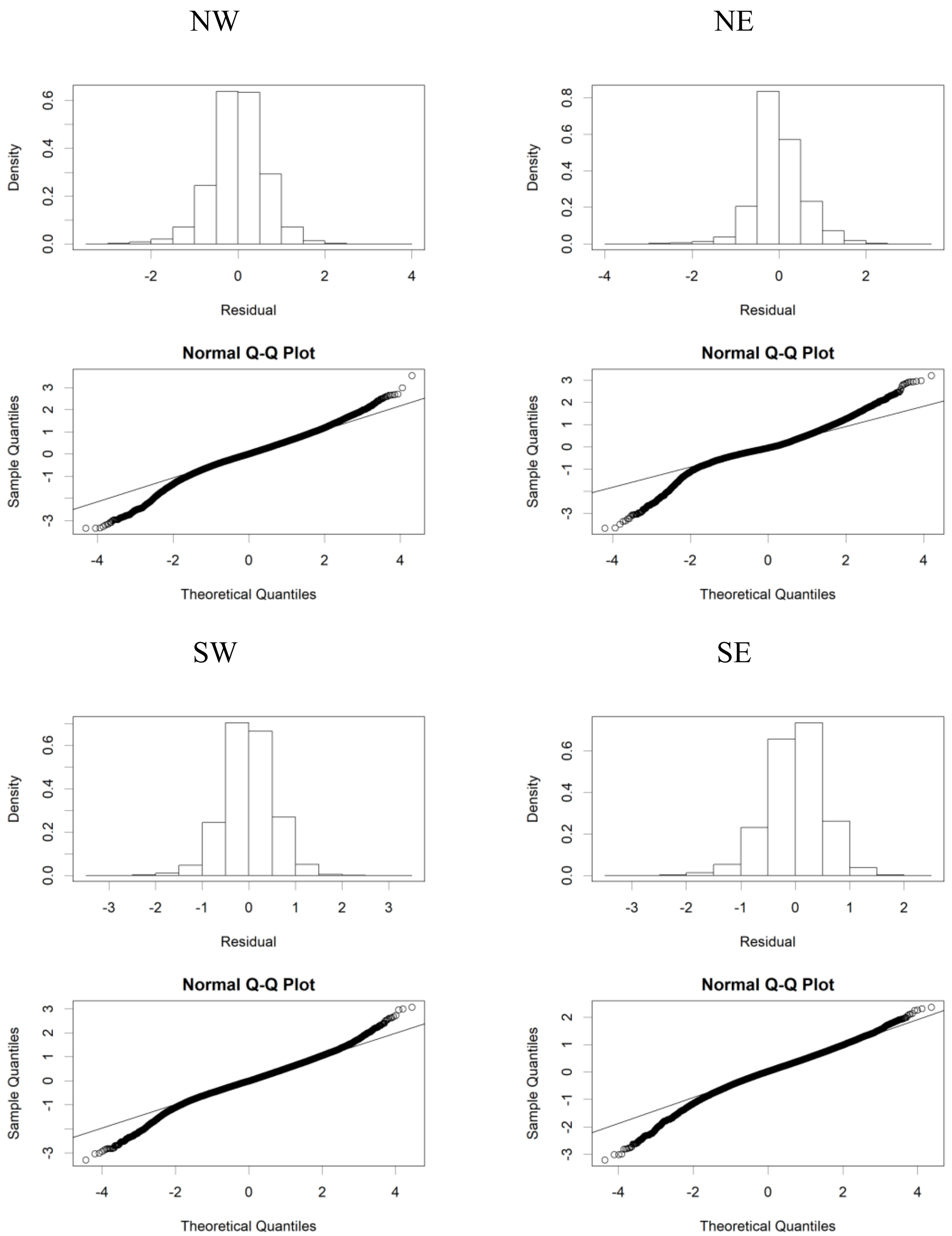


Fig. 33. Histogram and Quantile-Quantile plots obtained from the year-quarter GLMM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

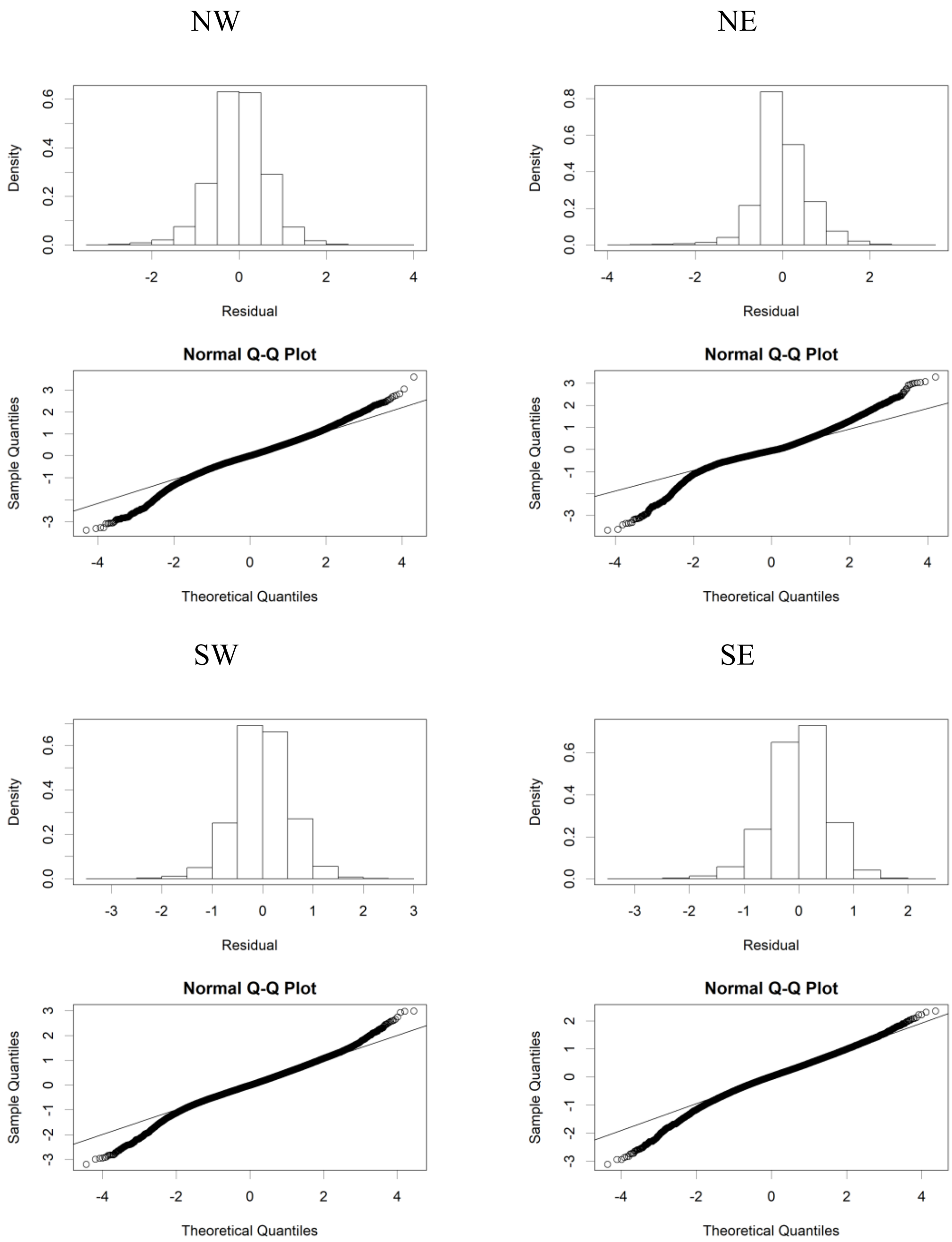


Fig. 34. Histogram and Quantile-Quantile plots obtained from the annual GLM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

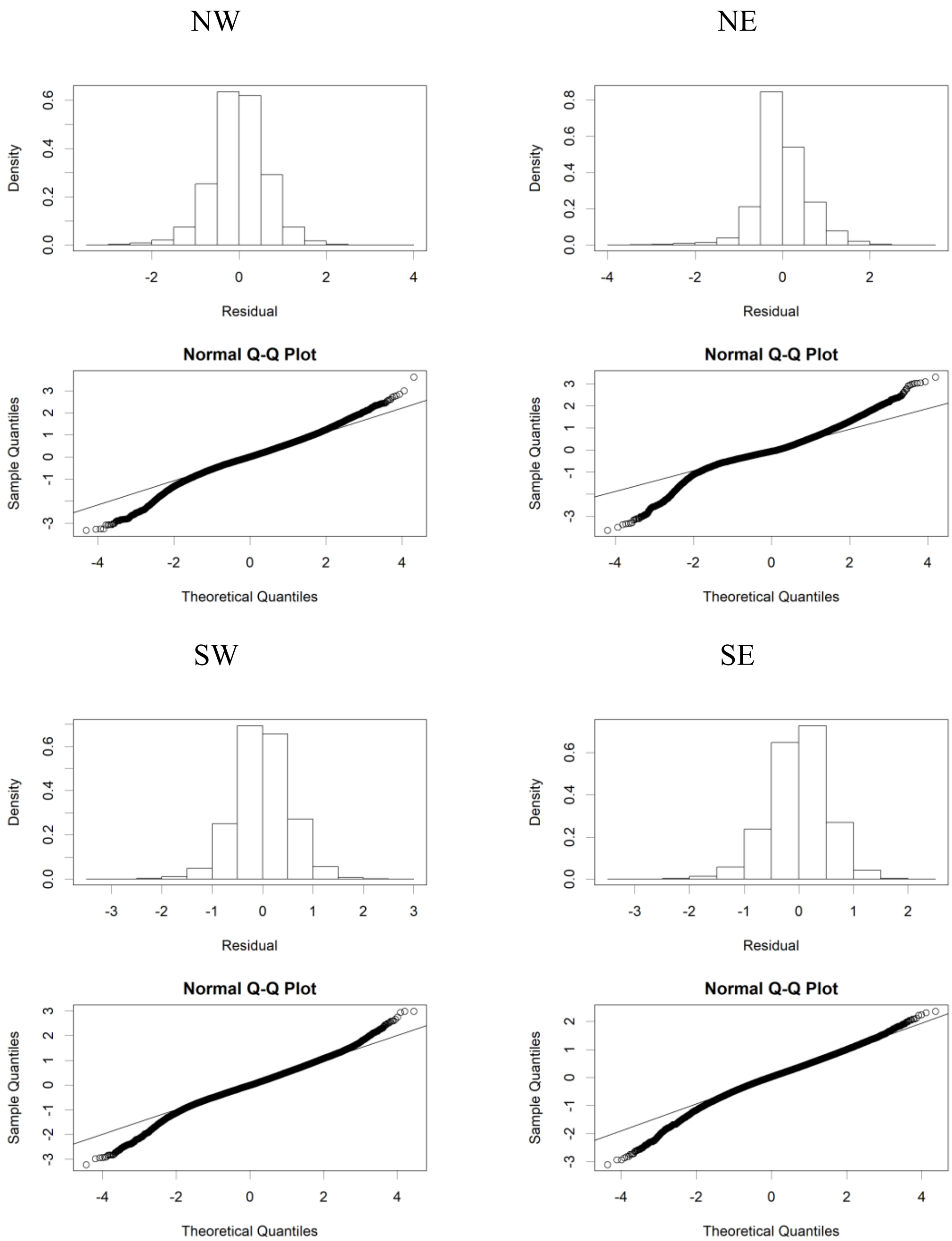


Fig. 35. Histogram and Quantile-Quantile plots obtained from the annual GLMM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

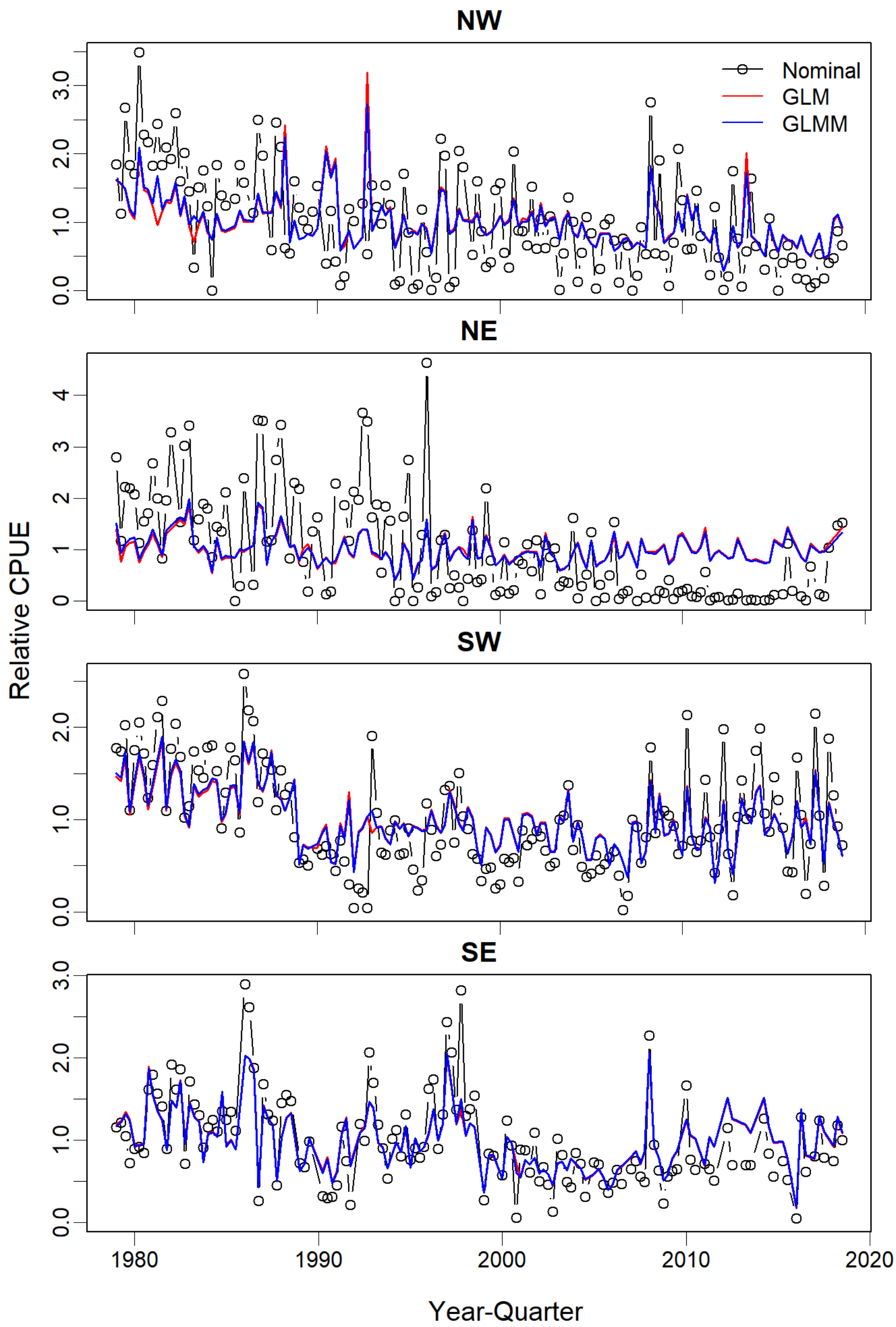


Fig. 36. Year-quarterly trends of standardized CPUE series for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

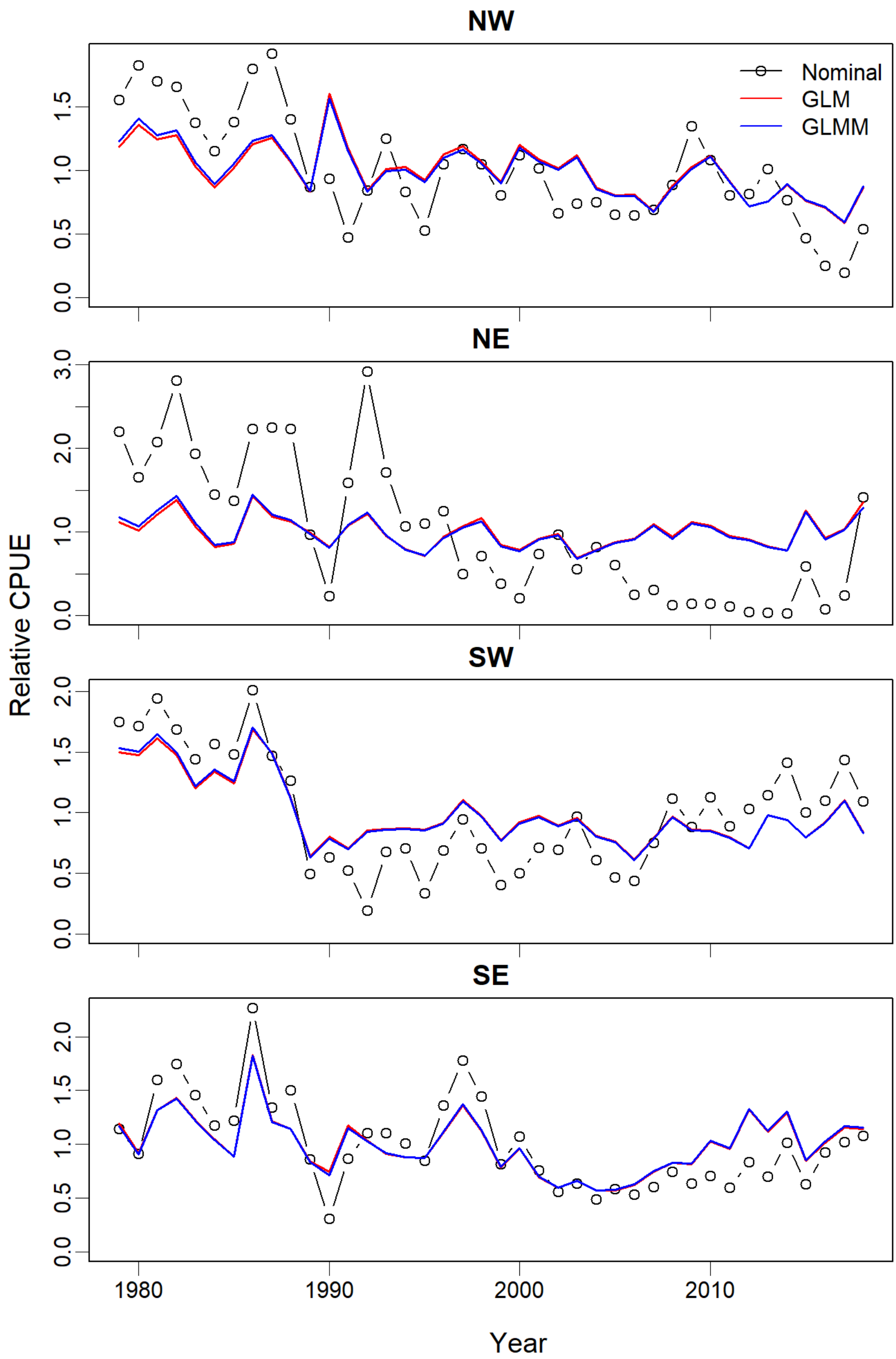


Fig. 37. Annual trends of standardized CPUE series for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

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	59744	779	76.69	202.36	2.2e-16 ***
Residual	22551	59504	0.38		
Total	82295	60283			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	1751	150	11.68	30.81	< 2.2e-16 ***
G	743	23	32.30	85.22	< 2.2e-16 ***
T	5177	2	2588.45	6829.99	< 2.2e-16 ***
V	6044	603	10.02	26.45	< 2.2e-16 ***
Residuals	22551	59504	0.38		

NE

	Sum Sq	Df	MS	F	Pr(>F)
Model	63670	699	91.09	276.51	2.2e-16 ***
Residual	11749	35667	0.33		
Total	75419	36366			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	1096	144	7.61	23.10	< 2.2e-16 ***
G	542	20	27.12	82.32	< 2.2e-16 ***
T	4453	2	2226.50	6758.92	< 2.2e-16 ***
V	2763	533	5.18	15.74	< 2.2e-16 ***
Residuals	11749	35667	0.33		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 1. (Continued).

SW

	Sum Sq	Df	MS	F	Pr(>F)
Model	104764	797	131.45	463.34	2.2e-16 ***
Residual	31887	112396	0.28		
Total	136651	113193			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	2824	158	17.87	63.00	< 2.2e-16 ***
G	871	30	29.03	102.38	< 2.2e-16 ***
T	13497	1	13497.00	47573.37	< 2.2e-16 ***
V	6815	608	11.21	39.51	< 2.2e-16 ***
Residuals	31887	112396	0.28		

SE

	Sum Sq	Df	MS	F	Pr(>F)
Model	25008	591	42.32	156.26	2.2e-16 ***
Residual	21142	78072	0.27		
Total	46150	78663			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	3181	137	23.22	85.74	< 2.2e-16 ***
G	241	20	12.07	44.57	< 2.2e-16 ***
T	3654	2	1827.15	6747.12	< 2.2e-16 ***
V	4149	432	9.60	35.46	< 2.2e-16 ***
Residuals	21142	78072	0.27		

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	1773	11.7	151	38786	30.96	< 2.2e-16 ***
G	768	33.4	23	59825	88.04	< 2.2e-16 ***
T	5460	2729.9	2	59625	7199.96	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	178	-63444.0	127244	11801	1	< 2.2e-16 ***

NE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
YQ	1139	7.9	144	34018	23.99	< 2.2e-16 ***
G	613	30.6	20	35996	92.93	< 2.2e-16 ***
T	5040	2520.1	2	33351	7643.57	< 2.2e-16 ***

	npar	logLik	AIC	LRT	DF	Pr(>Chisq)
V	168	-35251.0	70839	5715	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	2959	18.7	158	99753	65.99	< 2.2e-16 ***
G	884	29.4	30	112747	103.78	< 2.2e-16 ***
T	13880	13879.8	1	111162	48913.77	< 2.2e-16 ***

	npar	logLik	AIC	LRT	DF	Pr(>Chisq)
V	191	-100377.0	201135	19112	1	< 2.2e-16 ***

SE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
YQ	3231	23.6	137	75923	87.05	< 2.2e-16 ***
G	243	12.1	20	78085	44.76	< 2.2e-16 ***
T	3707	1853.4	2	78452	6842.30	< 2.2e-16 ***

	npar	logLik	AIC	LRT	DF	Pr(>Chisq)
V	161	-67382.0	135085	12068	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	59009	671	87.94	225.13	2.2e-16 ***
Residual	23286	59612	0.39		
Total	82295	60283			

	Sum Sq	Df	MS	F values	Pr(>F)
Y	843	39	21.62	55.35	< 2.2e-16 ***
Q	147	3	48.87	125.07	< 2.2e-16 ***
G	810	23	35.23	90.19	< 2.2e-16 ***
T	5777	2	2888.35	7394.19	< 2.2e-16 ***
V	6685	604	11.07	28.34	< 2.2e-16 ***
Residuals	23286	59612	0.39		

NE

	Sum Sq	Df	MS	F values	Pr(>F)
Model	63157	597	105.79	308.59	2.2e-16 ***
Residual	12262	35769	0.34		
Total	75419	36366			

	Sum Sq	Df	MS	F values	Pr(>F)
Y	466	39	11.94	34.82	< 2.2e-16 ***
Q	107	3	35.80	104.38	< 2.2e-16 ***
G	600	20	29.99	87.47	< 2.2e-16 ***
T	5095	2	2547.40	7430.80	< 2.2e-16 ***
V	3048	533	5.72	16.68	< 2.2e-16 ***
Residuals	12262	35769	0.34		

Table 3. (Continued).

SW

	Sum Sq	Df	MS	F values	Pr(>F)
Model	103861	681	152.51	523.33	2.2e-16 ***
Residual	32789	112512	0.29		
Total	136651	113193			

	Sum Sq	Df	MS	F values	Pr(>F)
Y	1463	39	37.51	128.76	< 2.2e-16 ***
Q	450	3	150.00	514.15	< 2.2e-16 ***
G	1061	30	35.37	121.30	< 2.2e-16 ***
T	14301	1	14301.00	49071.82	< 2.2e-16 ***
V	7009	608	11.53	39.55	< 2.2e-16 ***
Residuals	32789	112512	0.29		

SE

	Sum Sq	Df	MS	F values	Pr(>F)
Model	24438	496	49.27	177.37	2.2e-16 ***
Residual	21713	78167	0.28		
Total	46150	78663			

	Sum Sq	Df	MS	F values	Pr(>F)	
Y	2406	39	61.70	222.12	< 2.2e-16	***
Q	149	3	49.63	178.74	< 2.2e-16	***
G	247	20	12.36	44.48	< 2.2e-16	***
T	3885	2	1942.50	6993.19	< 2.2e-16	***
V	4360	432	10.09	36.33	< 2.2e-16	***
Residuals	21713	78167	0.28			

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	862	22.10	39	52643	56.56	< 2.2e-16 ***
Q	143	47.67	3	60135	122.00	< 2.2e-16 ***
G	834	36.27	23	59975	92.82	< 2.2e-16 ***
T	6100	3049.95	2	59707	7805.03	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	69	-64680.00	129498	12710	1	< 2.2e-16 ***

NE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Y	492	12.63	39	30795	36.81	< 2.2e-16 ***
Q	123	40.99	3	36113	119.49	< 2.2e-16 ***
G	663	33.14	20	36145	96.61	< 2.2e-16 ***
T	5748	2873.92	2	33415	8378.01	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	66	-36060.00	72251	6119	1	< 2.2e-16 ***

Table 4. (Continued).

SW

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Y	1601	41.10	39	99203	140.86	< 2.2e-16 ***
Q	450	150.00	3	113080	514.44	< 2.2e-16 ***
G	1077	35.90	30	112882	123.16	< 2.2e-16 ***
T	14686	14685.70	1	111381	50382.42	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	75	-101708.00	203566	19140	1	< 2.2e-16 ***

SE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Y	2449	62.79	39	70867	225.99	< 2.2e-16 ***
Q	151	50.27	3	78517	180.91	< 2.2e-16 ***
G	248	12.40	20	78276	44.64	< 2.2e-16 ***
T	3939	1969.59	2	78544	7088.72	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	66	-68403.00	136937	12375	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	0.2830	115081	121143
YQ	0.2740	113365	120399
NE			
Y	0.1626	64867	69960
YQ	0.1558	63517	69477
SW			
Y	0.2400	182349	188931
YQ	0.2333	179421	187121
SE			
Y	0.4705	122972	127590
YQ	0.4581	121066	126565

GLMM

	R^2_fixed	R^2_fixed and random	AIC	BIC
NW				
Y	0.5393	0.6793	116650	117421
YQ	0.5567	0.6920	115088	117058
NE				
Y	0.7369	0.8069	66001	66704
YQ	0.7475	0.8155	64788	66563
SW				
Y	0.6320	0.7231	184276	185161
YQ	0.6351	0.7269	181641	183876
SE				
Y	0.3907	0.5615	124430	125185
YQ	0.4049	0.5723	122696	124522