CPUE standardization for southern bluefin tuna caught by Taiwanese longline fishery for 2002-2016

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Abstract

In this study, the patterns of catch compositions and CPUE distributions were explored based on the data of Taiwanese longline fleets operated in the waters of the south of 20°S of the Indian Ocean during 2002-2016. Based on the suggestions in previous CCSBT meetings, the cluster analysis for selecting data and CPUE standardizations were conducted for the central-eastern and the western areas separately. To select data from SBT fishing operations, cluster analysis was performed based on the weekly-aggregated data instead of set-by-set data. For CPUE standardizations, the simple delta-lognormal models without interactions were adopted to avoid the confounding from interactions.

1. INTRODUCTION

Southern bluefin tuna (SBT) (*Thunnus maccoyii*) was by-catch of Taiwanese tuna longline fishery targeting albacore in the past, but after the fishing vessels equipped with deep-frozen freezers, some fishing vessels operating in the Indian Ocean started targeting SBT seasonally since the 1990s. Since Taiwanese SBT statistics system was reformed in 2002, the reporting rate of SBT catch has substantially improved since then (Anon, 2014). In this study, we attempted to explore the temporal and spatial patterns of catch and effort data of Taiwanese longline fishery operated in the waters of the south of 20°S of the Indian Ocean and also conduct the CPUE standardization for SBT caught by Taiwanese longline fishery for the year of 2002-2016.

2. MATERIALS AND METHODS

2.1. Catch and Effort data

In this study, monthly catch and effort data with 5x5 degree fishing location grids of Taiwanese active longline vessels authorized to seasonally target SBT operating in the Indian Ocean in the period of 2002-2016 were provided by Overseas Fisheries Development Council of Taiwan (OFDC).

2.2. Cluster analysis

Based on the approach of Wang et al. (2015) and suggestions from CCSBT ESC meetings in 2015 and 2016, the cluster analysis (He et al., 1997) was adopted to conduct the analysis of data filter to select 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, most of the catches consisted of oilfishes). However, the 2016 CCSBT ESC considered that clustering operational set-by-set data might include large amount noise because most of SBT was caught by Taiwanese vessels as bycatches and only part of vessels targeted SBT for some fishing operations during the fishing seasons. In addition, ESC suggested that the cluster analysis could be conducted based on the aggregated data rather than the operational data sets. Therefore, we performed the cluster analysis based monthly- and weekly-aggregated data and then merged the clusters with operational data sets to identify the SBT fishing operations. However, the proportion of SBT catches substantially decreased for data sets and it was more difficult to identify the cluster that contained SBT fishing operations when conducting the cluster analysis based on monthly-aggregated data. Therefore, the cluster analysis was performed based on weekly-aggregated data.

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 functions hclust and cutree (The R Foundation for Statistical Computing Platform, 2017). He et al. (1997) indicated that the choice for the number of clusters to produce was largely subjective. At least two clusters (SBT sets and other tuna sets) were expected. 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.

2.3. CPUE standardization

Because a large amount of zero SBT catch occurred in the fishing sets, the delta-lognormal models were applied to standardize the CPUE of SBT caught by Taiwanese longline fishery. As suggested in 2016 ESC, main effects of year, month, 5x5 grid and number of hooks between float were 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. In addition, the effects of cluster and number of hooks between float (NHBF) were included because various catch compositions can be observed in a cluster (Wang et al., 2017). The models were conducted as below:

lognormal model: $\log(CPUE)$
delta model: PA

$$= \mu + Y + M + G + C + NHBF + \varepsilon$$

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 float,
	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 (regular: <=9 hooks; deep: 10-14 hooks; ultra deep: >=15 hooks) (Wang and Nishida, 2011).

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

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. Temporal and spatial patterns of catch composition

Based on the catch composition during 2002-2016, the catches of OTH (most of the catches consisted of oilfishes) substantially increased since 2005 and the proportions of OTH were more than 70% of total catches (Fig. 1). Except for the OTH, ALB was still the main targeting species for the vessels operated in the waters of the south of 20°S, and the proportions of SBT were only 2-5% for most years (Fig. 2).

ALB was the main targeting species in the entire area before 2005 and OTH became to be the dominant species in the west area thereafter, while SBT was made accompanied with ALB and OTH operations in the central-eastern and the western areas, respectively (Fig. 3).

High SBT catches were mainly occurred in the central-eastern area from April to September, while some of SBT catches also made in the western area during this fishing season. From October to February, SBT catches were almost made in the western area and very few catches were made in the central-eastern area (Fig. 4).

Based on the annual and monthly distributions of catch compositions, high SBT catches were made in the central-eastern and western areas with different main catch species. Therefore, the data were divided into the central-eastern and the western areas based on 60°E, and the cluster analysis and CPUE standardizations were also performed by two fishing areas separately.

3.2. Cluster analysis

Fig. 5 shows the results of hierarchical cluster analysis for central-eastern and western areas. The proportions of SBT catches and efforts (number of hooks) were calculated based on various number of clusters. The proportions of SBT catches and the efforts decreased for a cluster (SBT cluster), which contained most of SBT catches among clusters, when the number of clusters increased (Table 1). For the central-eastern area, the proportion of SBT catches decreased from about 84% to 66% of total SBT catches for a cluster when cluster increased from 2 to 3 and the proportion of efforts substantially decreased from 92% to 47% of total efforts. For the western area, the proportion of SBT catches decreased from 54% to 50% and the proportion of efforts decreased from 27% to 13%. The proportion of SBT catches continuously decreased for a cluster but the proportion of efforts slightly changed when more clusters were chosen. In addition, the proportions of efforts for at least one cluster were less than 0.1% of total data for many years when increasing the number of clusters to more than 3. Therefore, the results of 3 clusters were adopted in this study (Table 2).

Figs. 6 and 7 show the trends of SBT catches and efforts. For the central-eastern area, Clusters 1 and 3 obviously contained large amount of SBT catches and less amount of efforts than other two clusters. For the western area, more SBT catches were contained in Cluster 2 and 3 although the catches mainly consisted of other species. In addition, the proportions of zero SBT catches from selected clusters were obviously less than the excluded clusters (Fig. 8). Figs. 9 and 10 show the annual and monthly CPUE distributions and values contributed by clusters. For most years and months, high CPUEs were contributed by Cluster 1 and 3 for the central-eastern area and by Cluster 2 and 3 for the western area.

To conduct the CPUE standardizations, the data of Cluster 2 and 1 were excluded for the central-eastern and the western areas, respectively (Table 2). About 83% of SBT catches remained and 45% of efforts were excluded for the central-eastern area, while about 96% of SBT catches and 87% of efforts remained for the western area because similar proportions of SBT catches (50% and 46%) were contained in two clusters.

Figs. 11 and 12 show the annual and monthly CPUE distributions based on the data of selected clusters. As the distribution of SBT catches, high CPUE values occurred in the central-eastern and the western areas. Obviously, the CPUE distributions were inappropriately divided by the stratification of CCSBT statistical areas.

3.3 CPUE standardization

For both of the central-eastern and the western areas, the models with the lowest value of AIC were selected as the final models. The ANVOA tables for the lognormal models are shown in Table 3. The effect of cluster was excluded from the model for the central-eastern area, while all of the main effects were statistically significant for the western area. About 17% and 31% of CPUE variances were explained by the models for the central-eastern and the western areas, 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. 13). For delta models, all of the main effects were also statistically significant for both areas (Table 4) and about 32% and 27% of CPUE variances were explained by the models for the central-eastern and the western areas, respectively.

Fig. 14 shows the area-specific standardized CPUE trends. Standardized CPUE series generally reveal quite different trends in two areas. For the central-eastern area, the standardized CPUEs gradually increased before 2007, revealed decreasing trend from 2007 to 2011, substantially increased in 2012 and then gradually decreased in recent years, but increased again in 2016. For the western area, the standardized CPUE series generally reveal a decreasing trend with a fluctuation since 2002.

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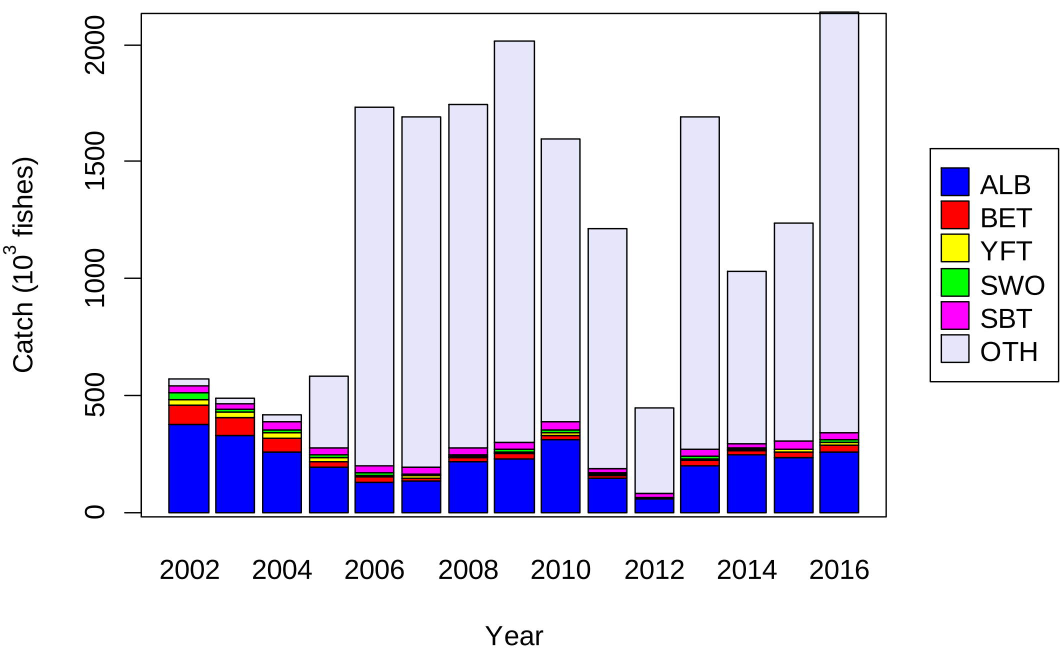


Fig. 1. Annual catch composition of Taiwanese longline fleets operated in the waters of south of 20°S.

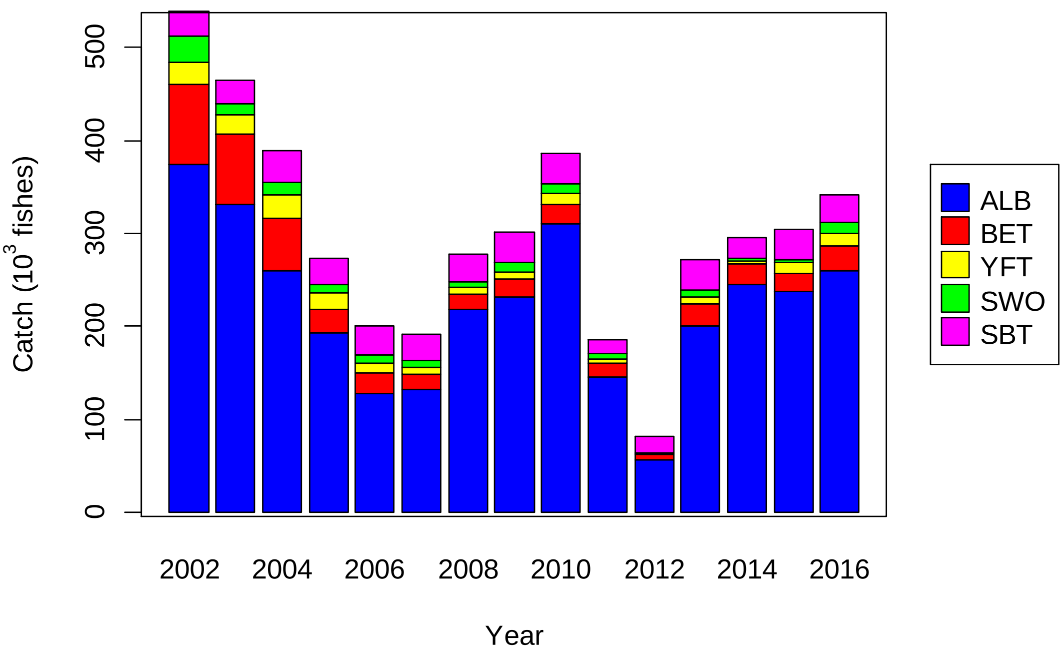


Fig. 2. Annual catch composition of Taiwanese longline fleets operated in the waters of south of 20°S. The catches of OTH are excluded.

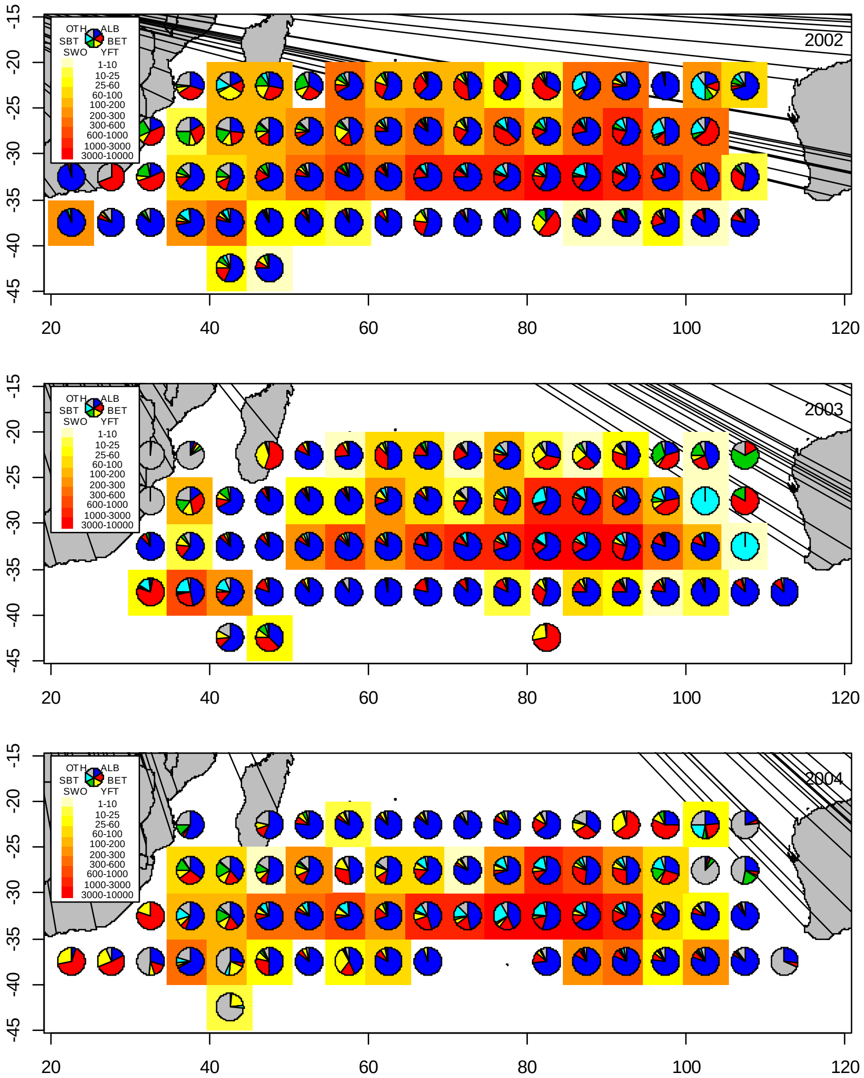
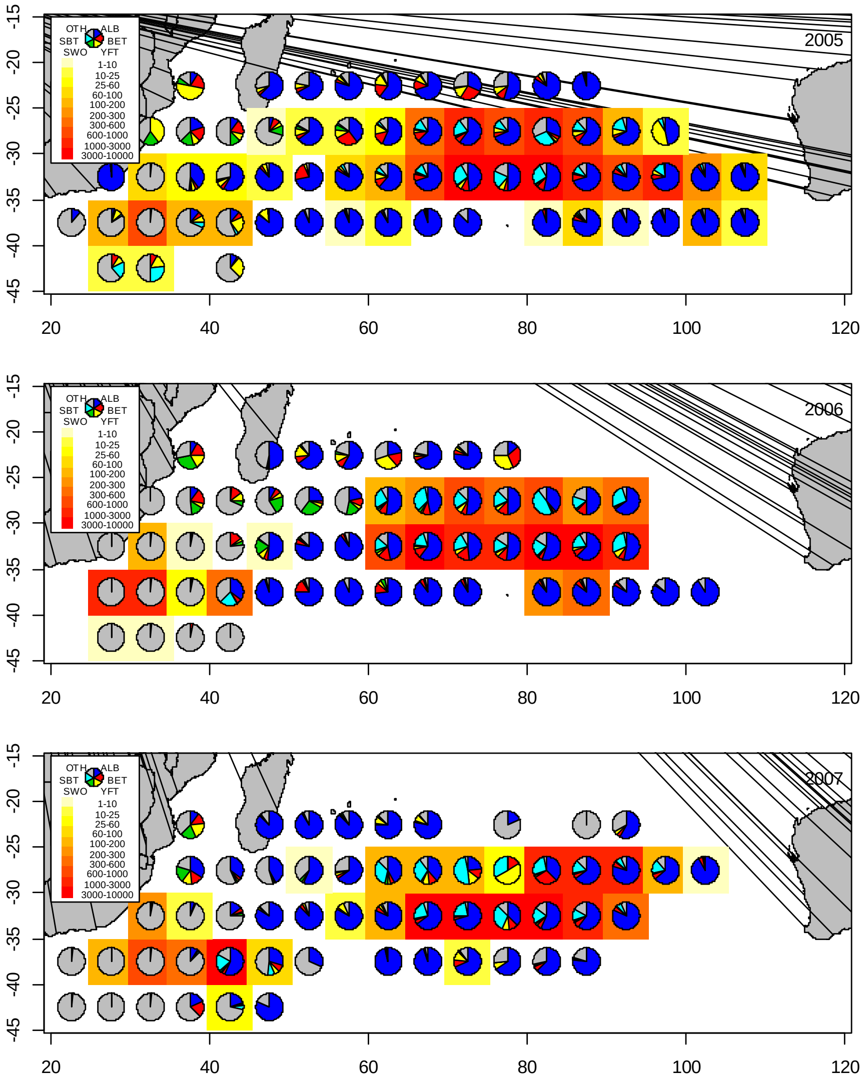


Fig. 3. Annual catch composition distribution of Taiwanese longline fleets operated in the waters of south of 20°S. Pie plots show the proportion by species and squares with heat colors show SBT catch in number (1000 fishes).



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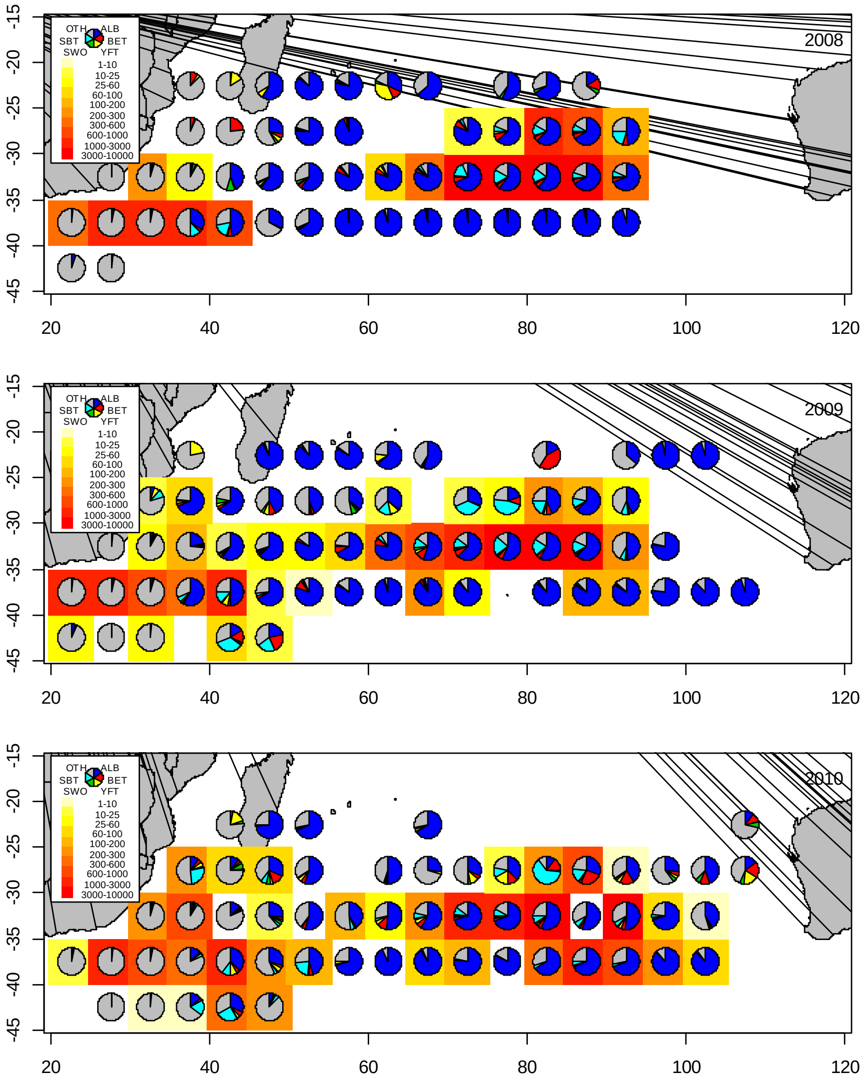


Fig. 3. (Continued).

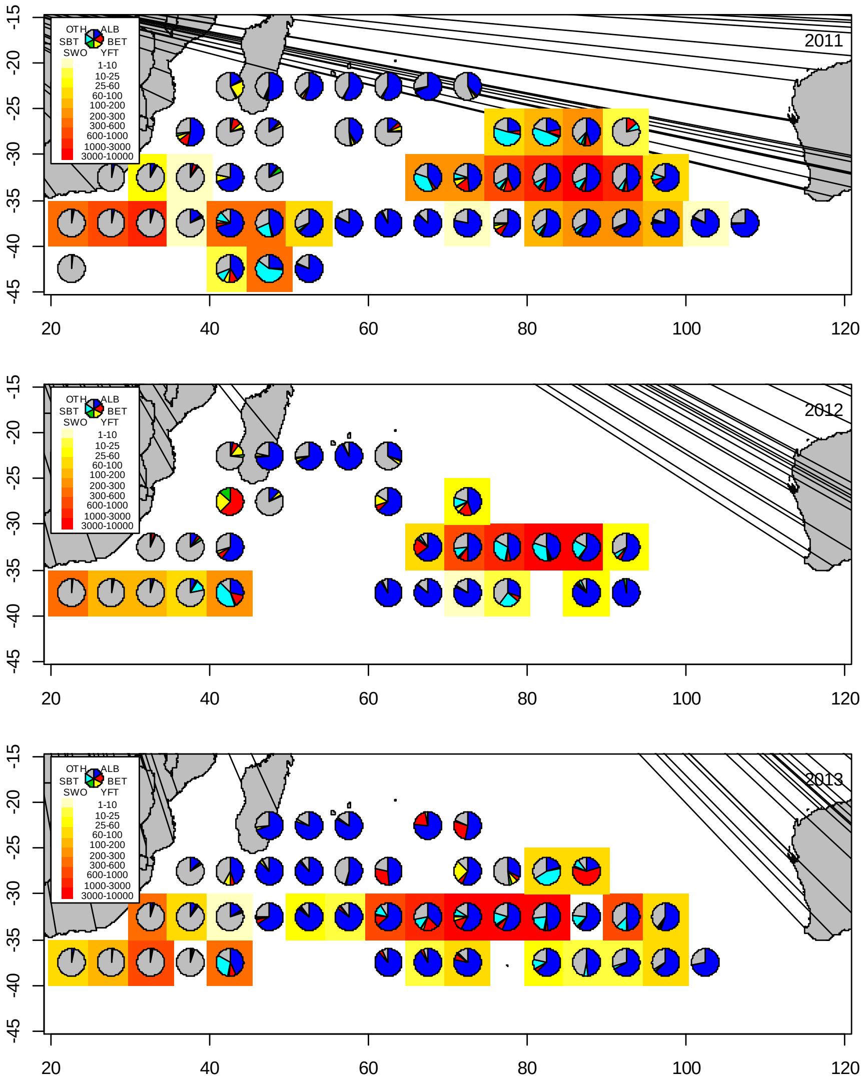


Fig. 3. (Continued).

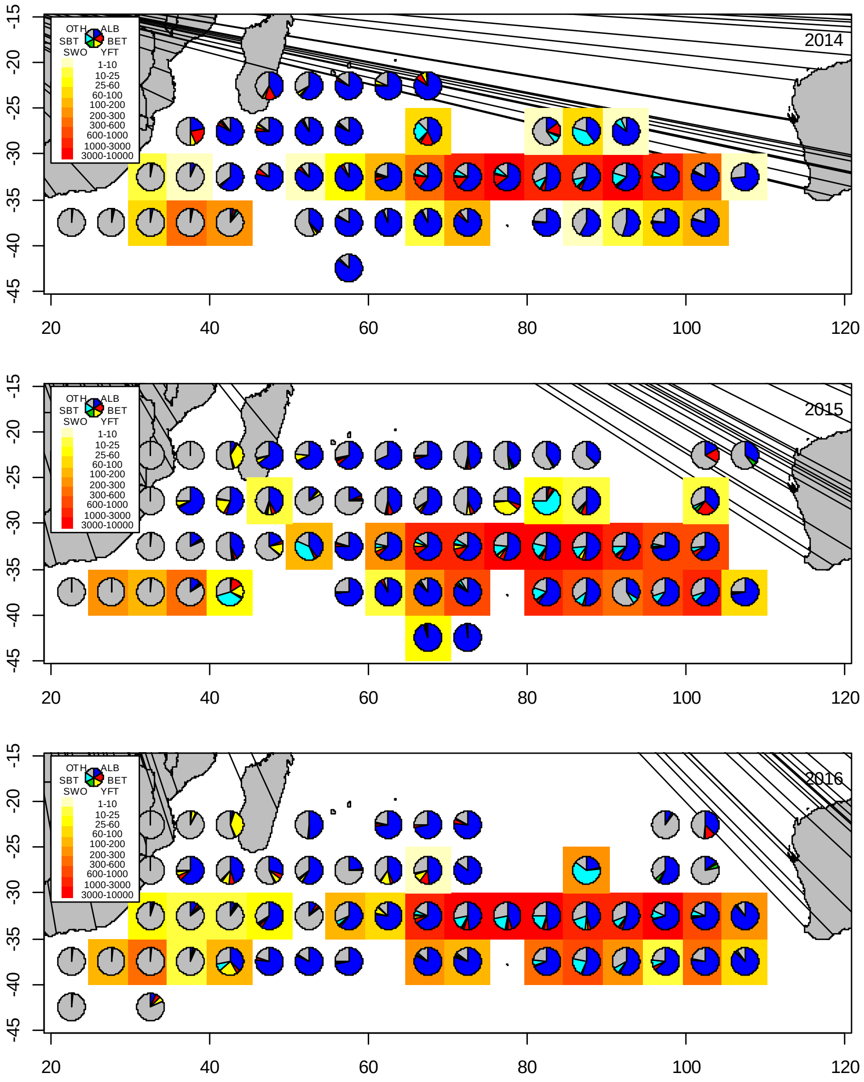


Fig. 3. (Continued).

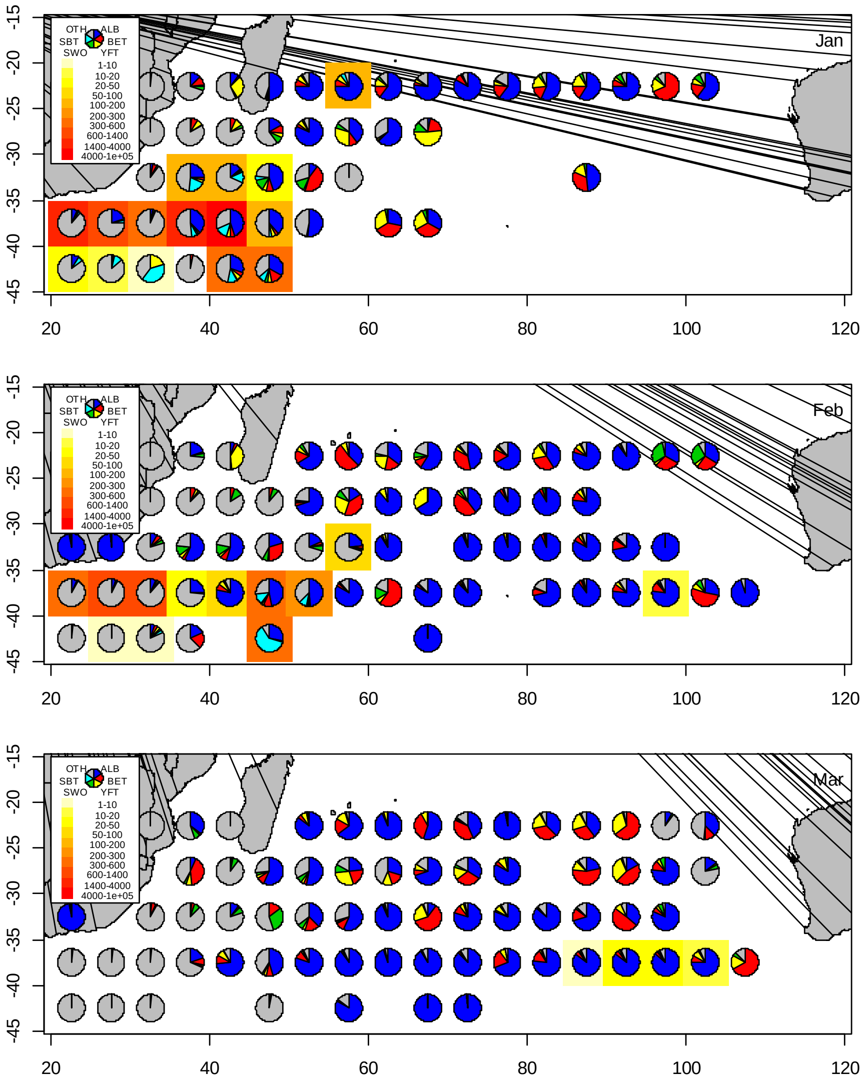


Fig. 4. Monthly catch composition distribution of Taiwanese longline fleets operated in the waters of south of 20°S. Pie plots show the proportion by species and squares with heat colors show SBT catch in number (1000 fishes).

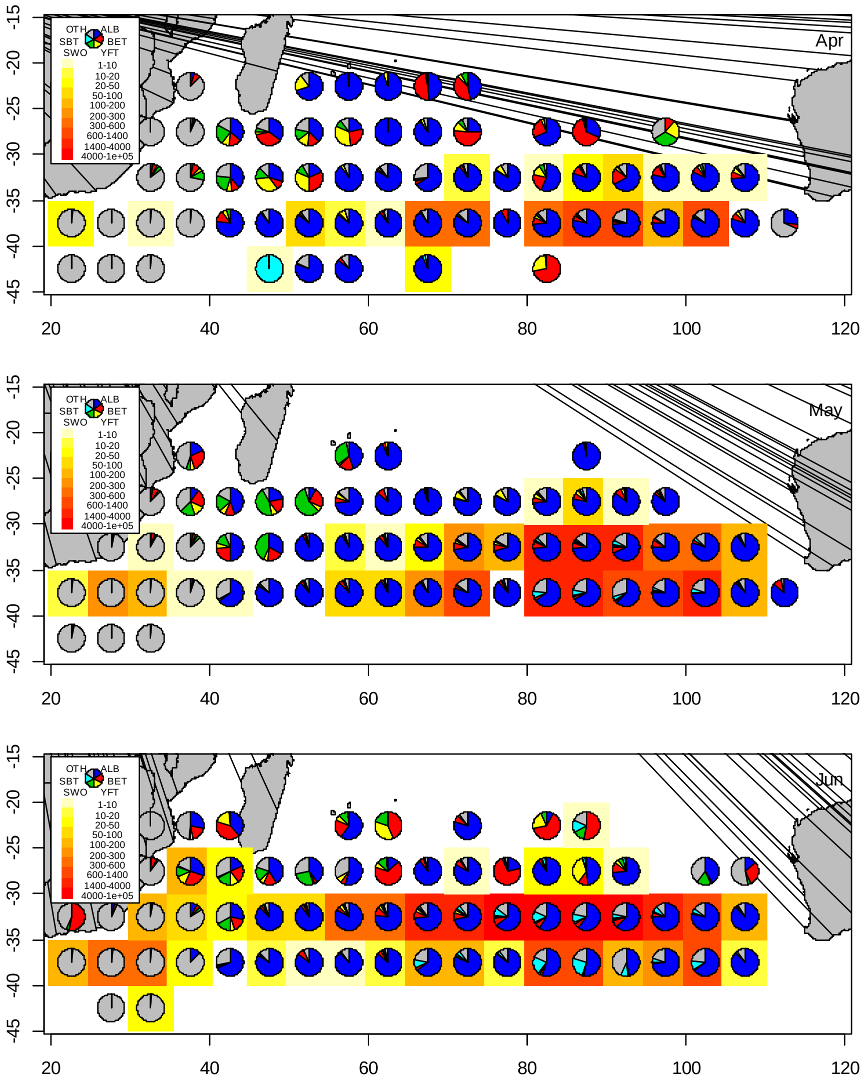


Fig. 4. (Continued).

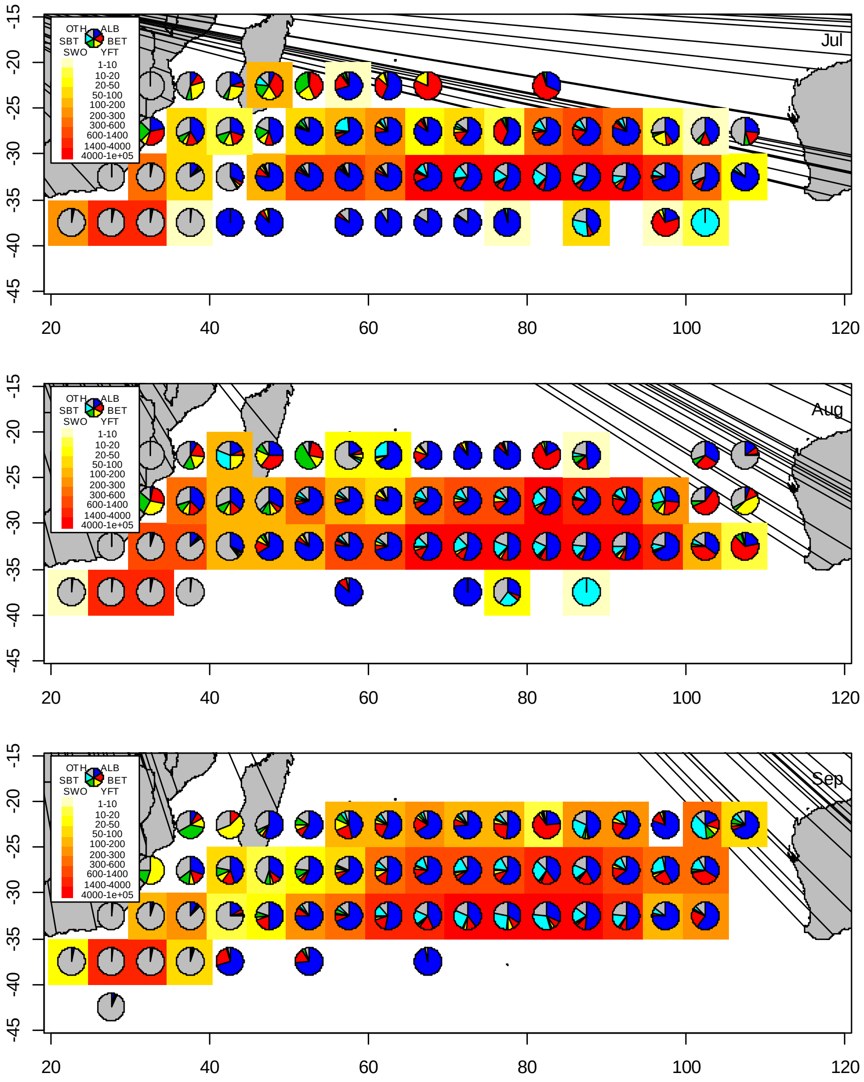


Fig. 4. (Continued).

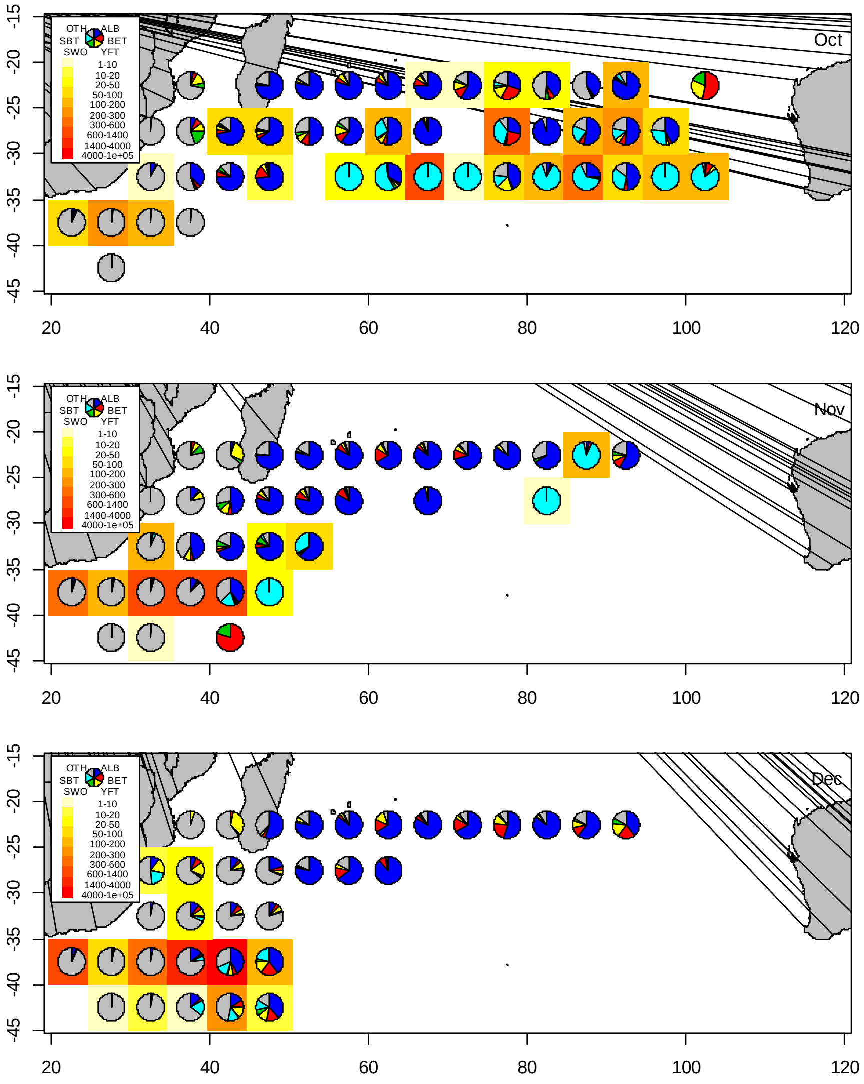


Fig. 4. (Continued).

Central-eastern area

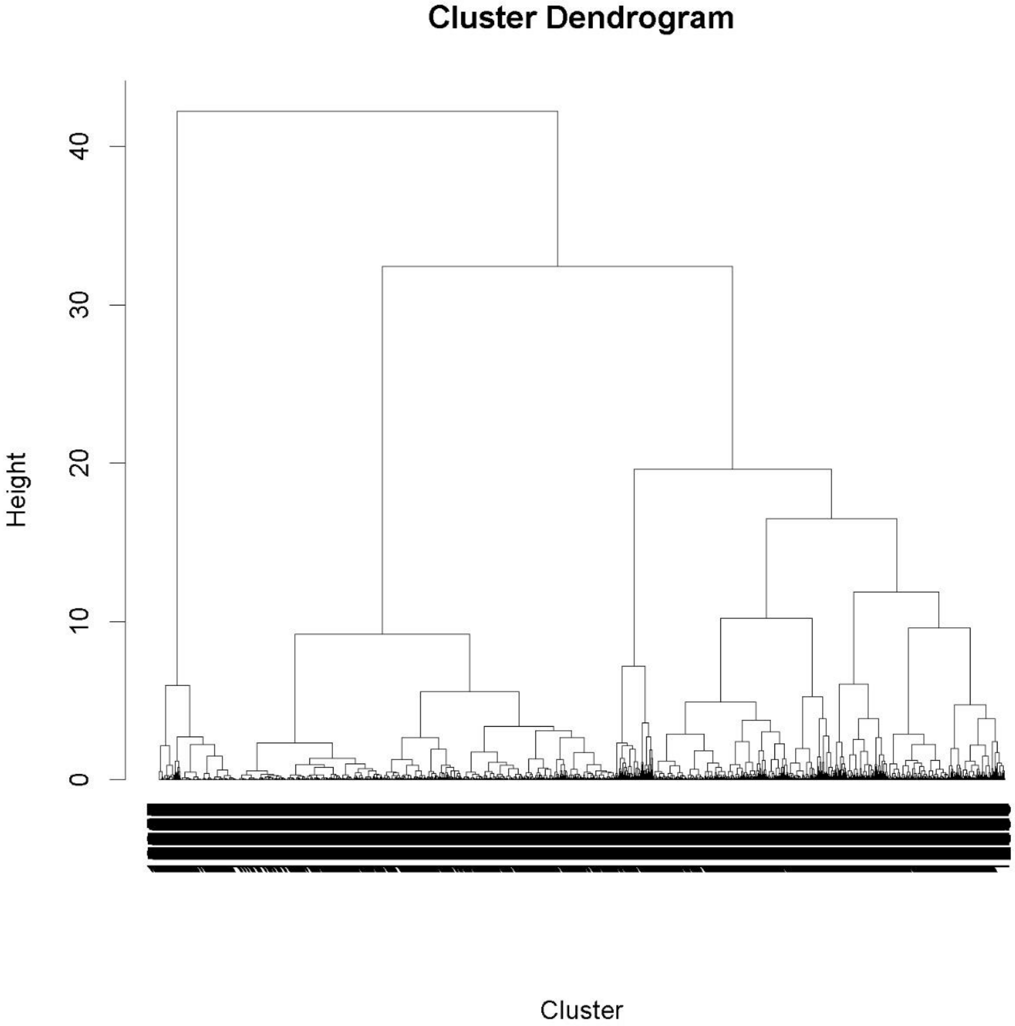


Fig. 5. The results of hierarchical cluster analysis based on the weekly-aggregated data of Taiwanese longline fleets operated in the waters of south of 20°S.

Western area

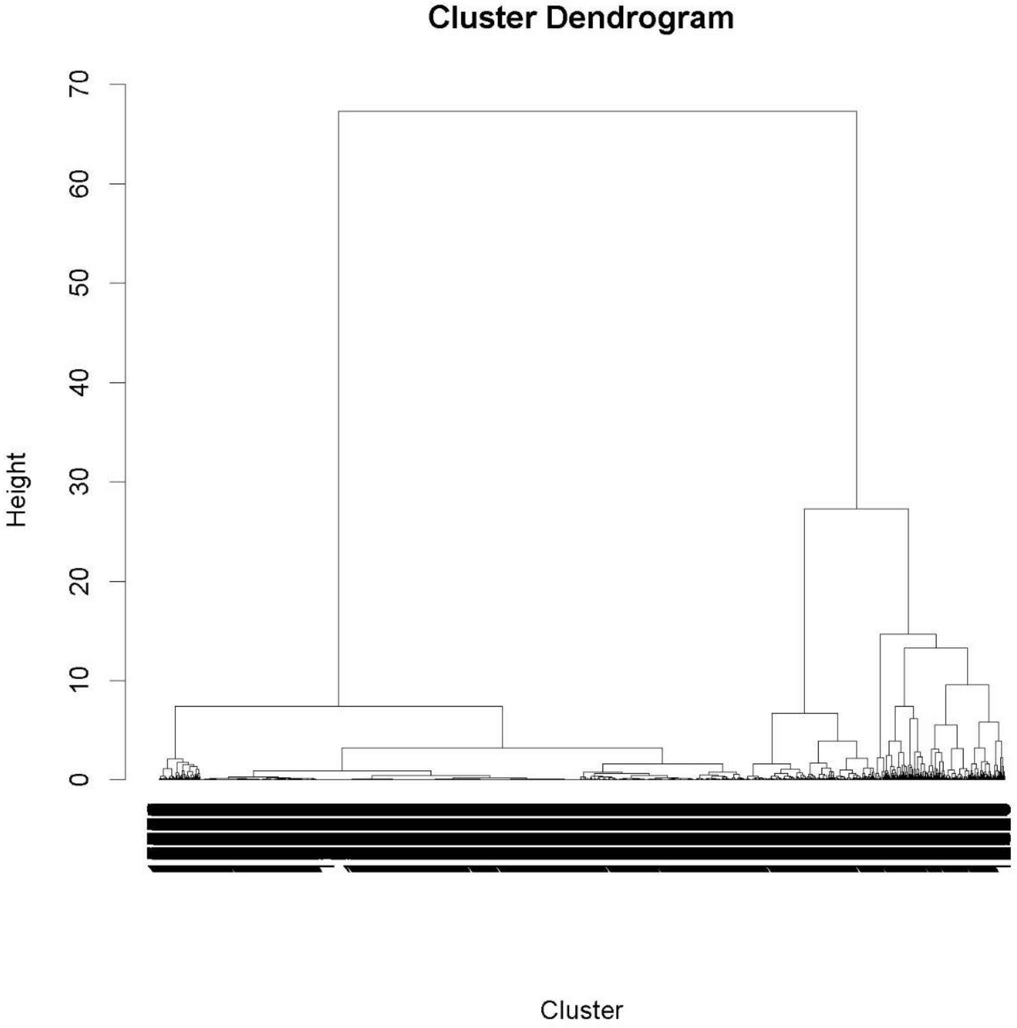


Fig. 5. (Continued).

Central-eastern area

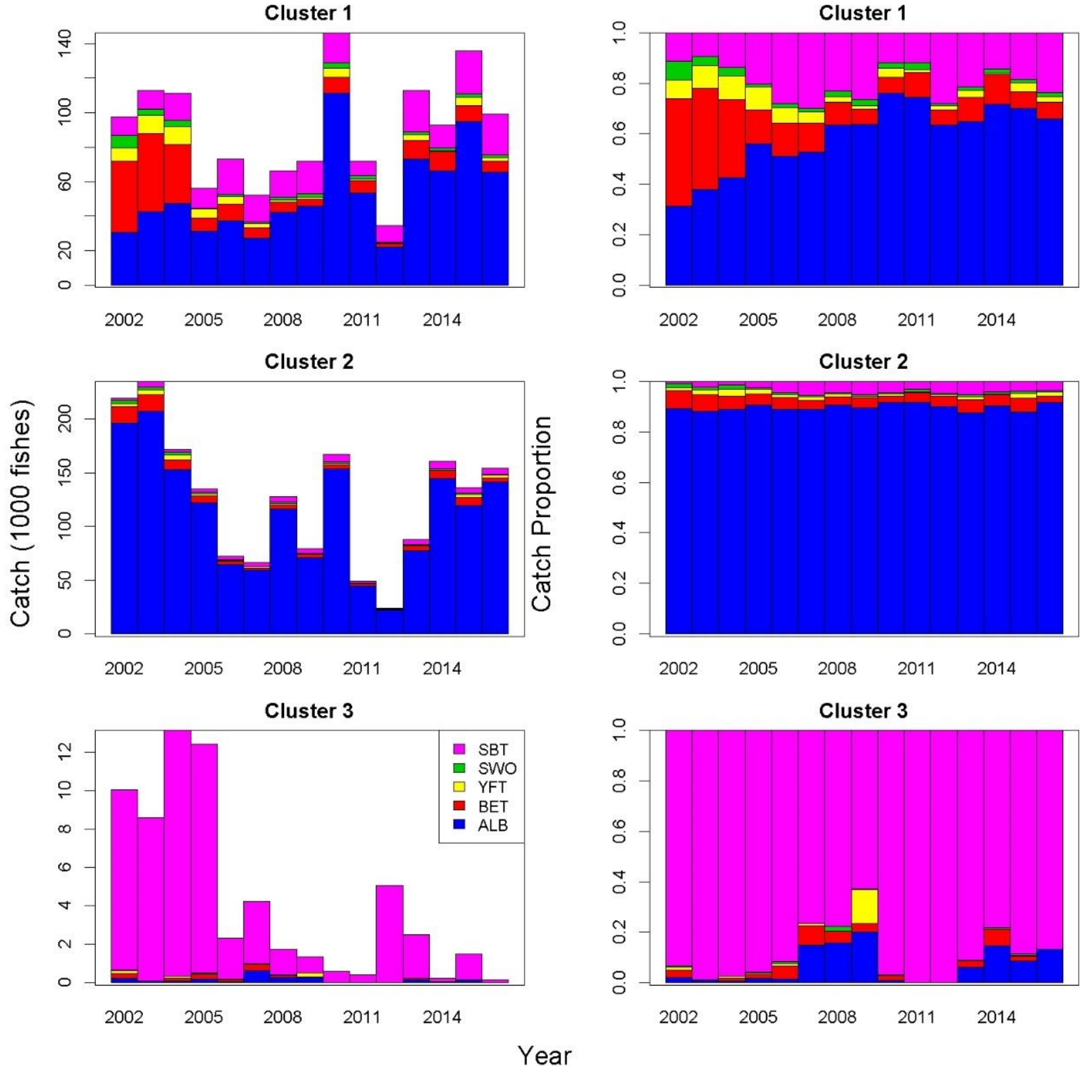


Fig. 6. Annual catch compositions (left panel) and proportions (right panel) by clusters based on data of Taiwanese longline fleets operated in the waters of south of 20°S.

Western area

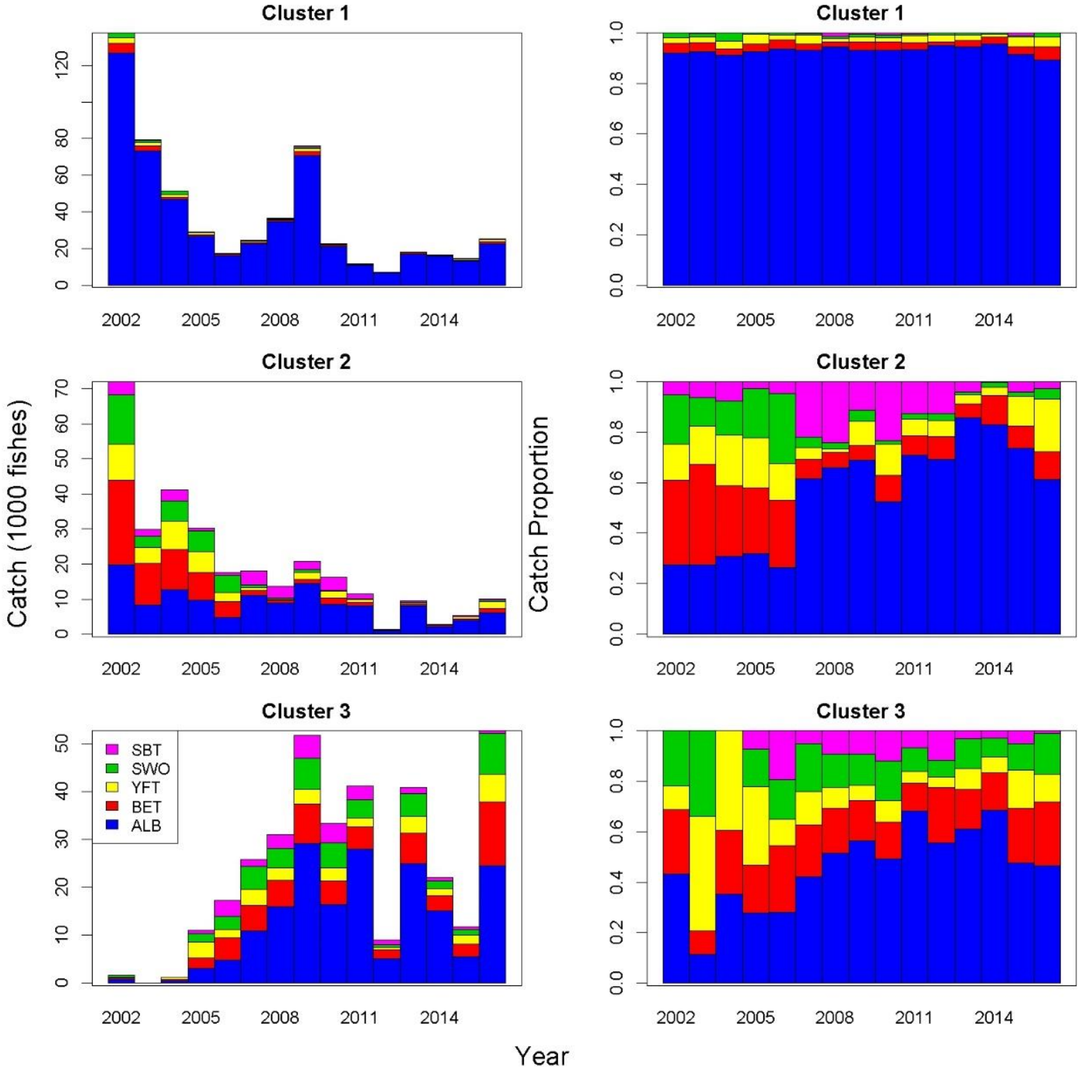


Fig. 6. (Continued).

Central-eastern area

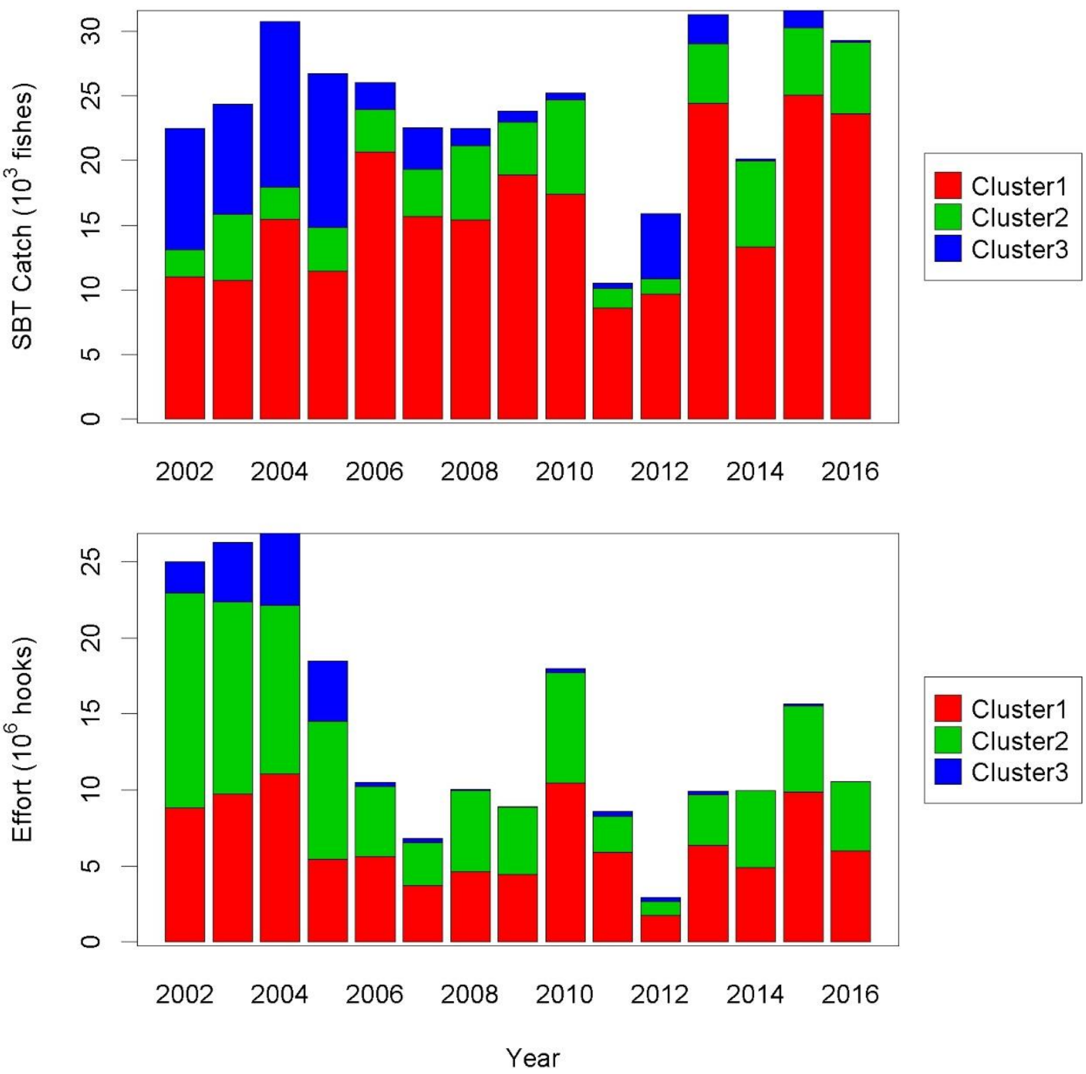


Fig. 7. Annual SBT catches (upper panel) and efforts (bottom panel) by clusters based on data of Taiwanese longline fleets operated in the waters of south of 20°S.

Western area

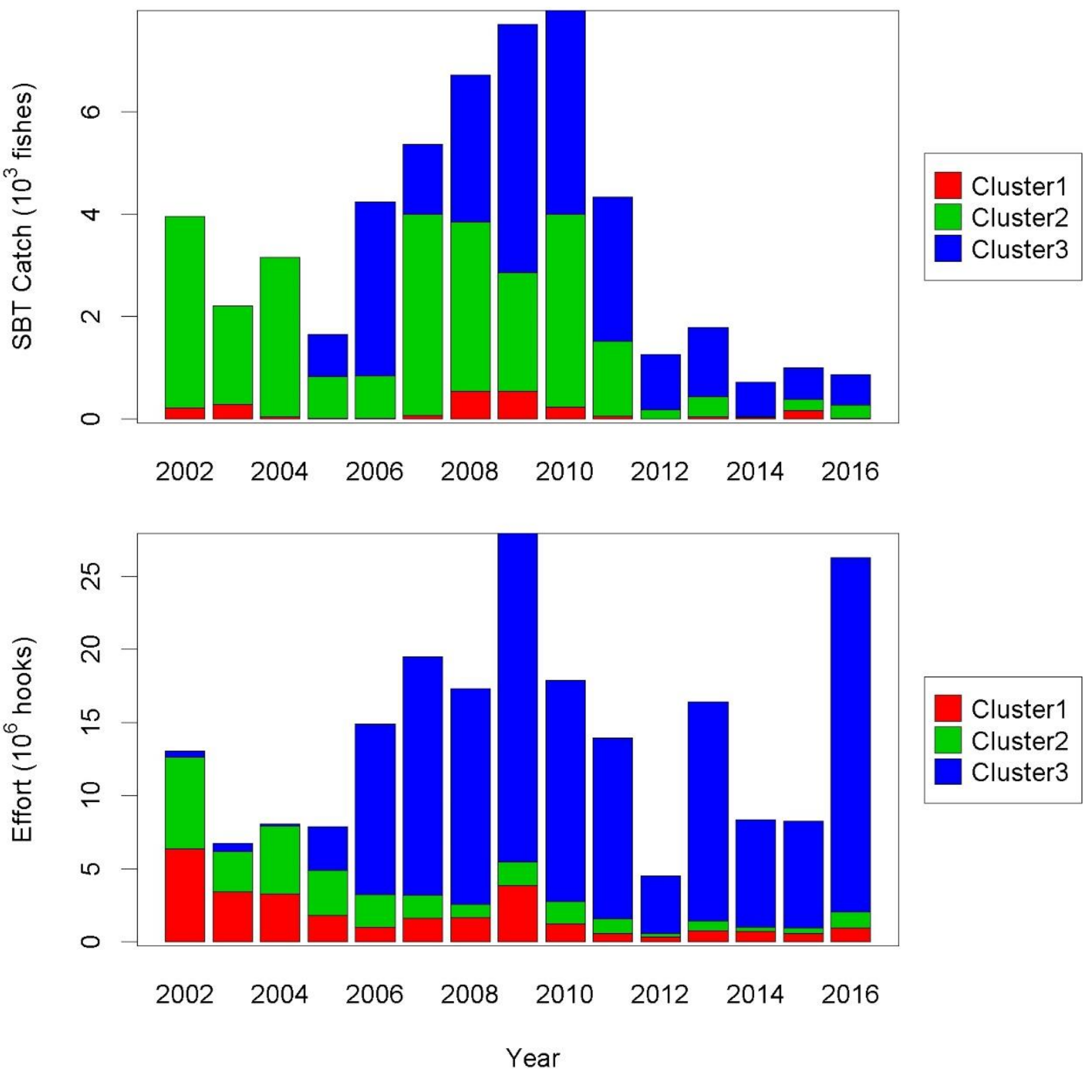
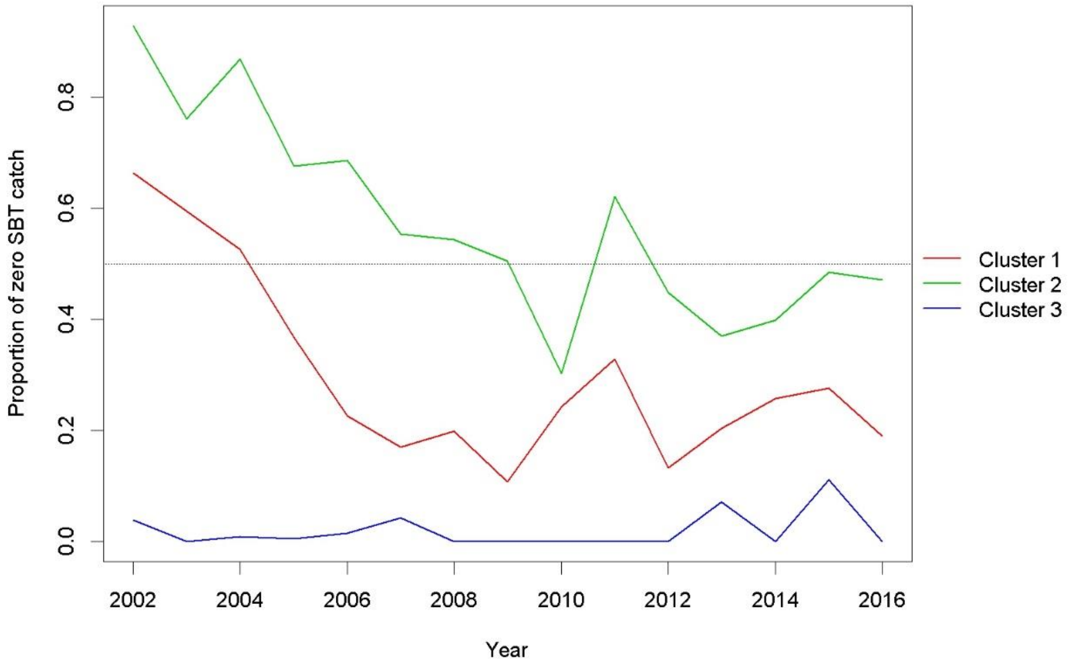


Fig. 7. (Continued).

Central-eastern area



Western area

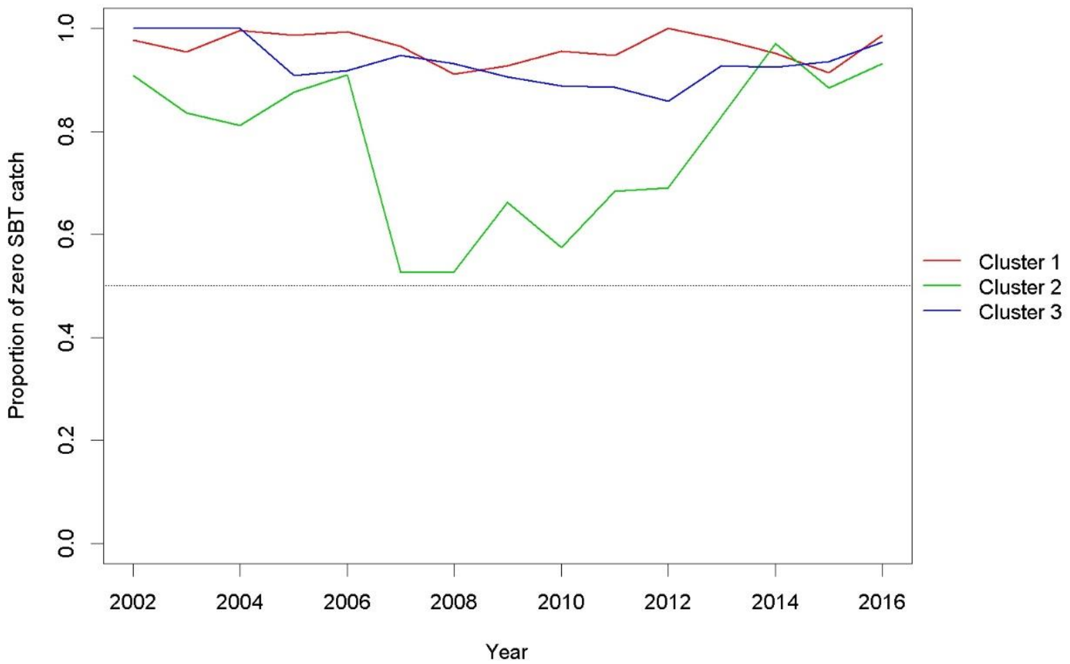


Fig. 8. Annual proportion of zero SBT catches by clusters based on data of Taiwanese longline fleets operated in the waters of south of 20°S.

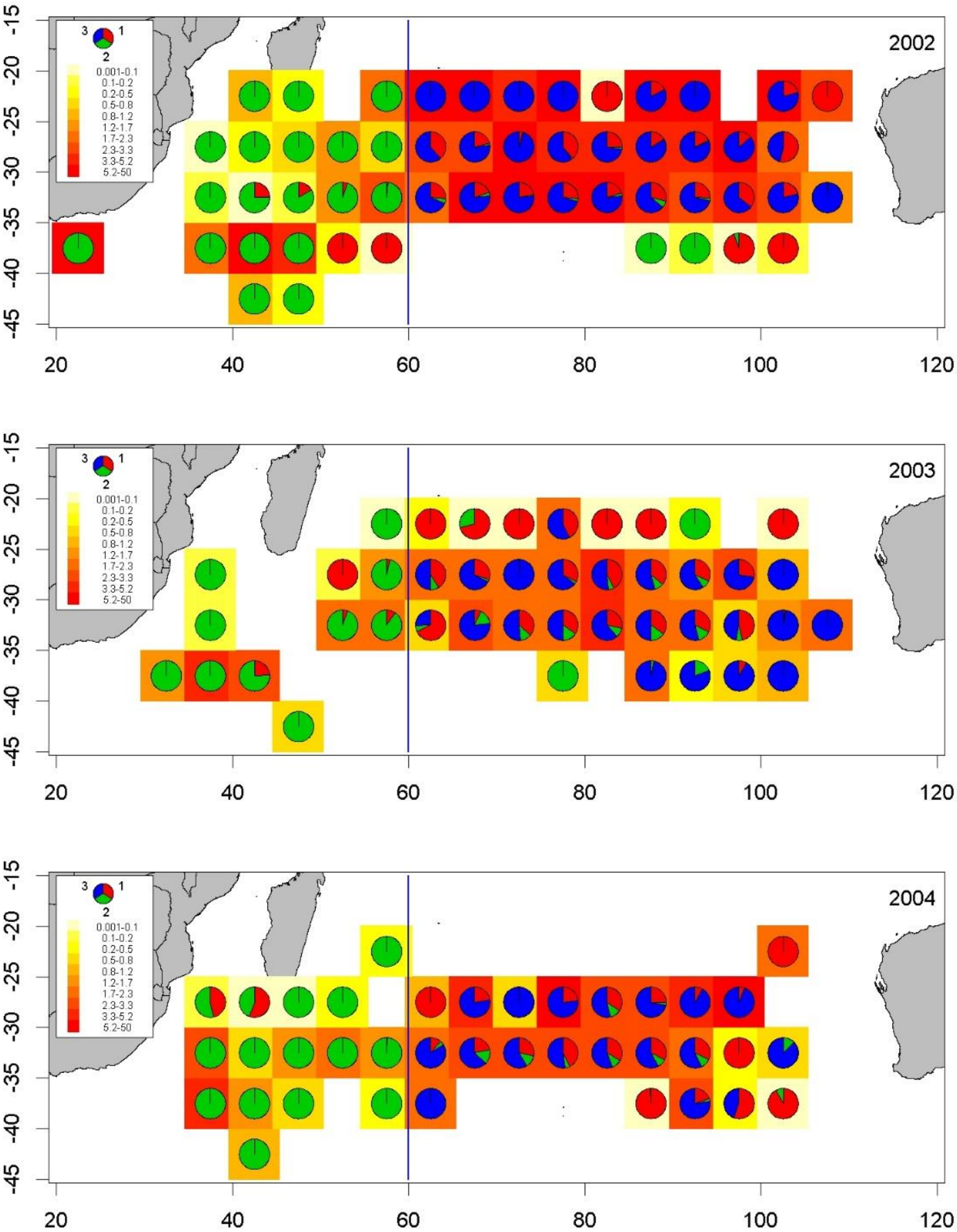
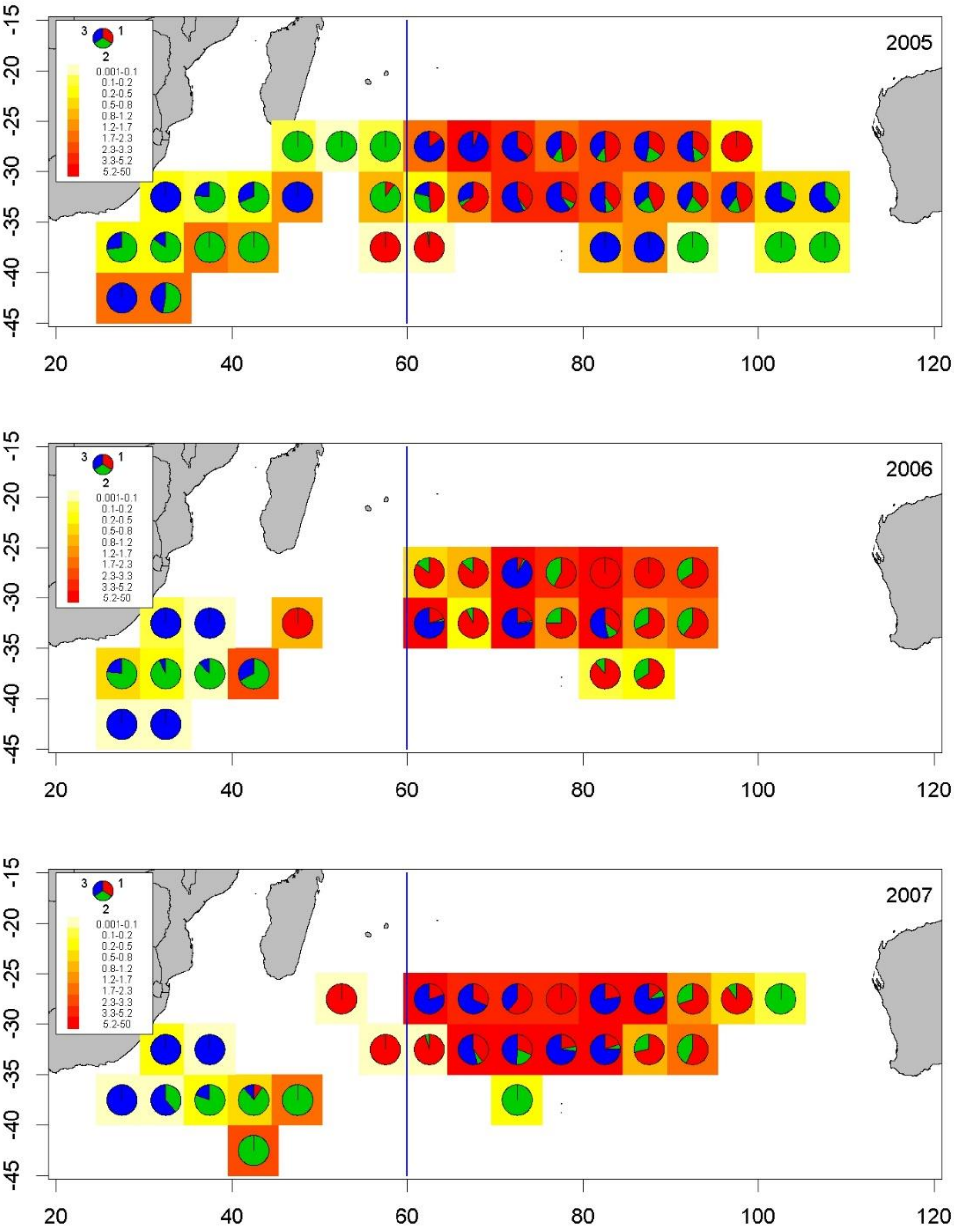


Fig. 9. Annual SBT CPUE distribution of Taiwanese longline fleets operated in the waters of south of 20°S. Pie plots show the proportions of CPUE contributed by clusters and squares with heat colors show the levels of SBT CPUE.



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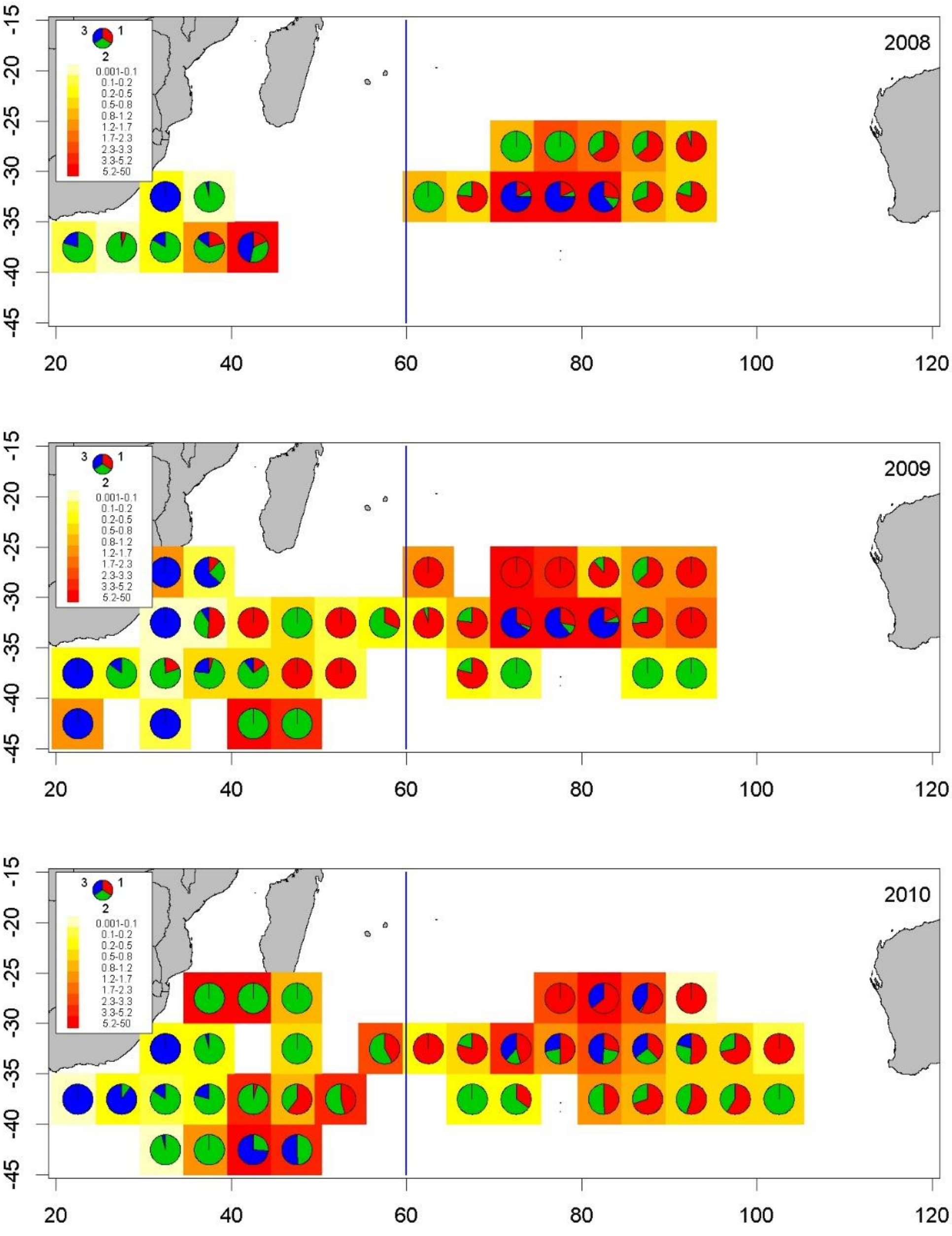

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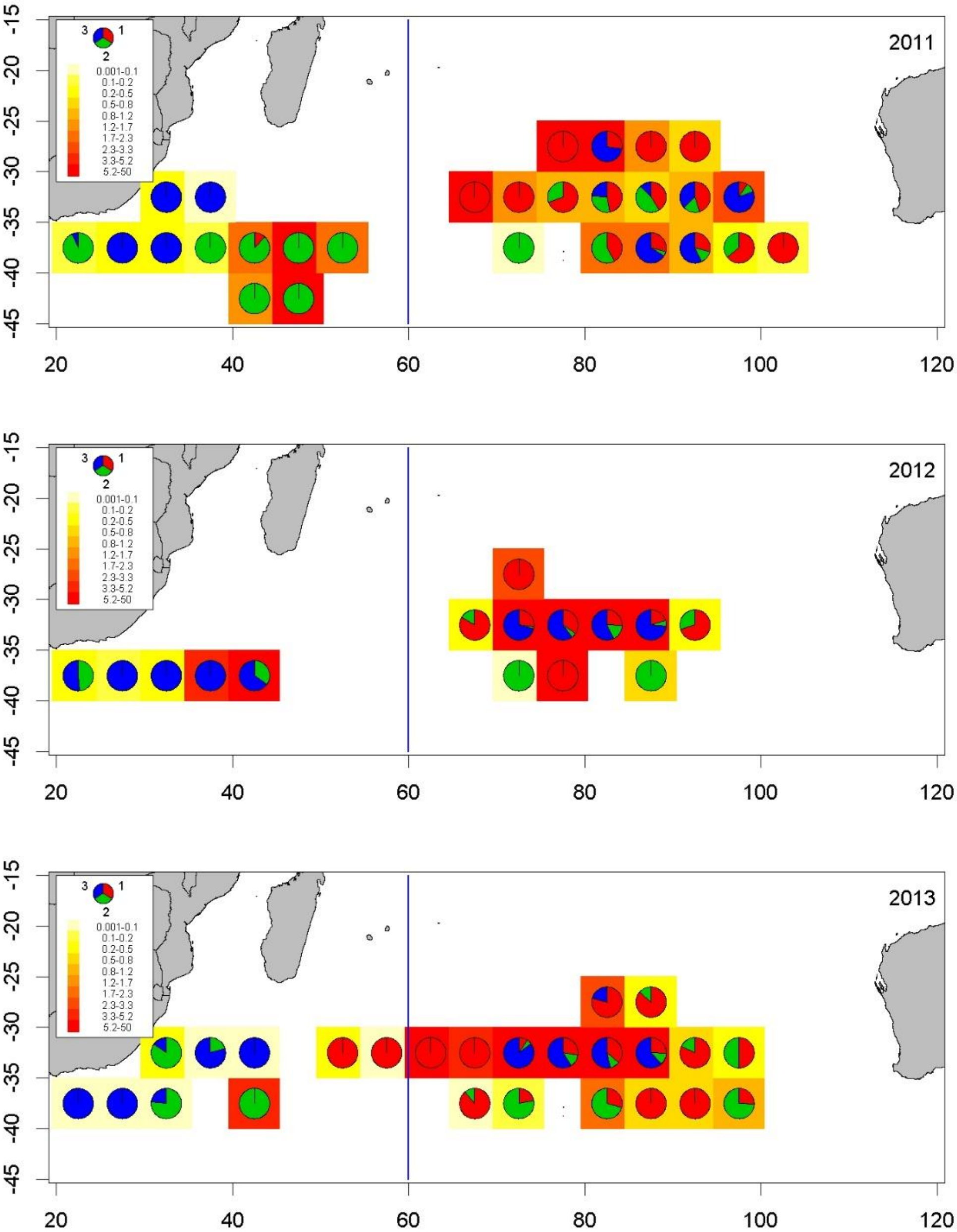

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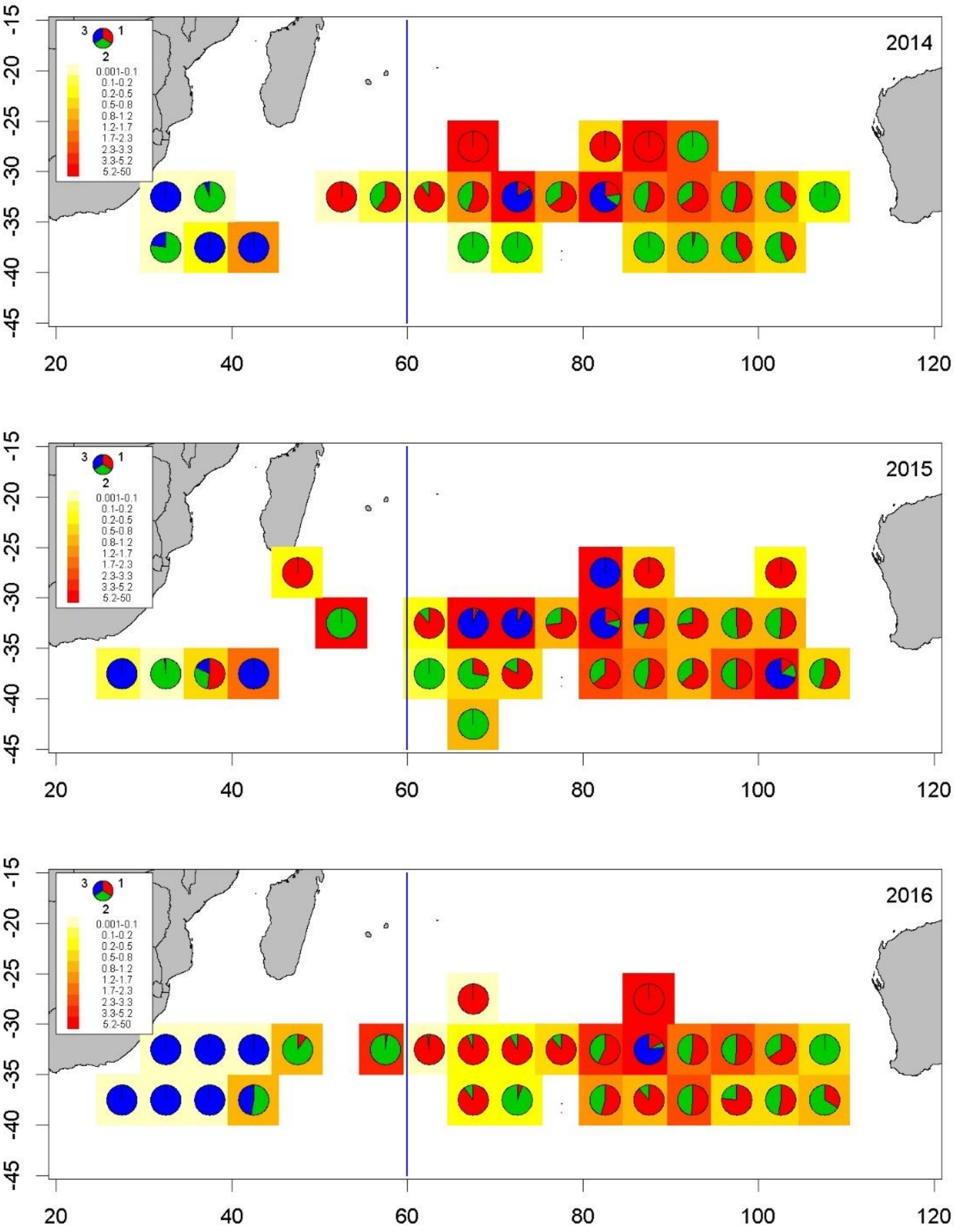

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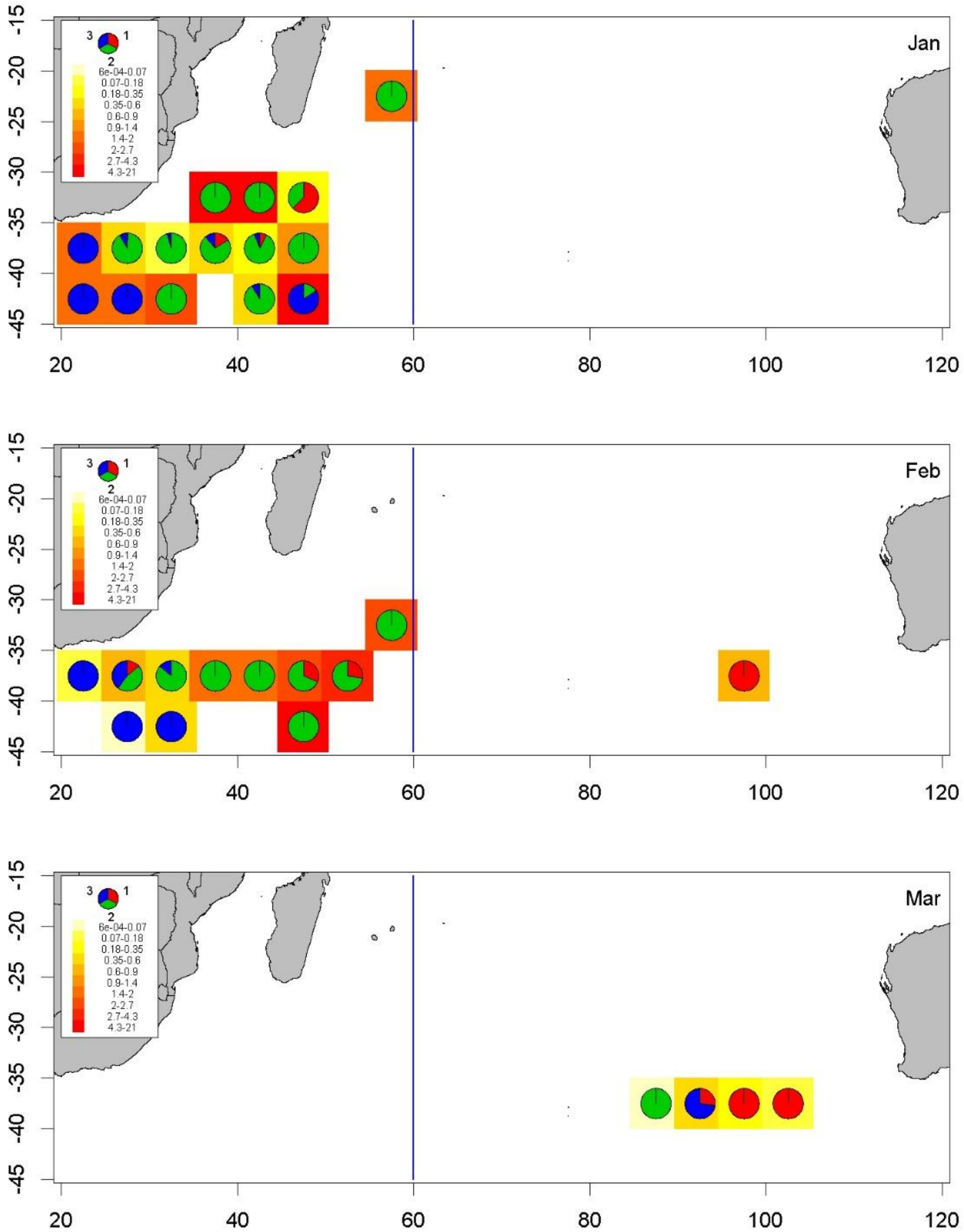
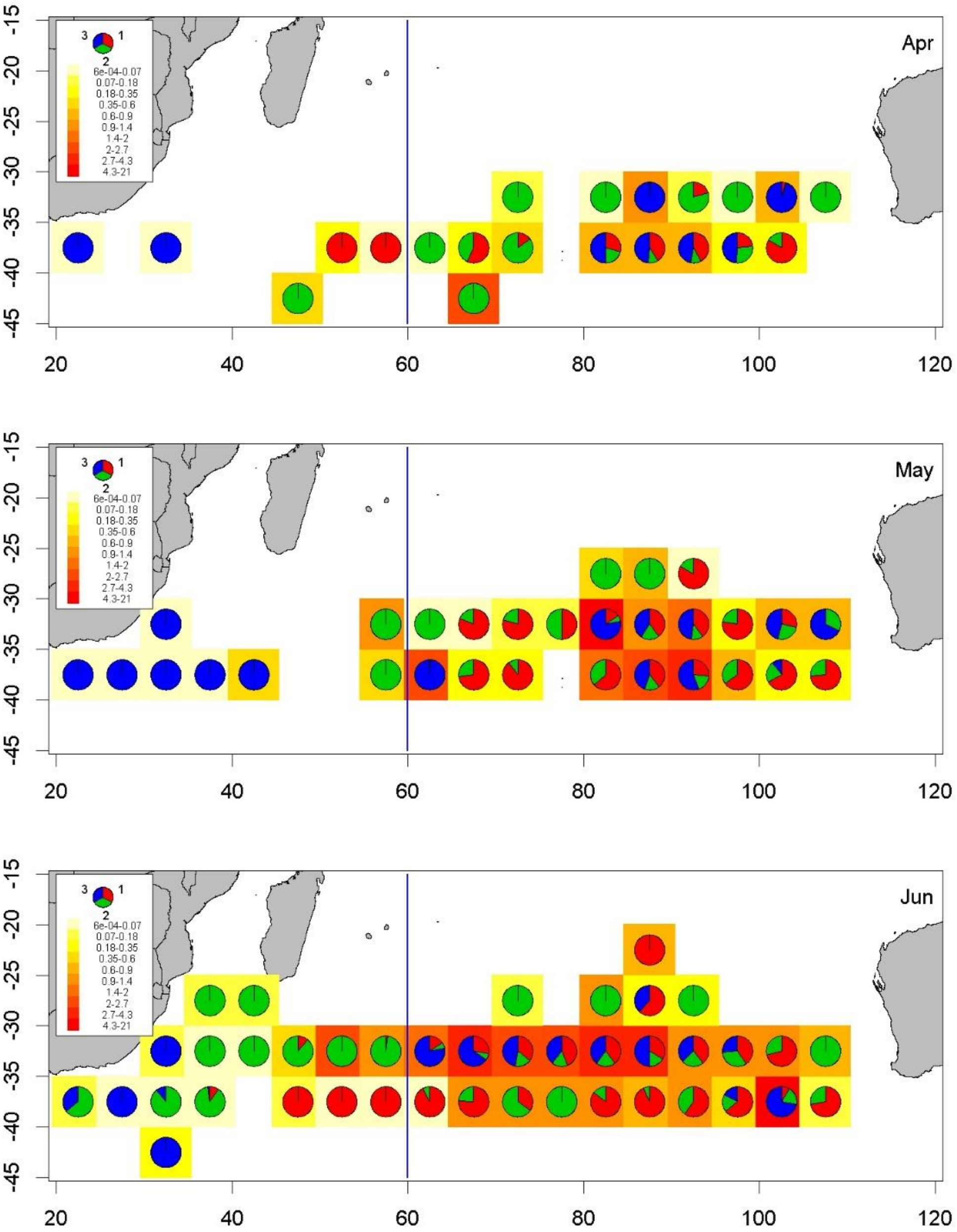


Fig. 10. Monthly SBT CPUE distribution of Taiwanese longline fleets operated in the waters of south of 20°S. Pie plots show the proportions of CPUE contributed by clusters and squares with heat colors show the levels of SBT CPUE.



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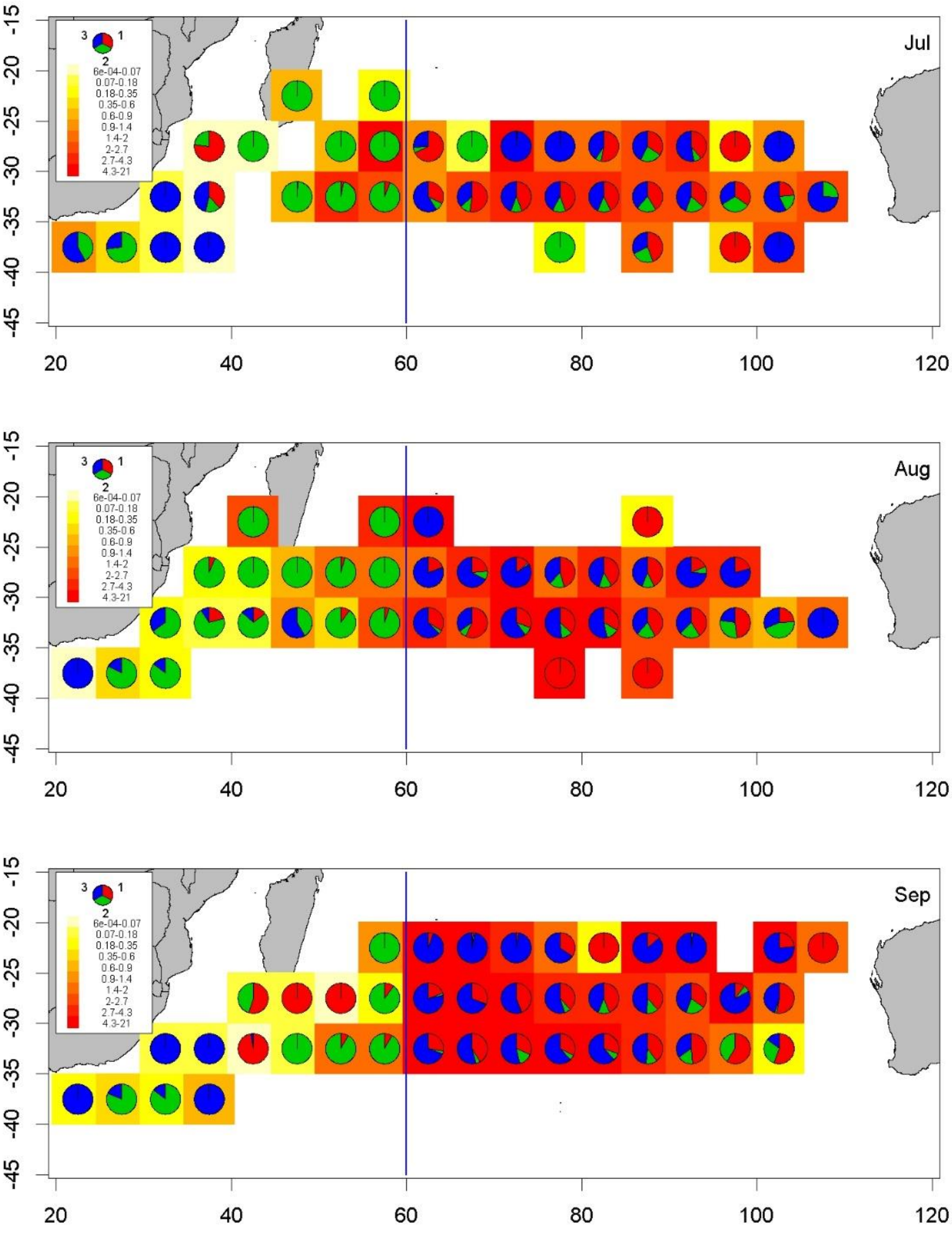

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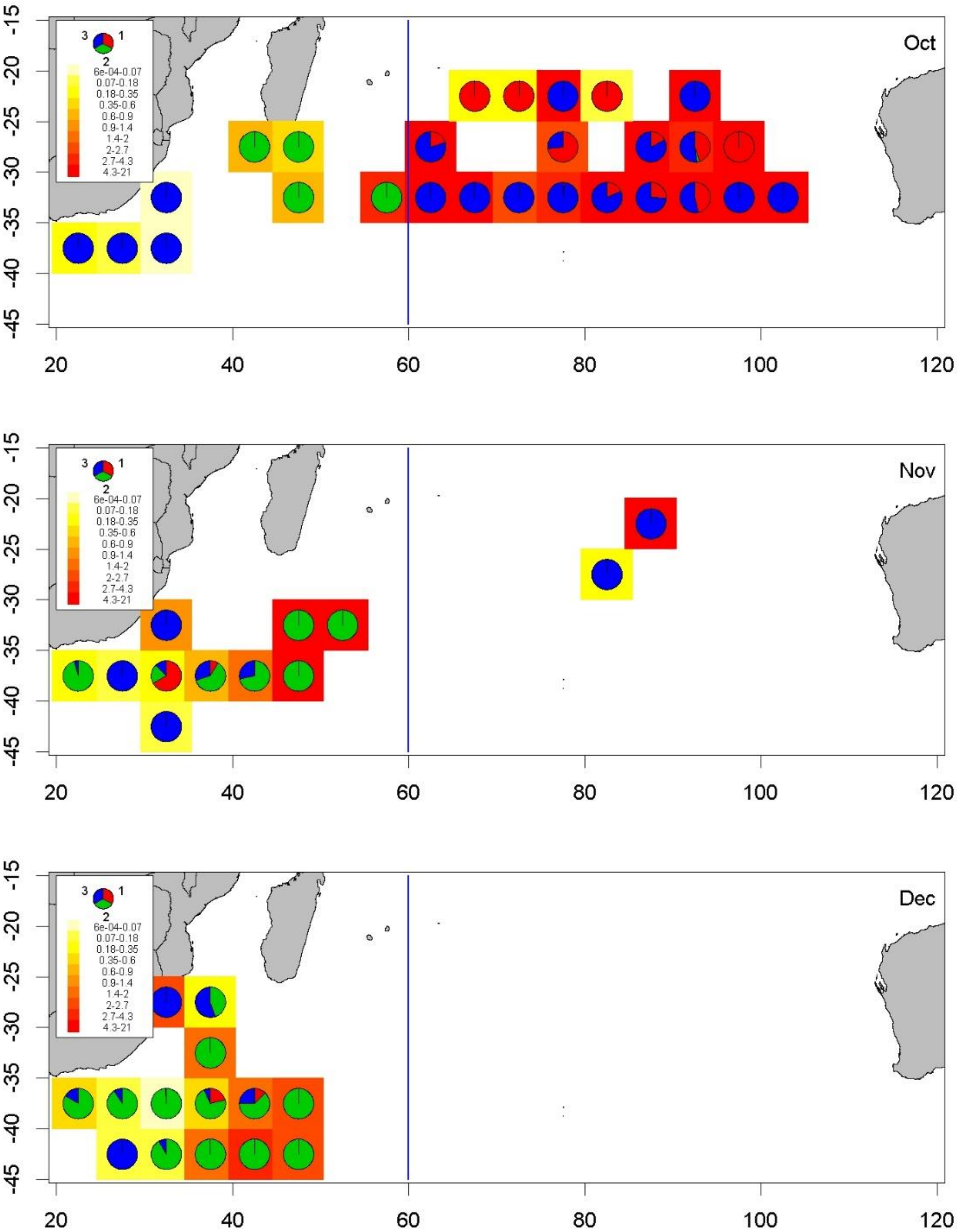

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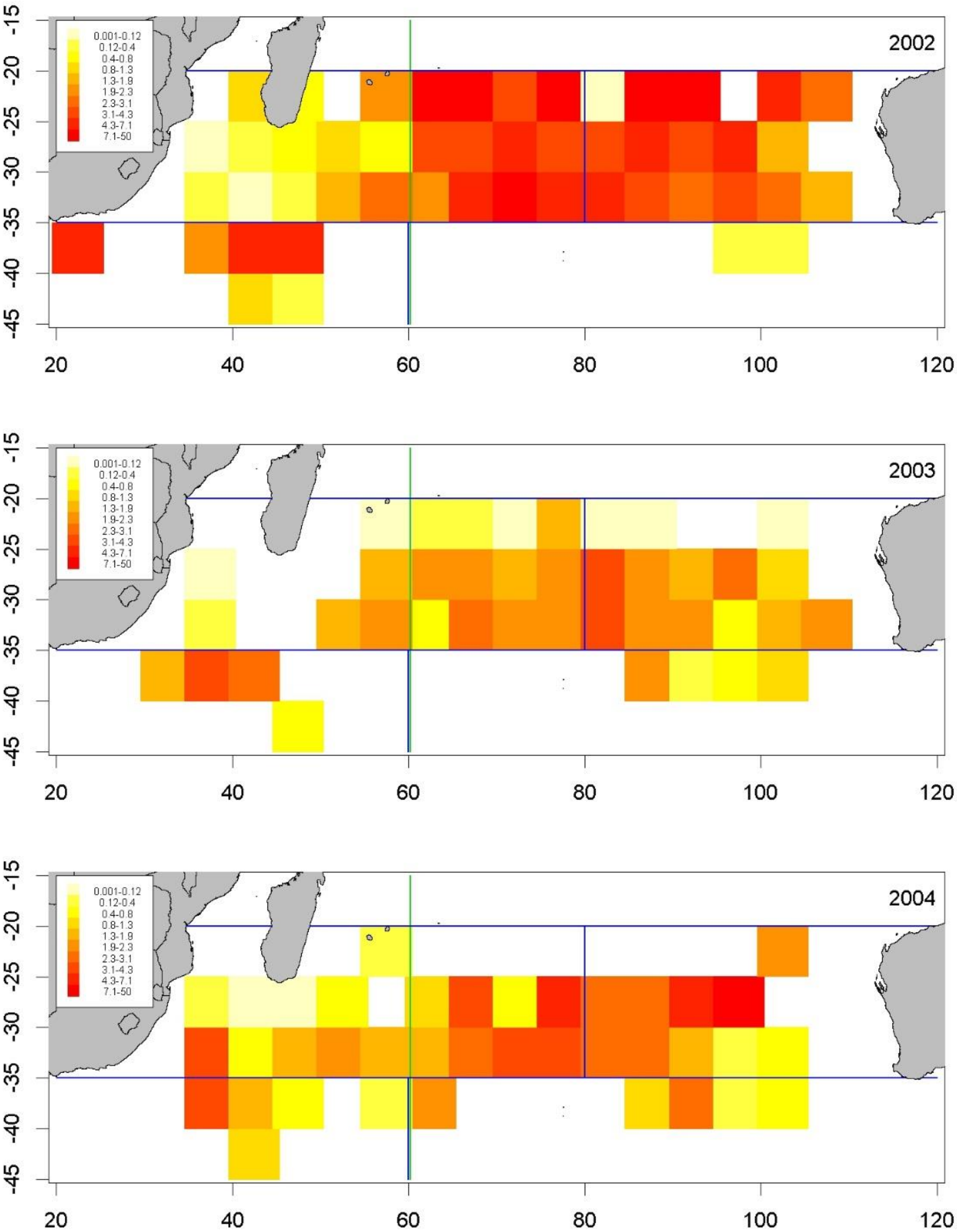
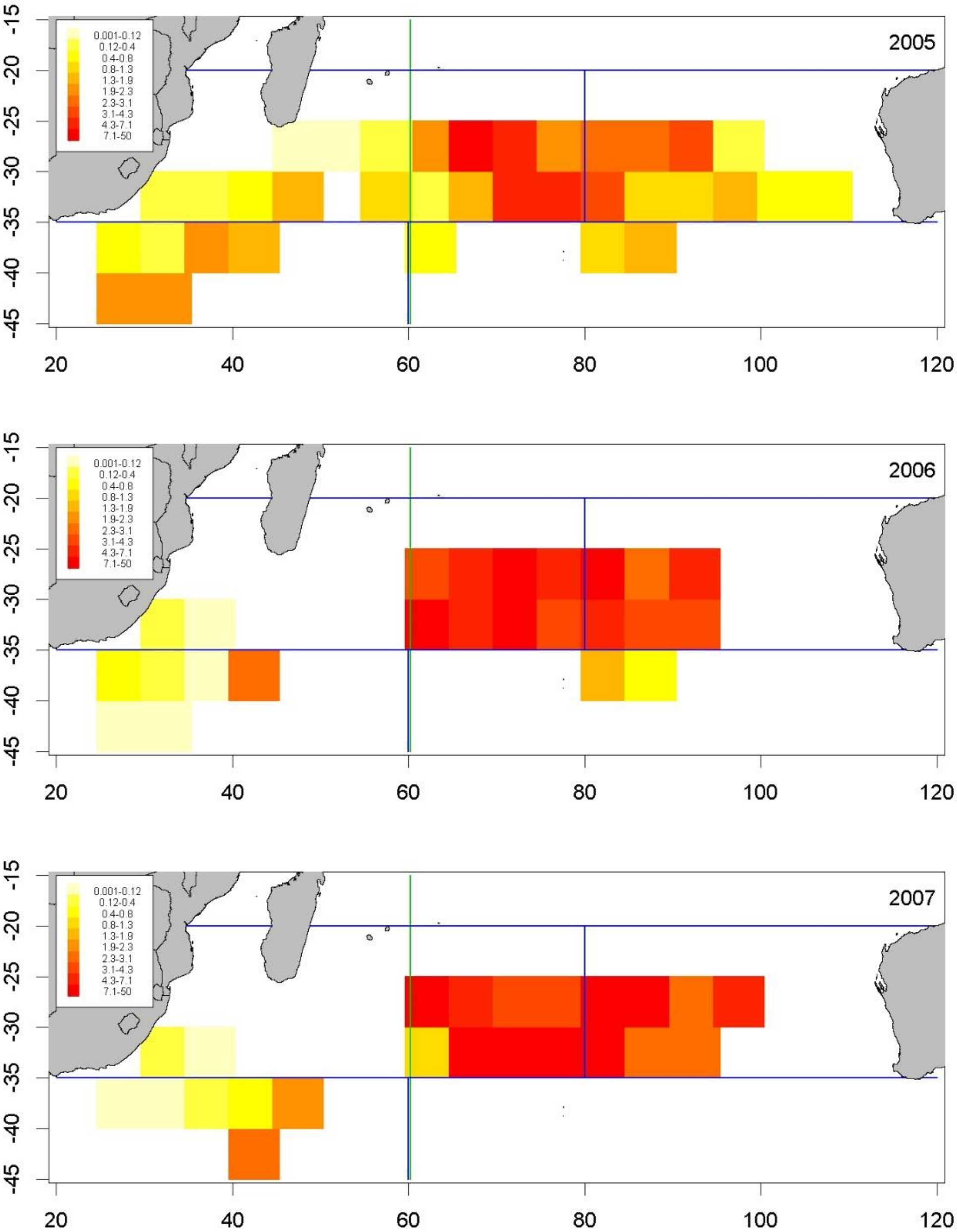


Fig. 11. Annual SBT CPUE distribution of Taiwanese longline fleets operated in the waters of south of 20°S based on the data of selected clusters.



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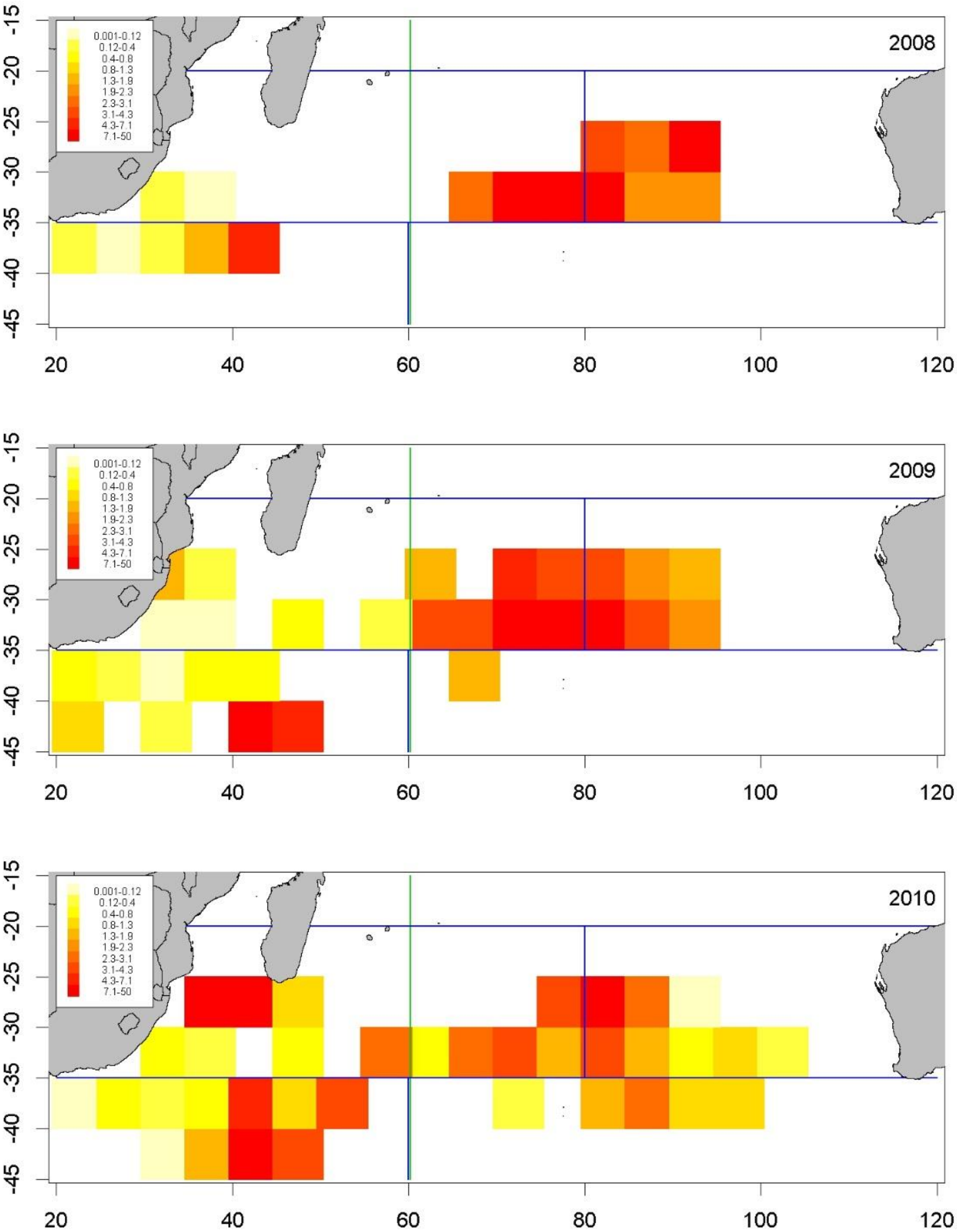

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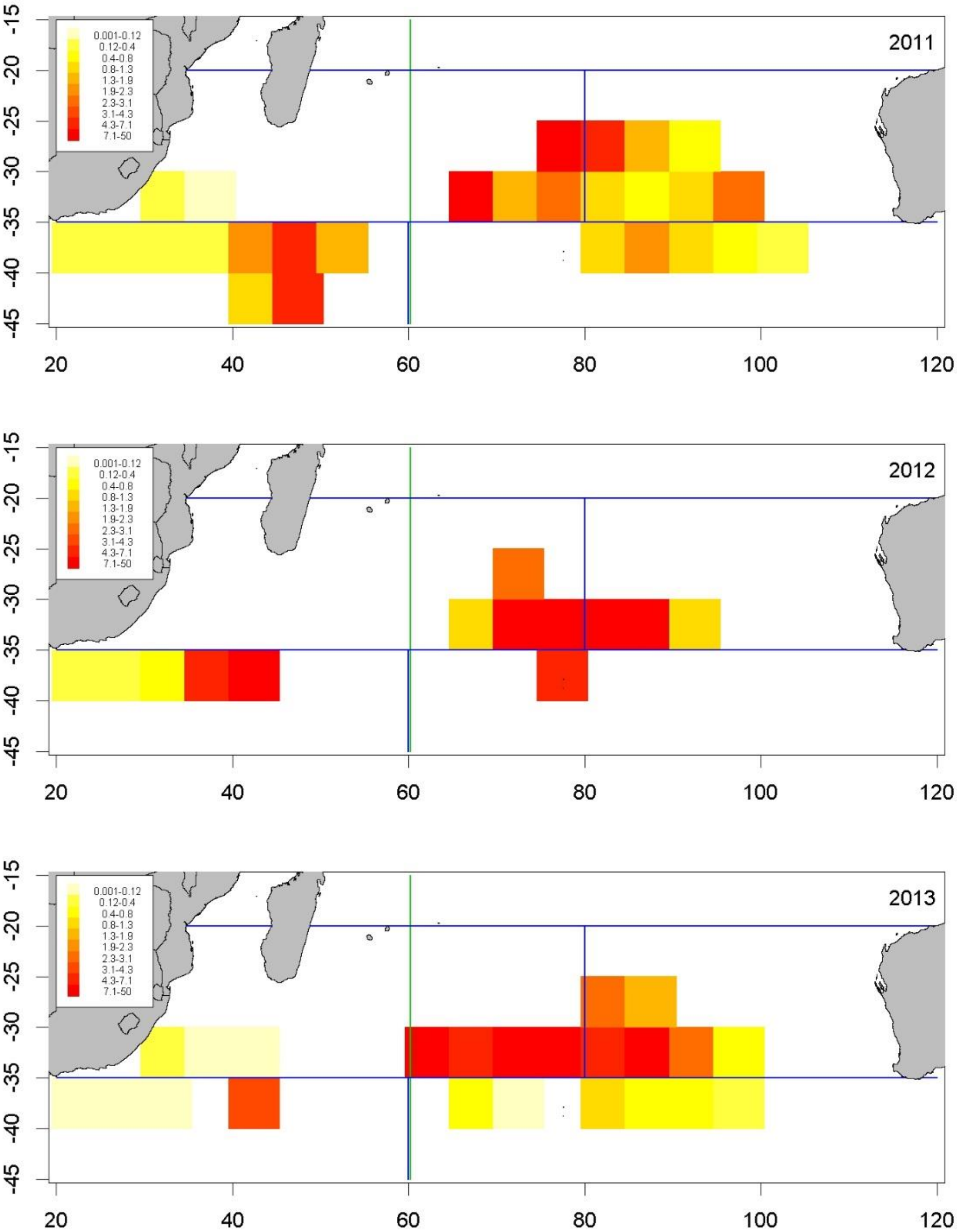

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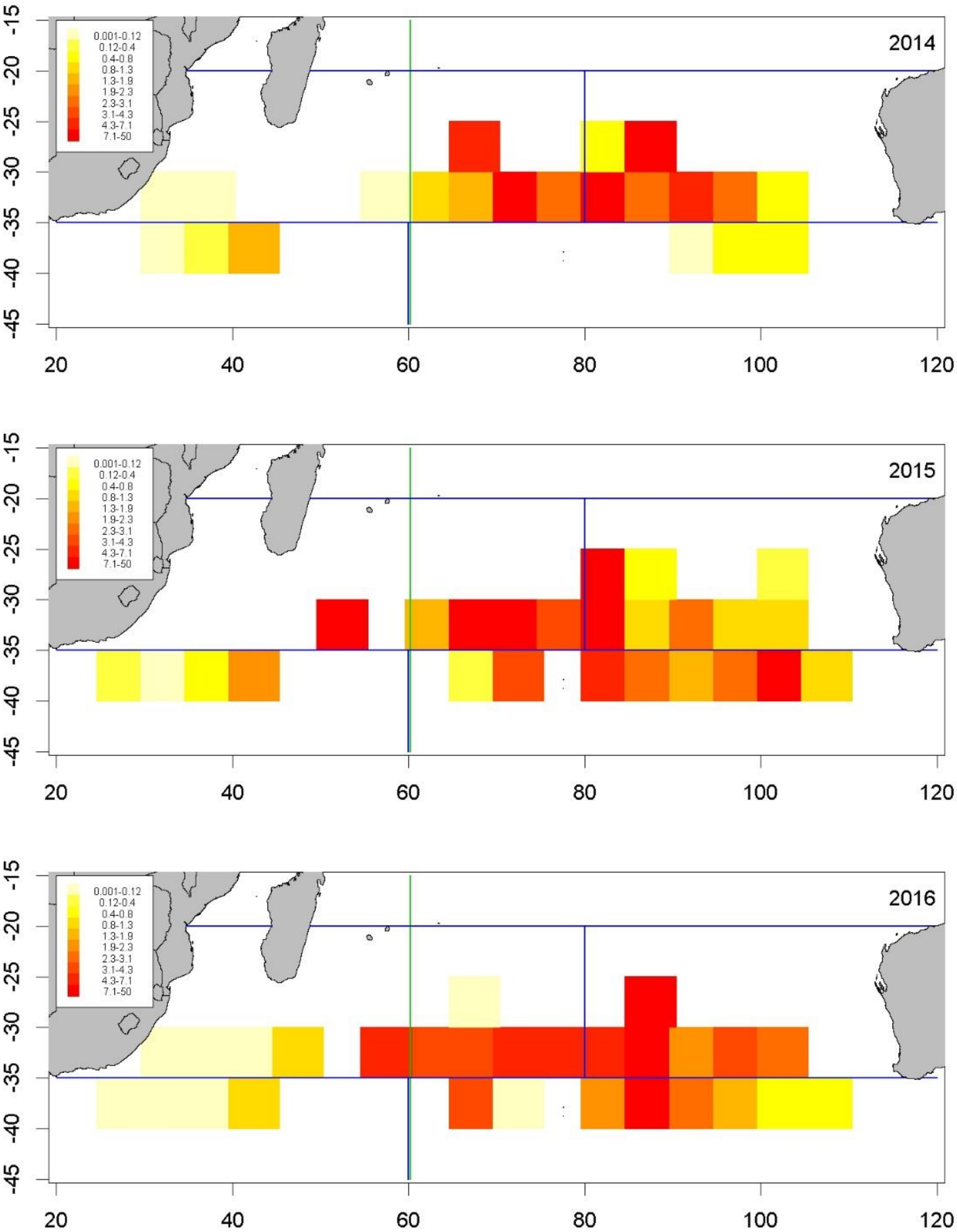

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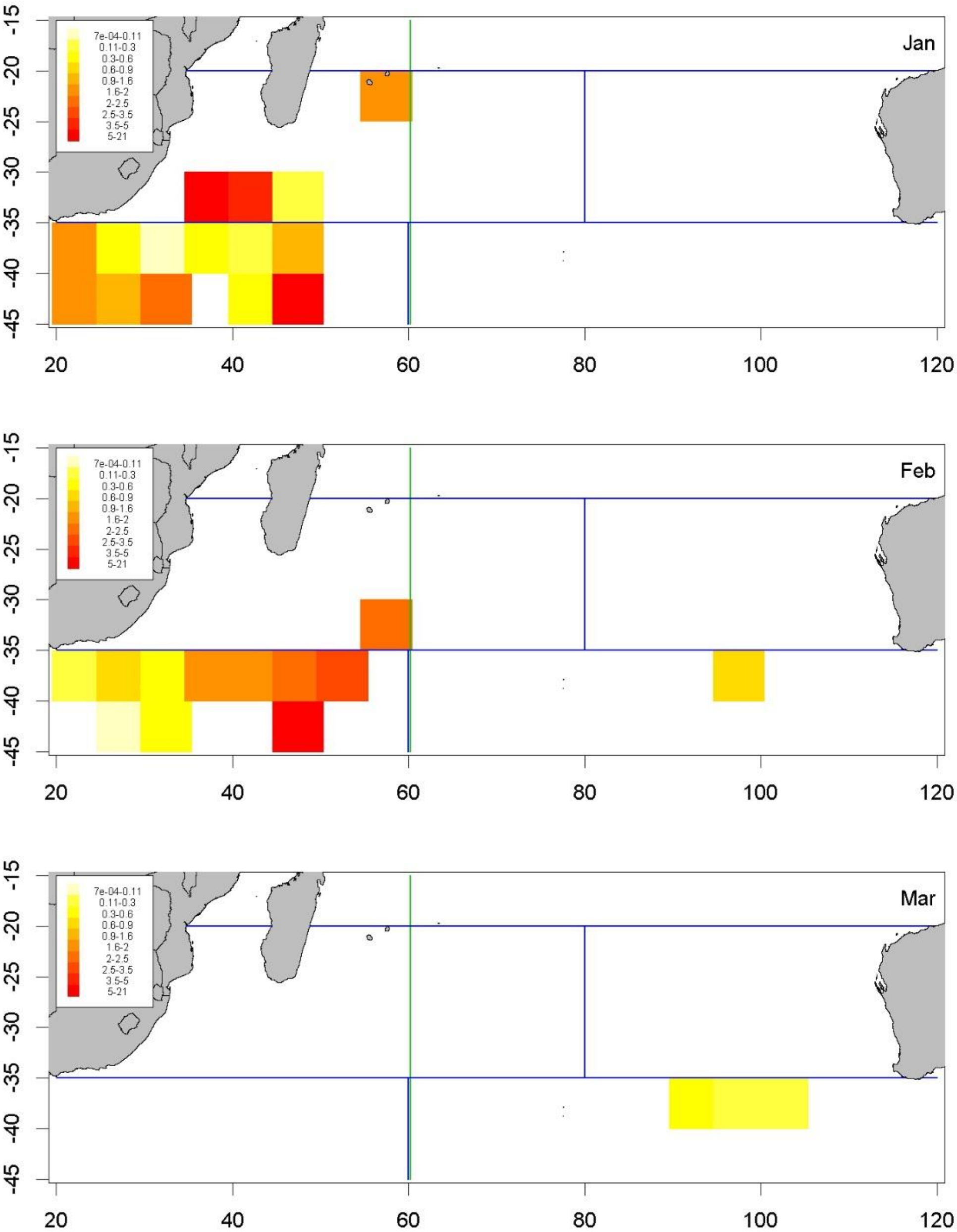
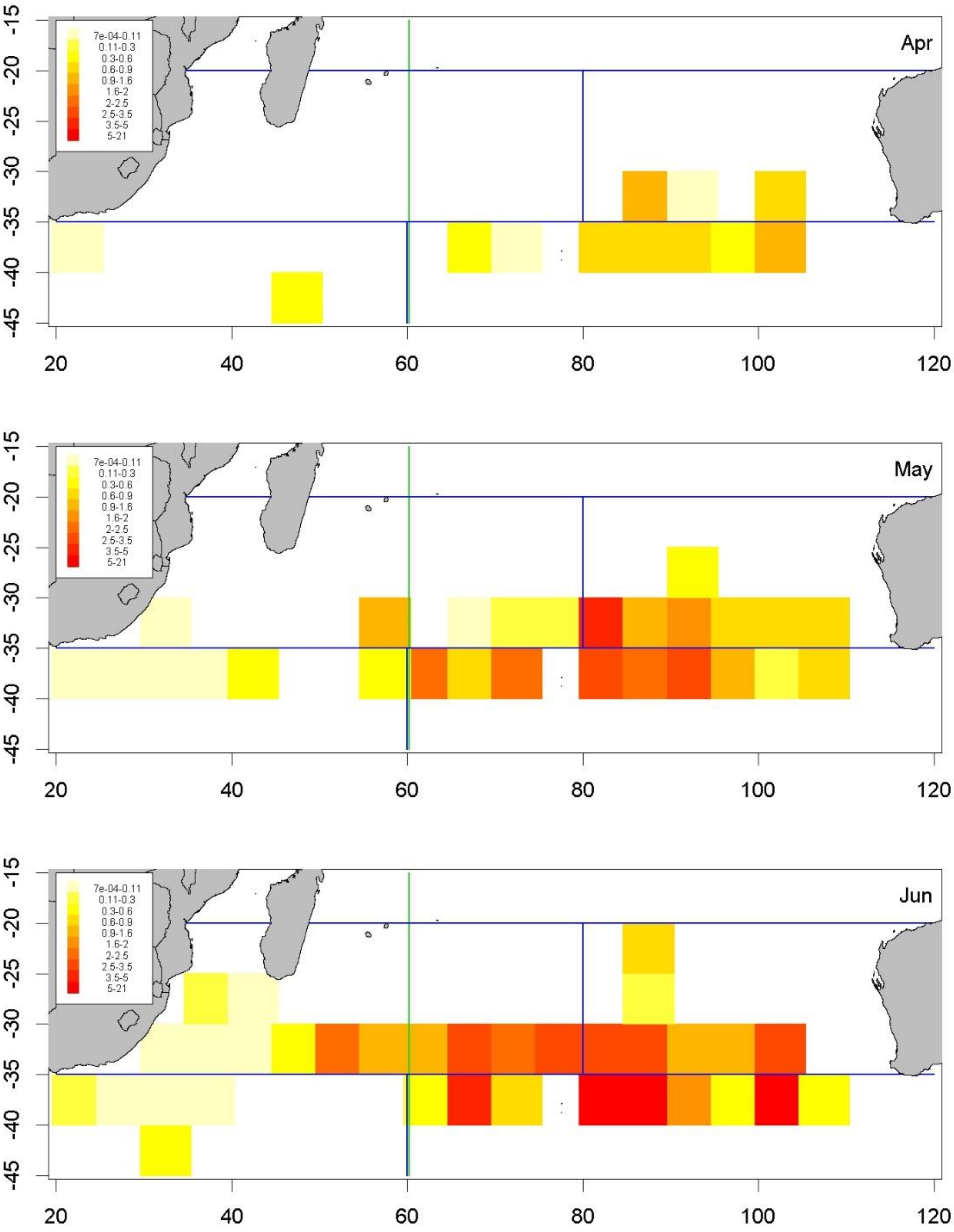


Fig. 12. Monthly SBT CPUE distribution of Taiwanese longline fleets operated in the waters of south of 20°S based on the data of selected clusters.



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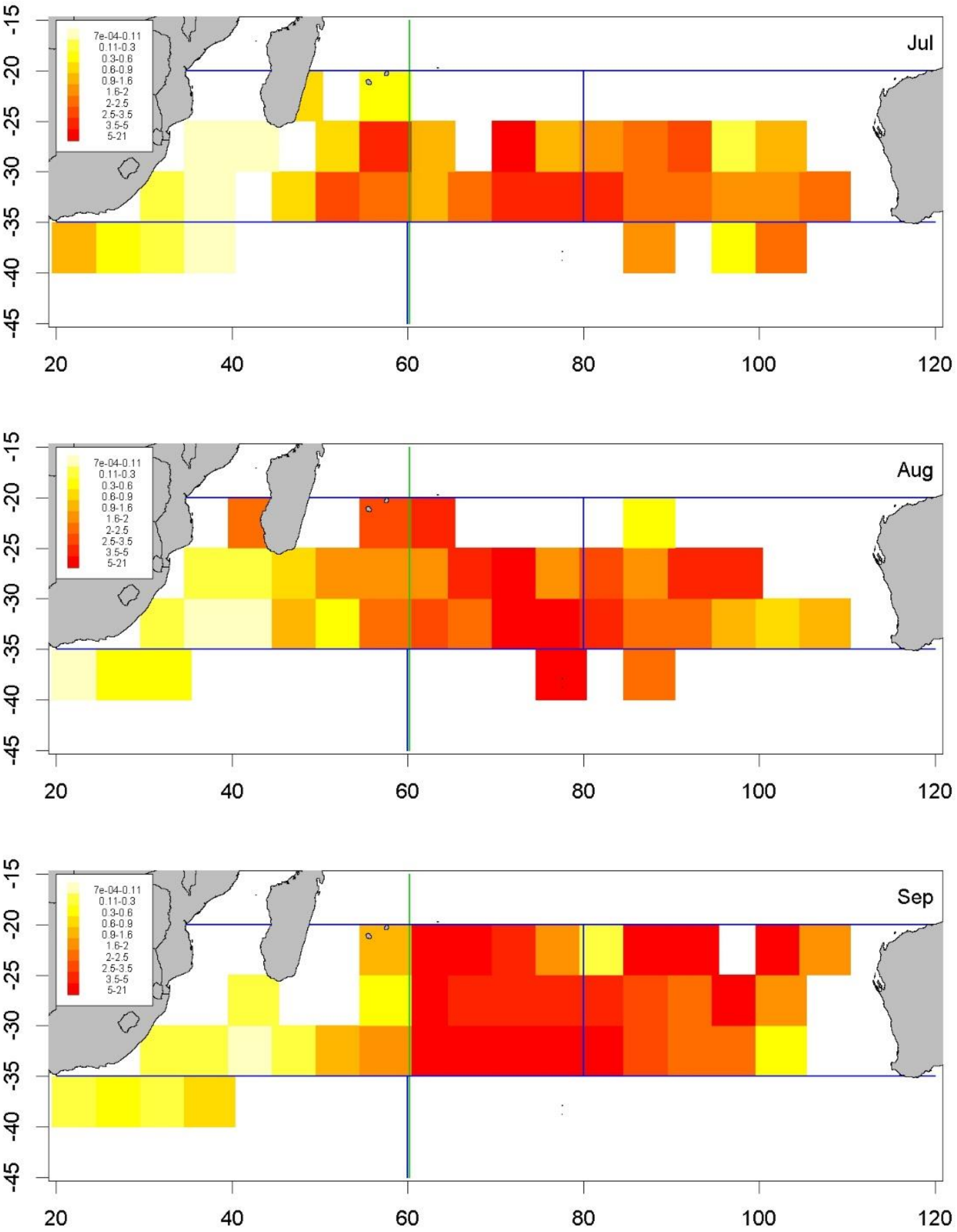

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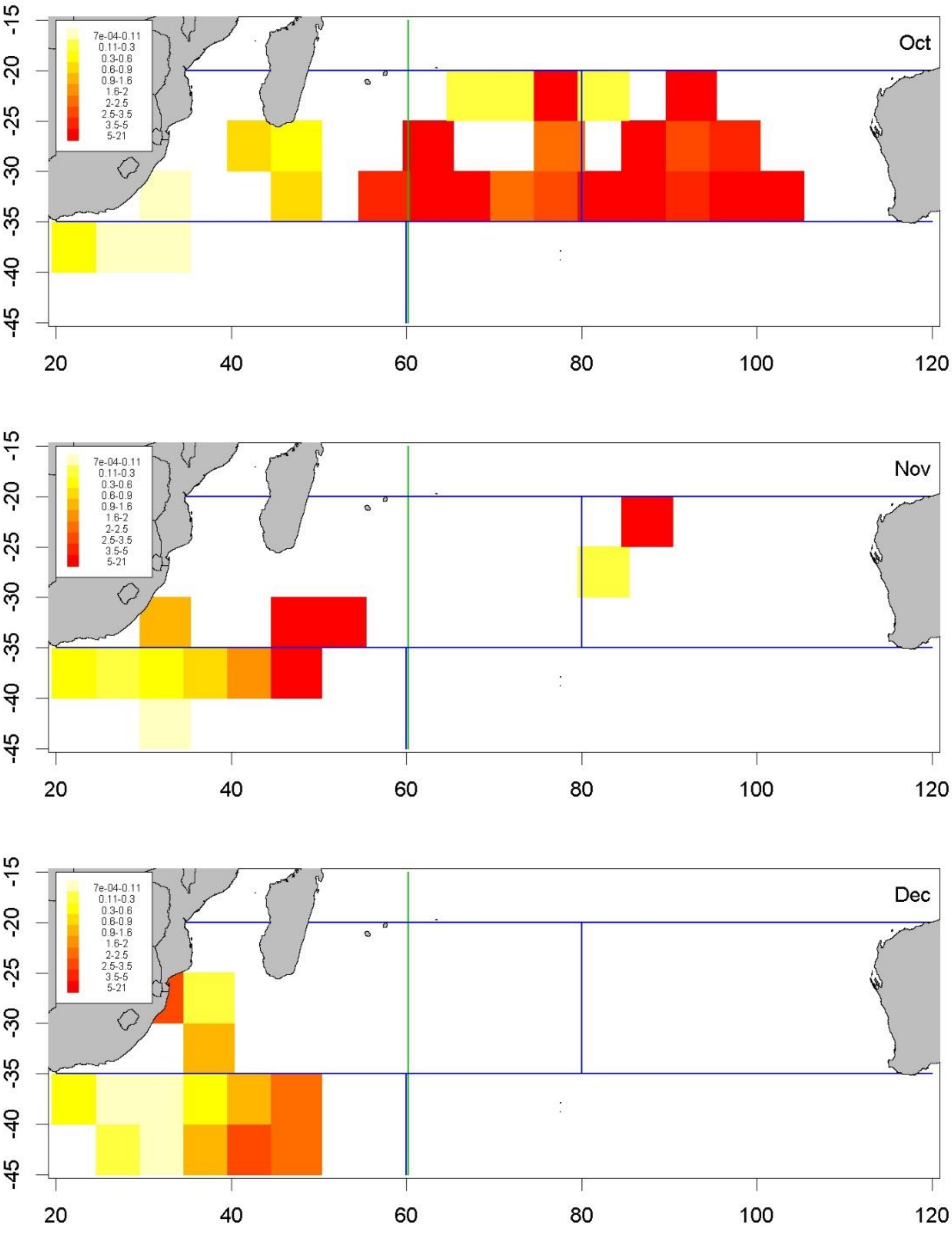

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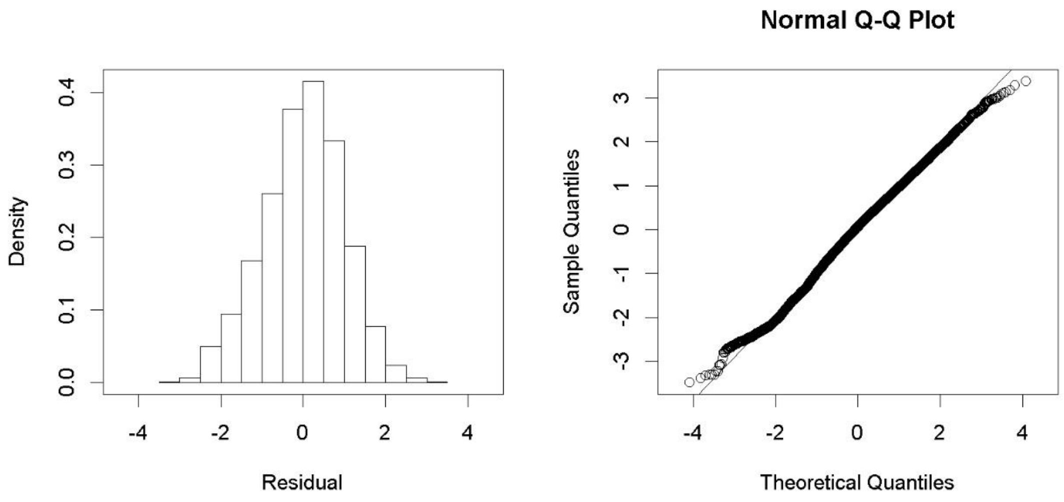
Central-eastern area



Western area

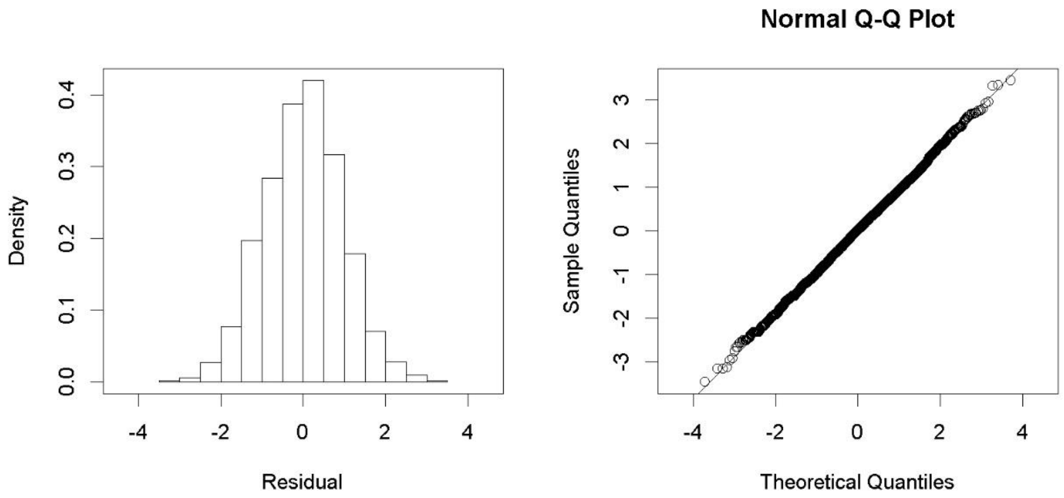
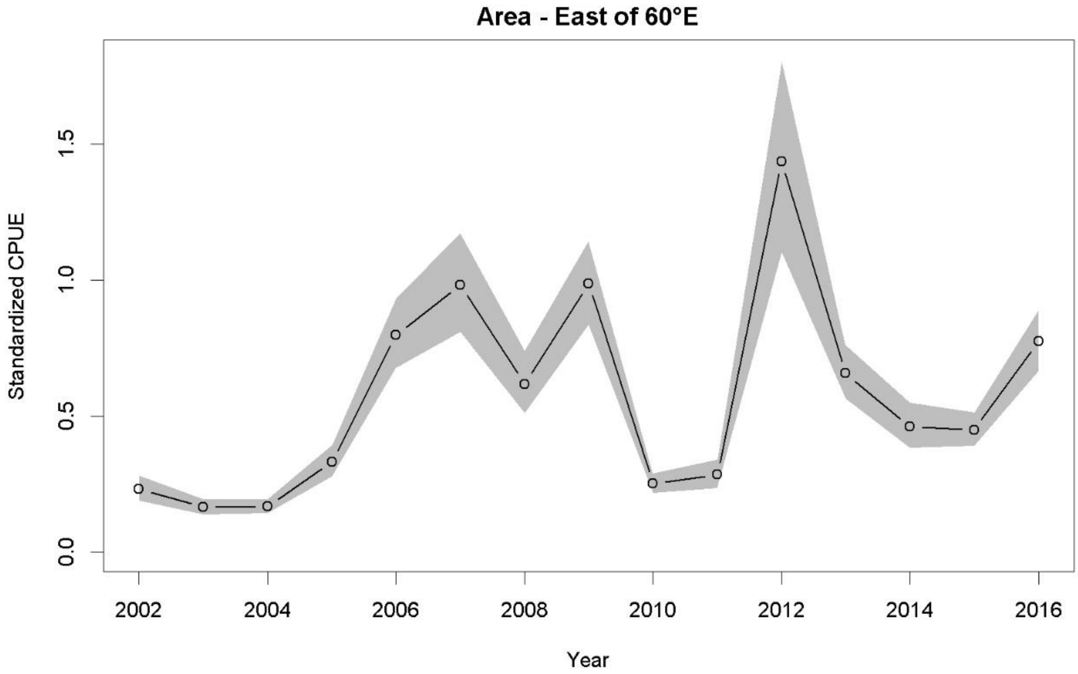


Fig. 13. The frequency distributions and Quantile-Quantile Plots for standardized residuals obtained from lognormal models for central-eastern and western areas.

Central-eastern area



Western area

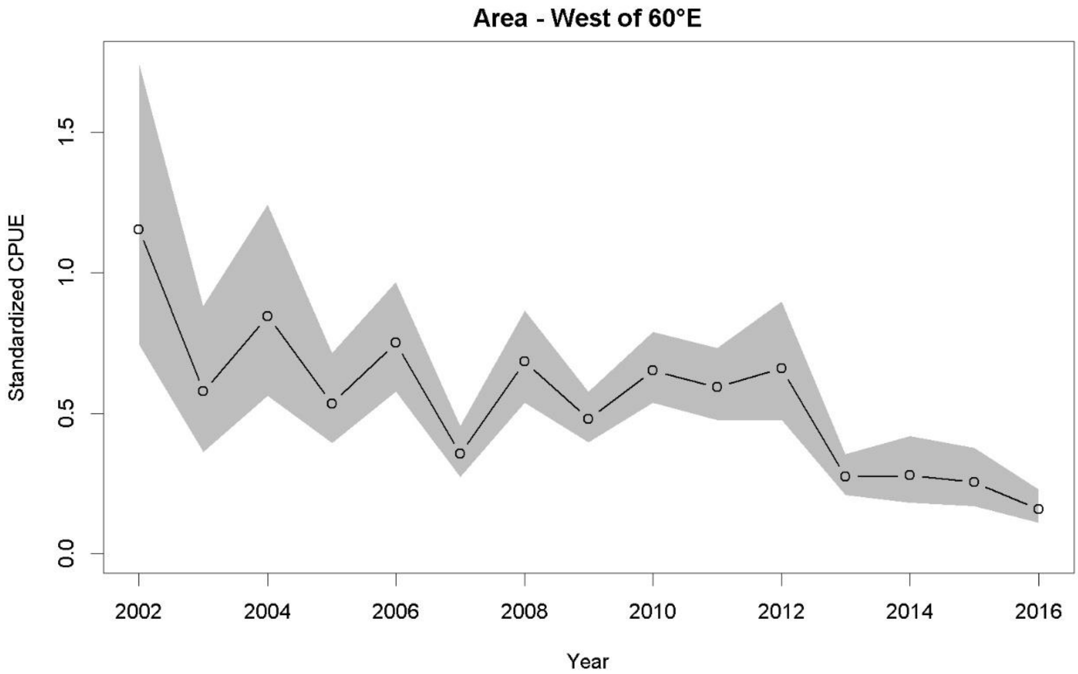


Fig. 14. Area-specific standardized CPUE of southern bluefin tuna caught by Taiwanese longline fishery. Shaded areas show the 95% confidence intervals.

Table 1. Proportions of SBT catches and efforts (number of hooks) for the cluster, which contained most of SBT catches among clusters.

Central-eastern area

	2 Clusters		3 Clusters		4 Clusters	
	SBT Catch	Hooks	SBT Catch	Hooks	SBT Catch	Hooks
2002	0.58	0.92	0.49	0.35	0.44	0.23
2003	0.65	0.85	0.44	0.37	0.42	0.26
2004	0.58	0.82	0.50	0.41	0.49	0.35
2005	0.55	0.79	0.43	0.29	0.43	0.29
2006	0.92	0.97	0.79	0.54	0.79	0.51
2007	0.86	0.96	0.70	0.54	0.69	0.53
2008	0.94	0.99	0.69	0.46	0.69	0.45
2009	0.96	0.99	0.79	0.50	0.79	0.50
2010	0.98	0.99	0.69	0.58	0.69	0.58
2011	0.96	0.96	0.82	0.69	0.82	0.69
2012	0.68	0.90	0.61	0.59	0.61	0.58
2013	0.93	0.98	0.78	0.64	0.78	0.64
2014	0.99	1.00	0.66	0.49	0.66	0.49
2015	0.96	0.99	0.79	0.63	0.79	0.63
2016	1.00	1.00	0.81	0.56	0.81	0.56
Total	0.83	0.92	0.66	0.47	0.66	0.45

Table 1. (Continued).

Western area

	2 Clusters		3 Clusters		4 Clusters	
	SBT Catch	Hooks	SBT Catch	Hooks	SBT Catch	Hooks
2002	1.00	0.97	0.95	0.48	0.30	0.45
2003	1.00	0.92	0.87	0.41	0.61	0.38
2004	1.00	0.98	0.99	0.58	0.35	0.48
2005	0.50	0.62	0.49	0.39	0.14	0.35
2006	0.20	0.22	0.20	0.15	0.17	0.15
2007	0.74	0.17	0.73	0.08	0.73	0.08
2008	0.57	0.15	0.49	0.05	0.48	0.05
2009	0.37	0.20	0.30	0.06	0.30	0.06
2010	0.50	0.15	0.47	0.08	0.35	0.08
2011	0.35	0.11	0.33	0.07	0.30	0.07
2012	0.14	0.13	0.14	0.06	0.13	0.05
2013	0.24	0.09	0.22	0.04	0.22	0.04
2014	0.05	0.12	0.01	0.04	0.01	0.04
2015	0.38	0.12	0.21	0.05	0.21	0.05
2016	0.32	0.08	0.30	0.04	0.30	0.04
Total	0.54	0.27	0.50	0.13	0.42	0.13

Table 2. Proportions of SBT catches and efforts (number of hooks) when three clusters were selected.

Central-eastern area

	Cluster 1		Cluster 2		Cluster 3	
	SBT catch	Hooks	SBT catch	Hooks	SBT catch	Hooks
2002	0.49	0.35	0.09	0.57	0.42	0.08
2003	0.44	0.37	0.21	0.48	0.35	0.15
2004	0.50	0.41	0.08	0.41	0.42	0.18
2005	0.43	0.29	0.13	0.49	0.45	0.21
2006	0.79	0.54	0.13	0.44	0.08	0.03
2007	0.70	0.54	0.16	0.42	0.14	0.04
2008	0.69	0.46	0.25	0.53	0.06	0.01
2009	0.79	0.50	0.17	0.49	0.04	0.01
2010	0.69	0.58	0.29	0.40	0.02	0.01
2011	0.82	0.69	0.14	0.28	0.04	0.04
2012	0.61	0.59	0.07	0.31	0.32	0.10
2013	0.78	0.64	0.15	0.34	0.07	0.02
2014	0.66	0.49	0.33	0.51	0.01	0.00
2015	0.79	0.63	0.17	0.36	0.04	0.01
2016	0.81	0.56	0.19	0.43	0.00	0.00
Total	0.66	0.47	0.17	0.45	0.17	0.08

Table 2. (Continued).

Western area

	Cluster 1		Cluster 2		Cluster 3	
	SBT catch	Hooks	SBT catch	Hooks	SBT catch	Hooks
2002	0.05	0.49	0.95	0.48	0.00	0.03
2003	0.13	0.51	0.87	0.41	0.00	0.08
2004	0.01	0.41	0.99	0.58	0.00	0.02
2005	0.01	0.23	0.49	0.39	0.50	0.38
2006	0.00	0.07	0.20	0.15	0.80	0.78
2007	0.01	0.08	0.73	0.08	0.26	0.83
2008	0.08	0.10	0.49	0.05	0.43	0.85
2009	0.07	0.14	0.30	0.06	0.63	0.80
2010	0.03	0.07	0.47	0.08	0.50	0.85
2011	0.01	0.04	0.33	0.07	0.65	0.89
2012	0.00	0.08	0.14	0.06	0.86	0.87
2013	0.02	0.05	0.22	0.04	0.76	0.91
2014	0.05	0.08	0.01	0.04	0.95	0.88
2015	0.16	0.07	0.21	0.05	0.62	0.88
2016	0.01	0.04	0.30	0.04	0.68	0.92
Total	0.04	0.13	0.50	0.13	0.46	0.73

Table 3. ANOVA tables for the lognormal models for central-eastern and western areas.

Central-eastern area

	SS	Df	F	Pr(>F)
Y	1852.3	14	137.691	< 2.2e-16 ***
M	310.1	9	35.863	< 2.2e-16 ***
G	784.7	37	22.072	< 2.2e-16 ***
NHBF	57.1	2	29.693	1.32E-13 ***
Residuals	21526.9	22403		

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

Western area

	SS	Df	F	Pr(>F)
Y	437.7	14	34.373	< 2.2e-16 ***
M	381.4	10	41.930	< 2.2e-16 ***
G	79.5	28	3.120	6.21E-08 ***
C	23.4	1	25.683	4.18E-07 ***
NHBF	46.4	2	25.526	9.41E-12 ***
Residuals	4314.8	4744		

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

Table 4. ANOVA tables for the delta models for central-eastern and western areas.

Central-eastern area

	LR Chisq	Df	Pr(>Chisq)
Y	2314.22	14	< 2.2e-16 ***
M	1927.13	11	< 2.2e-16 ***
G	1925.19	40	< 2.2e-16 ***
C	3135.14	1	< 2.2e-16 ***
NHBF	146.92	2	< 2.2e-16 ***

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

Western area

	LR Chisq	Df	Pr(>Chisq)
Y	531.95	14	< 2.2e-16 ***
M	2847.5	11	< 2.2e-16 ***
G	3019.18	33	< 2.2e-16 ***
C	391.61	1	< 2.2e-16 ***
NHBF	34.33	2	3.51E-08 ***

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