SCRS/2016/078 Collect. Vol. Sci. Pap. ICCAT, 73(4): 1490-1515 (2017)

CPUE STANDARDIZATION ON NORTHERN ATLANTIC ALBACORE CAUGHT BY CHINESE TAIPEI LONGLINERS, 1967 TO 2015

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SUMMARY

Both the logbooks (since 1981) and the task2 (since 1967) data sets of Taiwanese longliners were scrutinized, by three periods and 5o-square block, for the geographical distribution characters of four major tuna species (albacore, bigeye, yellowfin, and swordfish) and identified appropriate sampling areas for obtaining the better abundance indices for albacore resource. This paper used only those Taiwanese fisheries data sets within proposed sampling areas for the generalized linear model (GLM) standardization analyses and hopefully able to minimize most noises of non-albacore-targeting data. The Taiwanese longline catch per unit effort (CPUE) in appropriate albacore sampling areas was separately standardized into three periods. The GLM with log-normal error distribution was adopted for the standardization of both yearly and quarterly CPUE trends. The results showed that the yearly standardized CPUE continuously declined up to mid-1980s, highly fluctuated before early 2000s, thereafter, it increased since early 2000s up to 2015. The new fishing managements inevitably affected the understanding the status of the stock, as compared to those collected through traditional setup. Similar trends were also obtained for the quarterly standardized CPUE series.

RÉSUMÉ

Les carnets de pêche (depuis 1981) ainsi que les jeux de données de la tâche II (depuis 1967) des palangriers du Taipei chinois ont été minutieusement examinés, en trois périodes et en carré de 5º, afin de déterminer les caractéristiques de la distribution géographique des quatre principales espèces thonières (germon, thon obèse, albacore et espadon) et d'identifier les zones d'échantillonnage idéales pour obtenir les meilleurs indices d'abondance de la population du germon. Le présent document n'a utilisé que les jeux de données des pêcheries du Taipei chinois provenant des zones d'échantillonnage proposées pour les analyses de standardisation du modèle linéaire généralisé (GLM) et qui devraient, on l'espère, minimiser la plupart des bruits des données ne ciblant pas le germon. La prise par unité d'effort (CPUE) des palangriers du Taipei chinois dans les zones appropriées d'échantillonnage du germon a été standardisée séparément en trois périodes. Le modèle GLM avec une distribution d'erreur log-normale a été adopté pour la standardisation des tendances annuelles et trimestrielles de la CPUE. Les résultats ont fait apparaître que la CPUE annuelle standardisée descendait de manière continue jusqu'à la moitié des années 80, avant de fluctuer considérablement avant le début des années 2000. Par la suite, elle a augmenté depuis le début des années 2000 jusqu'en 2015. Les nouvelles dispositions en matière de gestion des pêches ont inévitablement affecté la compréhension de l'état du stock par rapport aux données recueillies au moyen de systèmes traditionnels. Des tendances similaires ont également été obtenues pour les séries des CPUE trimestrielles standardisées.

RESUMEN

Se examinaron tanto los cuadernos de pesca (desde 1981) como los conjuntos de datos de Tarea II (desde 1967) de los palangreros de Taipei Chino para tres periodos y por cuadrículas de 5º, para determinar las características de la distribución geográfica de cuatro especies principales de túnidos (atún blanco, patudo, rabil y pez espada) y se identificaron las áreas de muestreo más adecuadas para obtener mejores índices de abundancia para el recurso de atún blanco. Este documento utilizó únicamente los conjuntos de datos de las pesquerías de Taipei Chino dentro de las áreas de muestreo propuestas para análisis de estandarización mediante un modelo lineal

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generalizado (GLM) y se espera poder minimizar la mayoría de los ruidos de los datos no dirigidos al atún blanco. La captura por unidad de esfuerzo (CPUE) del palangre de Taipei Chino en las áreas de muestreo de atún blanco adecuadas fue estandarizada por separado en tres periodos. Se adoptó un modelo lineal generalizado (GLM) con una distribución de error lognormal para estandarizar las tendencias de la captura por unidad de esfuerzo (CPUE) tanto anuales como trimestrales. Los resultados mostraron que la CPUE estandarizada anualmente descendía de forma continua hasta mediados de los 80, fluctuaba mucho antes de principios de los 2000 y posteriormente aumentaba desde principios de los 2000 hasta 2015. La nuevas disposiciones de ordenación de la pesca afectaron inevitablemente a la comprensión del estado del stock, en comparación con los datos recopilados mediante sistemas tradicionales. Se obtuvieron tendencias similares para la serie de CPUE estandarizada trimestralmente.

KEYWORDS

Albacore, CPUE standardization, longline, GLM, North Atlantic

1. Introduction

1.1 Historical fisheries activities

In the Atlantic Ocean, two stocks of albacore (*Thunnus alalunga*), separated by 5°N latitude, were assumed for the fishery management. Taiwan is one of the main fishing nations utilizing the North Atlantic albacore resource, and contributes a significant part to the total landings. As one of the main fishing nations, it is equally our responsibility to acquire the catch and effort statistics for the purpose of monitoring its status.

Chinese Taipei longliners operated in the Atlantic Ocean were mainly composed of two types of fishing gears, i.e., regular longliner and deep longliner. The former, which was also called traditional longliner, was mainly targeting albacore, whereas the latter equipped with -70°C freezing capability was mainly targeting bigeye tuna and yellowfin tuna. Unfortunately, it was not possible until mid-1990s when the logbook reporting system was able to directly distinguish their major identities by the addition of 'the number of hooks per basket used' in new reporting logbooks. Nevertheless, historic Task II data series compiled by Chinese Taipei fisheries managerial sectors and reported to the ICCAT since late 1960s thus became one of the important data sources to investigate the long-term abundance fluctuation of this resource.

1.2 Chinese Taipei Fisheries management

The new fishing managements of Chinese Taipei fleets have been launched for abide by the new regulation requirement set by ICCAT recommendations. The Fisheries Agency announced:

(1) fishing only allowed as prior authorization by area and group; initial vessel quota are pre-set, yet later modification will be allowed as long as total catch limits as a whole is not exceed;

(2) for best controlling the fishing procedure not to cross the pre-set red-line, several further management tools are also implemented parallel to the progressive fishing activities, such as: VMS-reporting continuously for monitoring its fishing location; daily fill in catch logbook as well as weekly reporting its weekly total; prior permission for at sea transshipment; verification of catch documents versus weekly reporting;

(3) on-board observer; at-sea inspection; and e-logbook system are also organized and implemented for a better abide by the requests from ICCAT.

These new establishments inevitably will affect the understanding the status of the stock, as compared to those collected through traditional setup. As a result, how to standardize the information is something we have to concern.

1.3 Standardization CPUE of Chinese Taipei fleets

Although Catch Per Unit Effort (CPUE) standardization, using only three subareas of whole North Atlantic Ocean (North of 5ºN latitude) as subarea factor in the Generalized Linear Model (GLM), had been carried out for Chinese Taipei longliners data dating of 1967-2012 (Chang *et al*., 2014); how to properly sort out the entanglements of albacore information reported from the regular longliner (targeting albacore) and the deep longliner (targeting bigeye tuna) remained the major difficulty in obtaining a better indicator for albacore abundance. Undertaking this problem, as the attempt, an appropriate area or the best sampling area was investigated and proposed in this analysis for obtaining the better albacore abundance indices.

Both the logbooks (since 1981) and the Task II (since 1967) data sets of Chinese Taipei longliners were scrutinized, by three periods (1967-1987, 1987-1999 and 1999-2015) and 5º-square block, for the geographical distribution characters of four major tuna species (albacore, bigeye tuna, yellowfin tuna, and swordfish) and identified the appropriate sampling area for obtaining the better abundance indices for albacore resource. This paper used only those Chinese Taipei fisheries data sets within the proposed sampling areas for the GLM standardization analyses and hopefully able to minimize most noises of non-albacore-targeting data.

2. Materials and methods

2.1 Data

(1) Task I from 1962 to 2015

Task1 is compiled based on the data of weekly catch report; the total catch from the recovered logbooks; statistical documents reported to the Fisheries Agency; monthly traders' sales records; the verification on settlement of fish sales from the Fisheries Agency; and trading data from the Organization for the Promotion of Responsible Tuna Fishery (OPRT). The historical catch of North Atlantic albacore was showed in **Figure 1**.

(2) Logbook from 1981 to 2015

The logbooks data, aggregated by per vessel's year-monthly catch from 1981 to 2015, were compiled. The catches in weight (kg) of albacore, bigeye tuna, yellowfin tuna and swordfish of logbooks were used to conduct the k-means model cluster analysis to determine the albacore fleet. It was used Euclidean distances, so the cluster centers were based on least squares estimation. After confirmation operating distribution of the albacore fleet from logbooks, thus it can supplement the appropriate albacore sampling subareas which are applied to the Task II data.

(3) Task II from 1967 to 2015

Chinese Taipei longline catch and effort data, compiled by month and 5° square block, from 1967 to 2015 were compiled. The logbook and Task II data were the major sources of data used in this analysis. These data were kindly provided by the Overseas Fisheries Development Council (OFDC), Chinese Taipei fisheries managerial sector.

2.2 Three periods

The Chinese Taipei regular longline fishery which commenced since 1960s in the North Atlantic Ocean has reached the peak of its development between mid-1970s and mid-1980s and reached a historical high North Atlantic albacore catch in 1986 which was 19,646 t in **Figure 1**. Since mid-1980s, some operators began to build new vessels and switch to super freezer longline fishing. As a consequence, the proportion of albacore of the overall catches was decreased, and surpassed by bigeye tuna and yellowfin tuna caught by deep longliners. The aforementioned period (1987-1999) of situation can be viewed as the transitional phase of the Chinese Taipei longline fisheries in the North Atlantic Ocean. The catch decreased and remained in low levels after 1987 and fluctuated between 800 t to 6700 t. From 2002, the Fisheries Agency has requested that longliners shall apply to the statistical documents for catches of bigeye tuna, southern bluefin tuna and swordfish prior to their export to foreign countries. Furthermore, several measures of fisheries management and monitoring, such as VMS and e-logbook, have gradually carried out. Thus, three periods were 1967-1987, 1987-1999 and 1999-2015.

2.3 The appropriate albacore sampling subareas

In order to find the appropriate albacore sampling subareas for Chinese Taipei longline fishery, distribution maps of albacore CPUE, albacore catch, effort, proportion of catch by species, and amount of catch by species for three periods (1967-1987, 1987-1999 and 1999-2015) by Chinese Taipei longline fishery were used to examine.

2.4 Models of GLM

Three constants for the periods of 1967-1987, 1987-1999 and 1999-2015 respectively, which were obtained by averaging all Chinese Taipei longliners' nominal albacore CPUE reported in the appropriate albacore sampling subareas of the North Atlantic Ocean and dividing by 10, were determined and added to each nominal albacore CPUE before using SAS solver for the purpose of avoiding zero albacore catch rate problem (ICCAT, 1996).
In the appropriate albacore sampling subareas, the GLM with normal error structure (Robson, 1966; Gavaris, 1980; Kimura, 1981) was used in the present study to standardize yearly and quarterly CPUE trends, based on Chinese Taipei longline fisheries data set, for the North Atlantic albacore. Factors of year, quarter, subareas by 5° latitude x 5° longitude, bycatch effects of bigeye tuna, yellowfin tuna and swordfish, and interactions will be constructed for obtaining yearly standardized CPUE trend. Factors of quarter-series, subareas by 5° latitude x 5° longitude, and bycatch effects of bigeye tuna, yellowfin tuna and swordfish will be constructed for obtaining quarterly standardized CPUE trend. Bycatch effects of bigeye tuna, yellowfin tuna and swordfish were evaluated by quartile. The subareas by 5° latitude x 5° longitude were adopted in the model to minimize variations caused by fishing location. The Chinese Taipei longline CPUE was separately standardized into three periods (1967-1987, 1987-1999 and 1999-2015). The GLM models thus constructed for both yearly and quarterly standardizations are:

Yearly generalized linear model with normal error structure:

$$Log\ (U_{ijklmn} + C) = \mu + Y_i + Q_j + A_k + BET_l + YFT_m + SWO_n + interactions + \varepsilon_{ijklmn}$$

where *Log*: natural logarithm;
U_{ijklmn}: nominal CPUE in year i, quarter j, subarea k, with bycatch level of BET_l, YFT_m, SWO_n, and interactions;
μ: intercept;
C: constant (10% of the overall mean of nominal albacore CPUE);
Y_i: effect of year i;
Q_j: effect of quarter j;
A_k: effect of subarea k;
BET_l: bycatch effect of bigeye tuna in quartiles of CPUE (Wt./1000hooks);
YFT_m: bycatch effect of yellowfin tuna in quartiles of CPUE (Wt./1000hooks);
SWO_n: bycatch effect of swordfish in quartiles of CPUE (Wt./1000hooks);
Interactions are the interactions between main effects;
ε: error term with distribution character of $N(0,\sigma^2)$.

Quarterly generalized linear model with normal error structure:

$$Log\ (U_{jklmn} + C) = \mu + YQ_j + A_k + BET_l + YFT_m + SWO_n + \varepsilon_{jklmn}$$

where *Log*: natural logarithm;
U_{jklmn}: nominal CPUE in quarter-series j, subarea k, and with bycatch level of BET_l, YFT_m, SWO_n;
μ: intercept;
C: constant (10% of the overall mean of nominal albacore CPUE);
YQ_j: effect of quarter-series j;
A_k: effect of subarea k;
BET_l: bycatch effect of bigeye tuna in quartiles of CPUE (Wt./1000hooks);
YFT_m: bycatch effect of yellowfin tuna in quartiles of CPUE (Wt./1000hooks);
SWO_n: bycatch effect of swordfish in quartiles of CPUE (Wt./1000hooks);
ε: error term with distribution character of $N(0,\sigma^2)$.

SAS (Statistical Analysis Software) Ver. 9.4 package was used to find solutions.

3. Results and discussion

3.1 Cluster analysis

The cluster analysis was used to allocate sets to a main target species, with the goal of removing non-albacore-targeting sets and ensure that albacore catchability was the same across sets retained for the analysis. This approach is further justified by examining trends in regional nominal CPUE by cluster, which shows important contrasts between albacore and non-albacore-targeting clusters.

The results of cluster analysis based on the logbook catches in weight of albacore, bigeye tuna, yellowfin tuna and swordfish for three periods (i.e., 1981-1987, 1987-1999, and 1999-2015) showed a clear separation of 4 clusters (**Table 1**). Chinese Taipei longline fisheries operated in these 4 clusters had apparently different catch composition of main species. The fleets targeting albacore for three periods were as follows: Period_1 of 1981-1987: albacore (clusters 2, 3 and 4); Period_2 of 1987-1999: albacore (clusters 1 and 4); and Period_3 of 1999-2015: albacore (cluster 3). **Figures 2-5** showed the geographical distribution maps of the albacore fleet, albacore mostly distributed in subtropical and temperate waters of the North Atlantic Ocean. After confirmation operating distribution of the albacore fleet from logbooks, thus it can supplement the appropriate albacore sampling subareas which are applied to the Task II data.

For elucidating geographical distribution characteristics of the North Atlantic albacore resource, for three periods of geographic distribution maps of nominal albacore CPUE in weight were shown in **Figure 6**. As shown in **Figure 6**, significant area aggregation with different level of catch rate was observed. In particular, an aggregation with higher catch rate appeared between 15°N and 45°N of the North Atlantic Ocean. The same pattern was also observed in **Figures 6-9**, which was obtained exactly the same procedure used to obtain **Figure 6**. In **Figures 2-10**, three areas (**Figure 11**) were proposed for the periods of 1967-1987, 1987-1999 and 1999-2015 respectively as the appropriate albacore sampling subareas. These figures showed the areas located in subtropical and temperate waters of the North Atlantic Ocean were always the most dominate fishing grounds of albacore by Chinese Taipei longline fishery.

The subareas (**Figure 11**) by 5° latitude x 5° longitude were adopted in the model to minimize variations caused by fishing location. Longline catch in temperate waters, which were also the traditional fishing ground for North Atlantic albacore, was mainly comprised of albacore. As for subtropical waters, there often appeared mixture catches of albacore, bigeye and yellowfin tunas with various area-time intensities. To divide appropriately the North Atlantic albacore's entire habitat into subareas is one of the attempts used in the present study for providing corrections stemmed from area contrast. The character of subareas from the data set reflects that temperate waters are the main fishing areas of albacore, and subtropical waters are a mixture of albacore, bigeye and yellowfin tunas.

3.2 Standardization CPUE

In the appropriate albacore area, the standardized CPUE trends for both the yearly series and quarterly series were constructed by the GLM models. The results of ANOVA test for the yearly series show that either the model itself or the effects considered are significant at 0.0001 confidence level (**Table 2**). As shown in the table, the effect of subarea plays the most important role in explanation of the model variation. Comparatively, effects of quarter, yellowfin tuna and swordfish play less important roles as their sum of squares are relatively low, but they are still statistically significant. Similar results of ANOVA are obtained for the quarterly series, and importance of the effects in explanation of the model variation ranks from subareas, year-season/bigeye tuna, swordfish and yellowfin tuna (**Table 3**).

In the appropriate albacore sampling subareas, the yearly nominal CPUE trend and its respective standardized CPUE series thus obtained were tabulated in **Table 4** and plotted in **Figure 12**. The yearly standardized CPUE series continuously declined up to mid-1980s, highly fluctuated before early 2000s, thereafter, it increased since early 2000s up to 2015. The normalized residual pattern from this model was shown in **Figure 13**. As shown in the figure, main distributions of residuals ranged from –1.65 to +1.65 and obviously centered at zero as mode. The Q-Q plots of those residuals were also shown in **Figure 14** indicating the fitting was not far from normal distribution.

In the appropriate albacore sampling subareas, the quarterly standardized CPUE series were also tabulated in **Table 5** and plotted in **Figure 15**. In the period of 1967-1987, the quarterly standardized CPUE series continuously declined within a range between 156 and 615 Wt. (kg)/1000 hooks. Then a high fluctuation from late 1980s to early 2000s was apparently observed. Thereafter, the CPUE trend increased since early 2000s up to 2015. The new fishing managements inevitably affected the understanding the status of the stock, as compared to those collected through traditional setup. The trend appeared in quarterly CPUE series was very similar with those obtained in yearly CPUE trend. The normalized residual pattern from this model was shown in **Figure 16**. As shown in **Figure 16**, main distributions of residuals ranged from –1.65 to +1.65 and obviously centered at zero as mode. The Q-Q plots of those residuals were shown in **Figure 17** indicating the fitting was not far from normal distribution.

3.3 Discussion

Comparisons were made visually as in **Figure 12** and **Figure 15** among the yearly and quarterly nominal CPUE series respectively, which were evaluated in the appropriate albacore sampling subareas and in whole areas (Chang et al., 2014). They were similar to those in whole areas of the North Atlantic Ocean from 1977 to 1987. However, the series revealed a different tendency with those in whole areas since early 1990s. The new fishing managements inevitably affected the understanding the status of the stock, as compared to those collected through traditional setup. Although the true meaning of this difference is still needs further investigation, the proposed appropriate albacore sampling subareas do appear its own significance in this regard.

The appropriate albacore sampling subareas (**Figure 11**) were proposed in this analysis mainly for minimizing those non-albacore-targeting noises. Although the boundary of such a subarea was only based on Chinese Taipei longliners historic data sets, Chinese Taipei longliners fishing albacore in the North Atlantic Ocean have been longstanding since early 1960s, the three appropriate albacore sampling subareas thus proposed in this paper have its right implications.

Acknowledgments

We are indebted to the Fisheries Agency and Overseas Fisheries Development Council, Taiwan, for their financial supports. We are also grateful to the fishermen and fisheries companies who provided logbooks and related information.

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Table 1. The result of cluster analysis based on the logbook catches in weight (kg) of albacore, bigeye tuna, yellowfin tuna and swordfish for three periods: 1981-1987, 1987-1999 and 1999-2015.

1981-1987

cluster	ALB_wt	BET_wt	YFT_wt	SWO_wt
1	108	31,214	6,710	1,578
2	27,708	571	1,047	248
3	50,774	823	1,330	354
4	10,176	349	651	122

1987-1999

cluster	ALB_wt	BET_wt	YFT_wt	SWO_wt
1	28,436	495	1,286	401
2	1,089	24,804	7,152	2,262
3	1,350	4,193	1,660	542
4	76,948	589	1,751	248

1999-2015

cluster	ALB_wt	BET_wt	YFT_wt	SWO_wt
1	-	646	90,421	1,731
2	4,079	3,393	2,143	338
3	42,421	824	1,405	172
4	204	23,266	3,717	839

Remark: ALB: Albacore, BET: Bigeye tuna, YFT: Yellowfin tuna, and SWO: Swordfish.

Table 2. Analysis of variance on the yearly standardized CPUE based on northern Atlantic albacore data (in the appropriate albacore sampling subareas) of Chinese Taipei longline fishery from 1967 to 2015 (three periods: 1967-1987, 1987-1999 and 1999-2015).

1. Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	104	277.37123	2.66703	13.13	<.0001
Error	2564	520.71061	0.20309		
Corrected Total	2668	798.08184			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.34755	7.59339	0.45065	5.93477

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	20	68.79311	3.43966	16.94	<.0001
quarter	3	6.89174	2.29725	11.31	<.0001
subarea	57	106.45921	1.86771	9.20	<.0001
codebet	3	6.87895	2.29298	11.29	<.0001
codeswo	3	9.61068	3.20356	15.77	<.0001
quarter*codebet	9	5.87268	0.65252	3.21	0.0036
quarter*codeswo	9	6.34611	0.70512	3.47	0.0007

2. Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	85	251.42844	2.95798	5.96	<.0001
Error	803	398.50418	0.49627		
Corrected Total	888	649.93262			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.38685	12.29840	0.70446	5.72809

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	12	25.79907	2.14992	4.33	<.0001
quarter	3	11.20353	3.73451	7.53	<.0001
subarea	52	73.11101	1.40598	2.83	<.0001
codebet	3	26.00773	8.66924	17.47	<.0001
codeyft	3	10.89056	3.63019	7.31	<.0001
codeswo	3	7.63373	2.54458	5.13	0.0016
quarter*codebet	9	27.34704	3.03856	6.12	<.0001

3. Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	81	410.68712	5.07021	16.22	<.0001
Error	1462	456.92899	0.31254		
Corrected Total	1543	867.61611			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.47335	9.87096	0.55905	5.66359

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	16	230.87838	14.42990	46.17	<.0001
quarter	3	15.72735	5.24245	16.77	<.0001
subarea	50	50.72510	1.01450	3.25	<.0001
codebet	3	27.72468	9.24156	29.57	<.0001
quarter*codebet	9	17.16214	1.90690	6.10	<.0001

Table 3. Analysis of variance on the quarterly standardized CPUE based on northern Atlantic albacore data (in the appropriate albacore sampling subareas) of Chinese Taipei longline fishery from 1967 to 2015 (three periods: 1967-1987, 1987-1999 and 1999-2015).

1. Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	144	321.44571	2.23226	11.82	<.0001
Error	2524	476.63613	0.18884		
Corrected Total	2668	798.08184			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.40277	7.32226	0.43456	5.93477

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yq	81	135.93689	1.67823	8.89	<.0001
subarea	57	99.16513	1.73974	9.21	<.0001
codebet	3	7.34067	2.44689	12.96	<.0001
codeswo	3	10.18472	3.39491	17.98	<.0001

2. Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	109	254.01260	2.33039	4.59	<.0001
Error	779	395.92002	0.50824		
Corrected Total	888	649.93262			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.39083	12.44586	0.71291	5.72809

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yq	48	73.40810	1.52934	3.01	<.0001
subarea	52	73.85570	1.42030	2.79	<.0001
codebet	3	18.45274	6.15091	12.10	<.0001
codeyft	3	11.92611	3.97537	7.82	<.0001
codeswo	3	5.92061	1.97354	3.88	0.009

3. Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	117	457.22439	3.90790	13.58	<.0001
Error	1426	410.39173	0.28779		
Corrected Total	1543	867.61611			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.52699	9.47214	0.53646	5.66359

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yq	64	341.70845	5.33919	18.55	<.0001
subarea	50	52.64958	1.05299	3.66	<.0001
codebet	3	29.83620	9.94540	34.56	<.0001

Table 4. The nominal CPUE and its respective yearly standardized CPUE of the appropriate northern Atlantic albacore area based on the Chinese Taipei catch statistics from 1967 to 2015.

Year	Nominal CPUE 1	Nominal CPUE 2	Nominal CPUE 3	Standardized CPUE 1	CV	Standardized CPUE 2	CV	Standardized CPUE 3	CV
1967	295.58			294.6791	0.0302				
1968	508.84			509.5313	0.0108				
1969	595.80			409.4818	0.0090				
1970	447.53			389.2505	0.0074				
1971	503.22			317.8628	0.0095				
1972	482.38			311.4597	0.0096				
1973	469.94			305.3485	0.0090				
1974	453.98			317.9450	0.0071				
1975	471.44			294.2251	0.0075				
1976	362.64			291.7729	0.0071				
1977	351.84			287.0757	0.0067				
1978	333.71			256.3453	0.0075				
1979	440.88			295.9886	0.0088				
1980	471.67			329.5752	0.0078				
1981	486.70			383.6085	0.0069				
1982	558.78			458.9732	0.0063				
1983	521.38			432.0405	0.0060				
1984	477.45			366.9191	0.0055				
1985	392.17			310.7035	0.0057				
1986	340.03			274.2483	0.0056				
1987	275.14	273.38		235.7245	0.0078	283.9162	0.0149		
1988		442.06				353.0965	0.0271		
1989		380.82				342.1148	0.0317		
1990		343.38				301.7633	0.0377		
1991		193.27				285.1749	0.0227		
1992		467.95				226.0827	0.0417		
1993		417.17				424.6678	0.0227		
1994		486.71				345.4850	0.0156		
1995		564.56				398.5791	0.0175		
1996		479.38				234.5771	0.0195		
1997		556.96				312.8780	0.0193		
1998		520.49				431.8790	0.0140		
1999		280.29	289.43			245.1944	0.0136	220.9084	0.0081
2000			257.01					175.4527	0.0094
2001			220.92					170.0116	0.0090
2002			223.53					158.9563	0.0098
2003			228.42					199.2920	0.0106
2004			301.07					281.6502	0.0173
2005			240.42					281.8669	0.0095
2006			347.02					404.8764	0.0100
2007			319.58					320.8192	0.0122
2008			330.21					305.1050	0.0134
2009			379.39					375.2456	0.0141
2010			524.79					448.5055	0.0126
2011			412.05					347.5100	0.0134
2012			553.02					456.7708	0.0129
2013			690.12					706.7904	0.0115
2014			1012.62					1263.3011	0.0152
2015			758.32					492.6446	0.0106

Table 5. The nominal CPUE and its respective quarterly standardized CPUE of the appropriate northern Atlantic albacore area based on the Chinese Taipei catch statistics from 1967 to 2015.

Year*Quarter	Nominal CPUE 1	Nominal CPUE 2	Nominal CPUE 3	Standardized CPUE 1	CV	Standardized CPUE 2	CV	Standardized CPUE 3	CV
19841	533.01			425.4215	0.0098				
19842	511.65			423.4659	0.0096				
19843	427.71			333.2979	0.0103				
19844	419.26			311.3586	0.0111				
19851	424.58			358.1227	0.0095				
19852	372.42			365.1925	0.0112				
19853	332.36			255.4856	0.0110				
19854	418.64			293.4043	0.0106				
19861	369.13			292.7994	0.0098				
19862	340.88			298.8864	0.0098				
19863	307.99			283.9463	0.0101				
19864	321.25			229.5350	0.0120				
19871	275.23	273.68		244.0455	0.0108	279.6750	0.0196		
19872	281.54	280.31		225.4435	0.0160	315.7035	0.0265		
19873	267.01	262.58		256.9999	0.0144	400.2894	0.0248		
19874	272.99	272.99		225.3919	0.0240	244.6447	0.0414		
19881		380.42				305.9810	0.0503		
19882		504.65				470.3171	0.0391		
19883		473.36				380.3127	0.0621		
19884		353.02				325.9034	0.0530		
19891		374.85				292.8154	0.0586		
19892		378.06				427.3643	0.0557		
19893		389.87				535.6658	0.0689		
19894		384.56				322.2982	0.0585		
19901		409.41				331.8014	0.0648		
19902		320.47				404.3482	0.0572		
19903		304.29				424.2469	0.1194		
19904		307.22				265.9937	0.0762		
19911		202.28				324.1209	0.0401		
19912		183.04				344.6443	0.0336		
19913		210.18				318.1667	0.0382		
19914		169.22				359.8352	0.0434		
19921									
19922		334.99				332.0421	0.0483		
19923		567.50				311.9192	0.0643		
19924									
19931									
19932		477.53				593.0790	0.0378		
19933		432.03				591.0804	0.0415		
19934		360.15				279.4686	0.0343		
19941		393.62				334.0710	0.0321		
19942		452.78				517.2393	0.0317		
19943		605.88				463.6491	0.0249		
19944		405.70				241.7943	0.0257		
19951		951.54				678.2497	0.0447		
19952		726.52				830.2380	0.0324		
19953		604.52				597.8342	0.0293		
19954		401.46				211.5014	0.0265		
19961		576.65				270.2903	0.0273		
19962		262.29				308.7386	0.0333		
19963		312.26				237.1058	0.0393		
19964		463.42				175.9421	0.0421		
19971		497.69				397.9611	0.0238		
19972		420.70				429.0478	0.0323		
19973		366.59				185.7517	0.0512		
19974		1156.30				300.1045	0.0443		
19981		645.21				458.1537	0.0284		
19982		462.38				466.0582	0.0216		
19983		474.36				502.1251	0.0214		
19984		434.54				460.1218	0.0238		
19991		336.92	349.40			338.0023	0.0210	369.4184	0.0140
19992		244.23	244.23			168.5971	0.0235	132.7721	0.0163
19993		234.54	248.69			258.4677	0.0205	189.1771	0.0134
19994		316.21	331.76			200.0077	0.0242	218.3362	0.0162
20001			314.13					239.4808	0.0152
20002			268.48					150.9496	0.0161
20003			171.79					130.2247	0.0183
20004			236.39					168.5291	0.0240
20011			221.31					155.6291	0.0154
20012			243.61					160.3412	0.0169
20013			204.47					192.3244	0.0152
20014			211.58					164.0076	0.0196
20021			262.09					187.5587	0.0176
20022			185.22					143.8327	0.0185
20023			208.47					140.8034	0.0183
20024			217.74					149.1766	0.0206
20031			235.08					197.5741	0.0203
20032			233.95					188.5163	0.0179
20033			203.68					186.4030	0.0166
20034			282.87					213.6981	0.0291
20041									
20042			353.57					327.2954	0.0260
20043			255.49					225.4778	0.0259
20044			336.18					205.3640	0.0357
20051			382.50					354.3779	0.0176
20052			177.20					171.4618	0.0153
20053			214.96					231.8221	0.0176
20054			516.92					587.7132	0.0205
20061			454.25					465.5723	0.0191
20062			263.92					306.1327	0.0178
20063			352.35					431.8781	0.0163
20064			465.11					411.4421	0.0237
20071			360.28					281.5995	0.0364
20072			286.31					329.5501	0.0201
20073			305.05					366.0571	0.0169
20074			379.51					248.9901	0.0276
20081			396.93					431.9668	0.0273
20082			262.27					249.7814	0.0189
20083			236.95					306.4103	0.0234
20084			461.16					375.5279	0.0345
20091			411.18					351.5175	0.0269
20092			305.14					298.5663	0.0205
20093			461.17					646.2482	0.0231
20094			125.12					236.3424	0.0563
20101			826.95					671.2707	0.0229
20102			447.75					438.7235	0.0189
20103			354.38					388.3947	0.0212
20104			392.67					268.3233	0.0428
20111			454.46					380.3800	0.0223
20112			303.37					266.2500	0.0224
20113			498.63					604.0575	0.0230
20114			539.01					172.2387	0.0419
20121			790.24					634.4809	0.0200
20122			307.77					305.7353	0.0237
20123			416.30					459.4987	0.0203
20124			1131.35					712.8340	0.0583
20131			817.17					751.6398	0.0208
20132			434.73					394.1183	0.0200
20133			877.00					1074.3217	0.0174
20134			668.61					776.7322	0.0408
20141			826.88					1002.4454	0.0193
20142			1379.64					1619.0792	0.0196
20143									
20144									
20151			428.58					350.7210	0.0220
20152			802.67					522.8554	0.0160
20153			736.77					603.1052	0.0209
20154			929.16					491.0174	0.0228

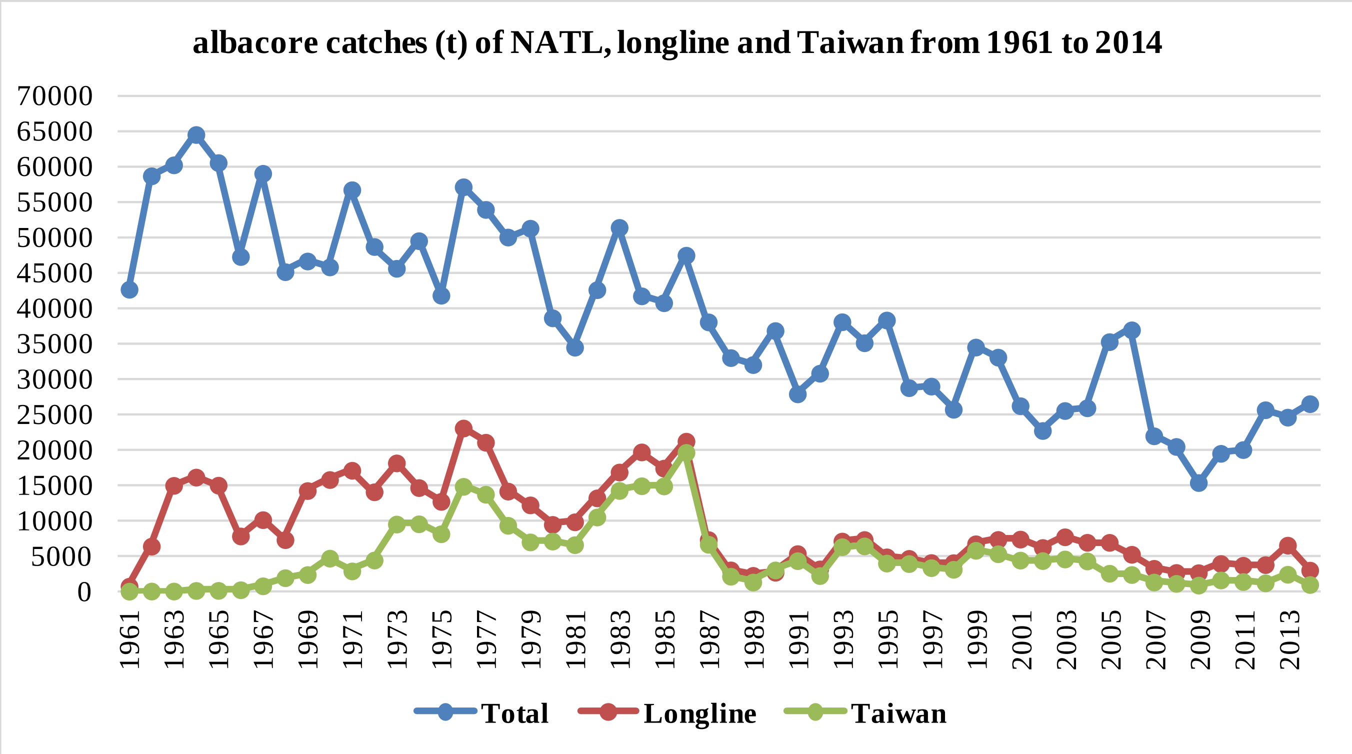

Figure 1. Historical albacore catch of Chinese Taipei longline fishing vessels in the North Atlantic Ocean, 1961-2014. Sources: ICCAT (Task I) and OFDC.

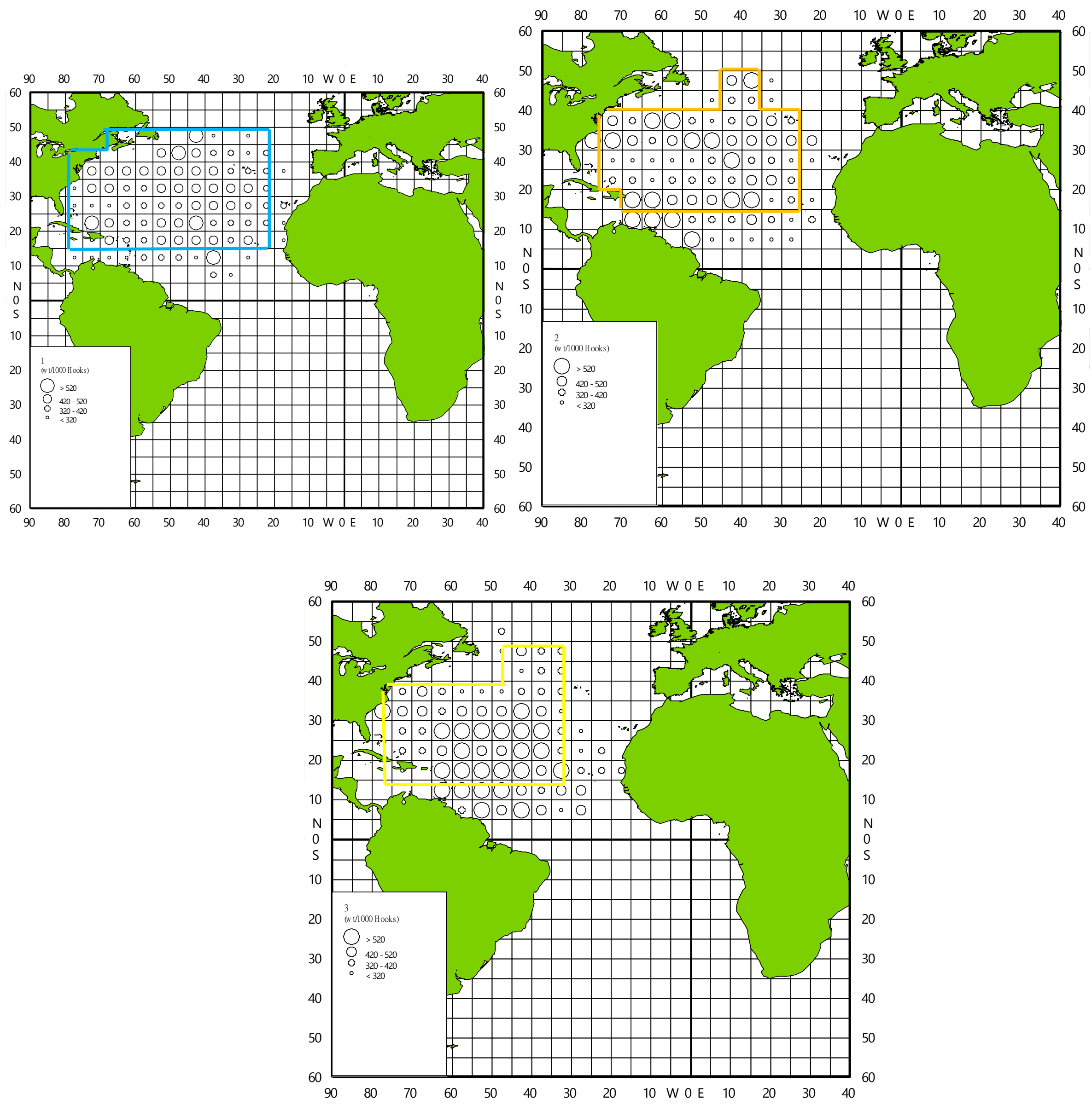

Figure 2. Geographic distribution, by 5o-square block, of nominal CPUE (Wt./1000 Hooks from logbooks) of albacore caught by Chinese Taipei longliners in the North Atlantic Ocean for periods of 1981-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower).

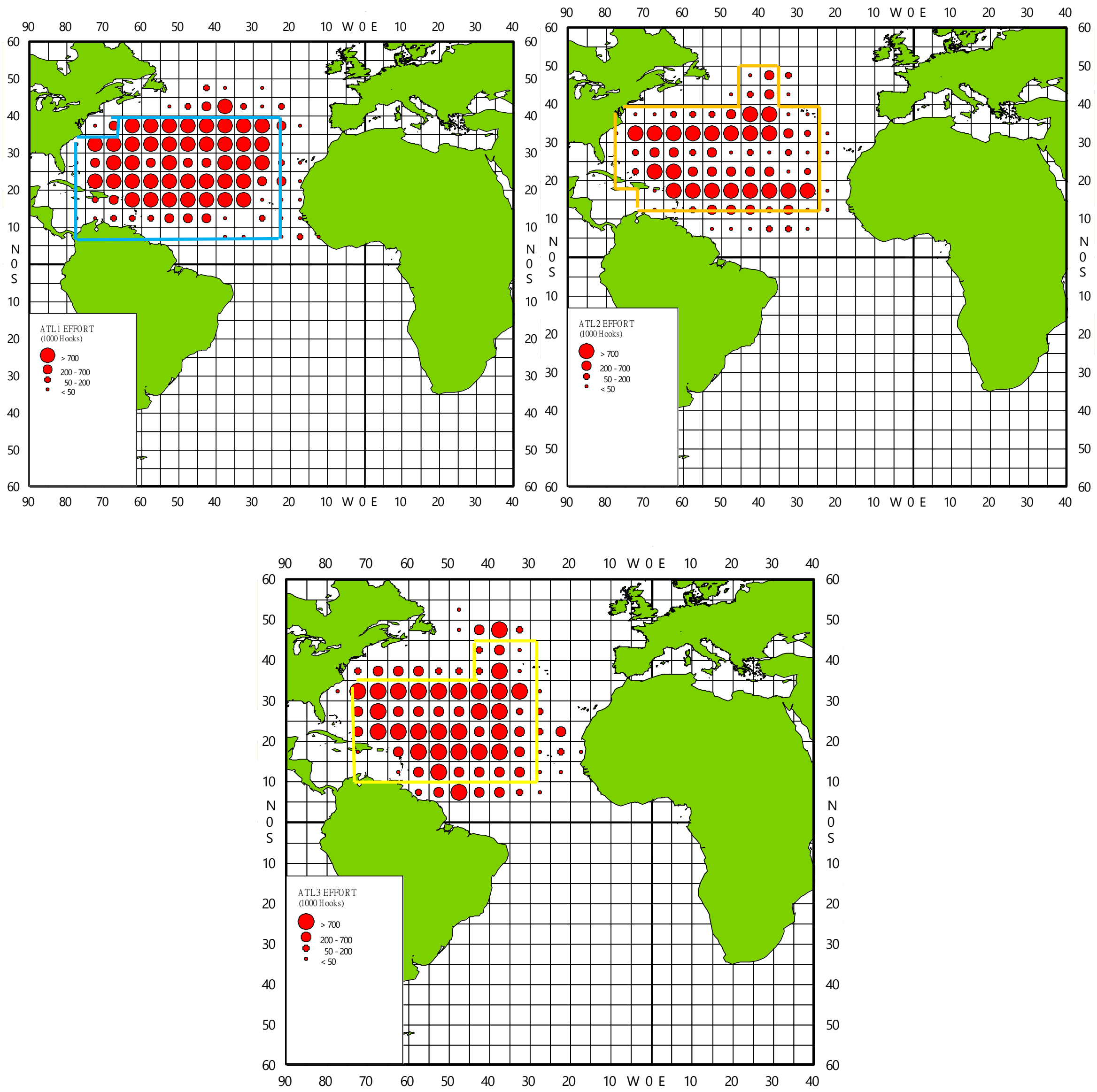

Figure 3. The fishing efforts (Number of hooks from logbooks) cast by Chinese Taipeiese longliners in the North Atlantic Ocean for periods of 1981-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower).

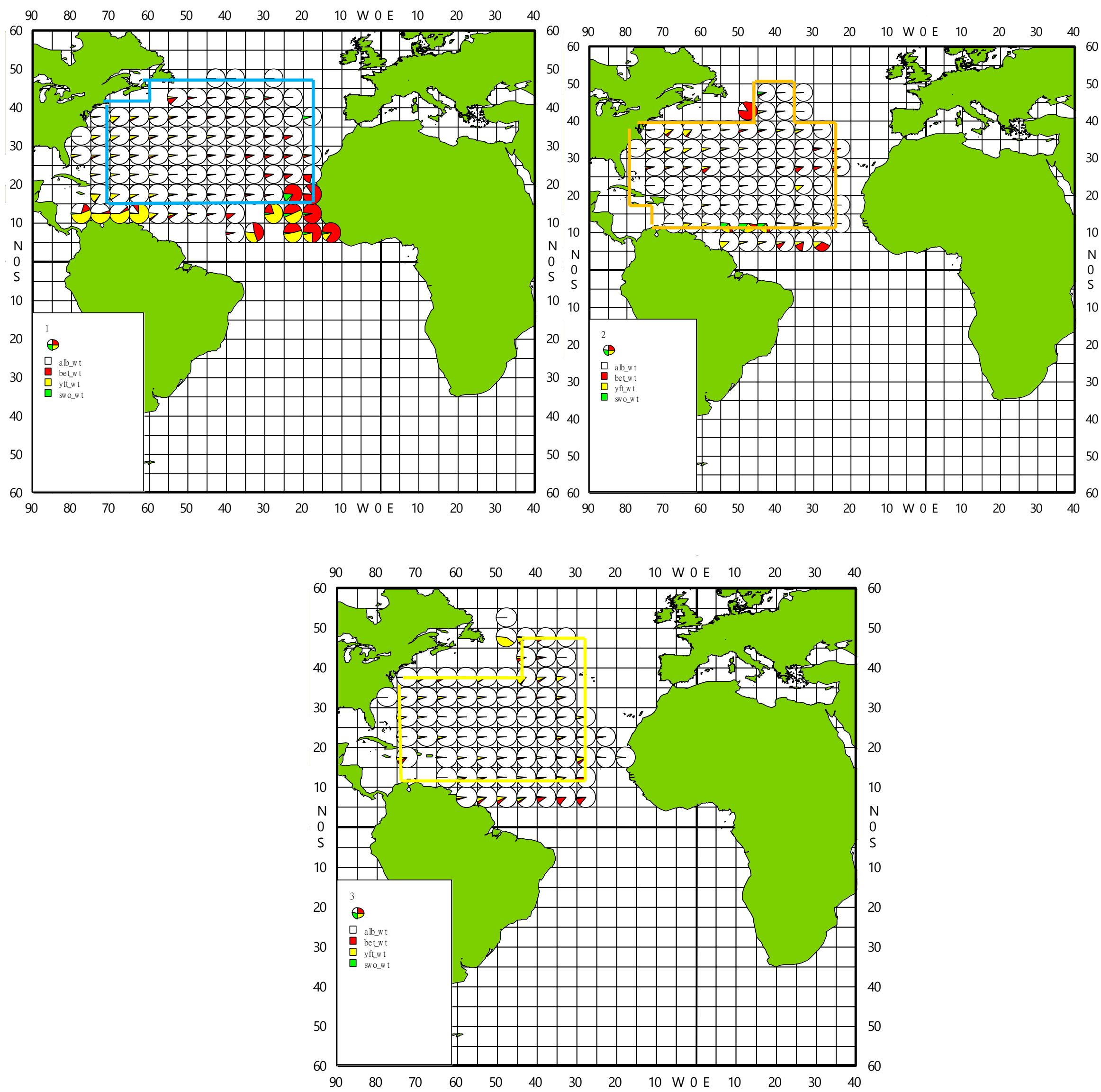

Figure 4. Geographic distribution, by 5º-square block, of four major species composition, in terms of catch in weight (from logbooks), caught by Chinese Taipei longliners in the North Atlantic Ocean for periods of 1981-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower). Four major species are: albacore (ALB in white), bigeye tuna (BET in red), yellowfin tuna (YFT in yellow) and swordfish (SWO in green).

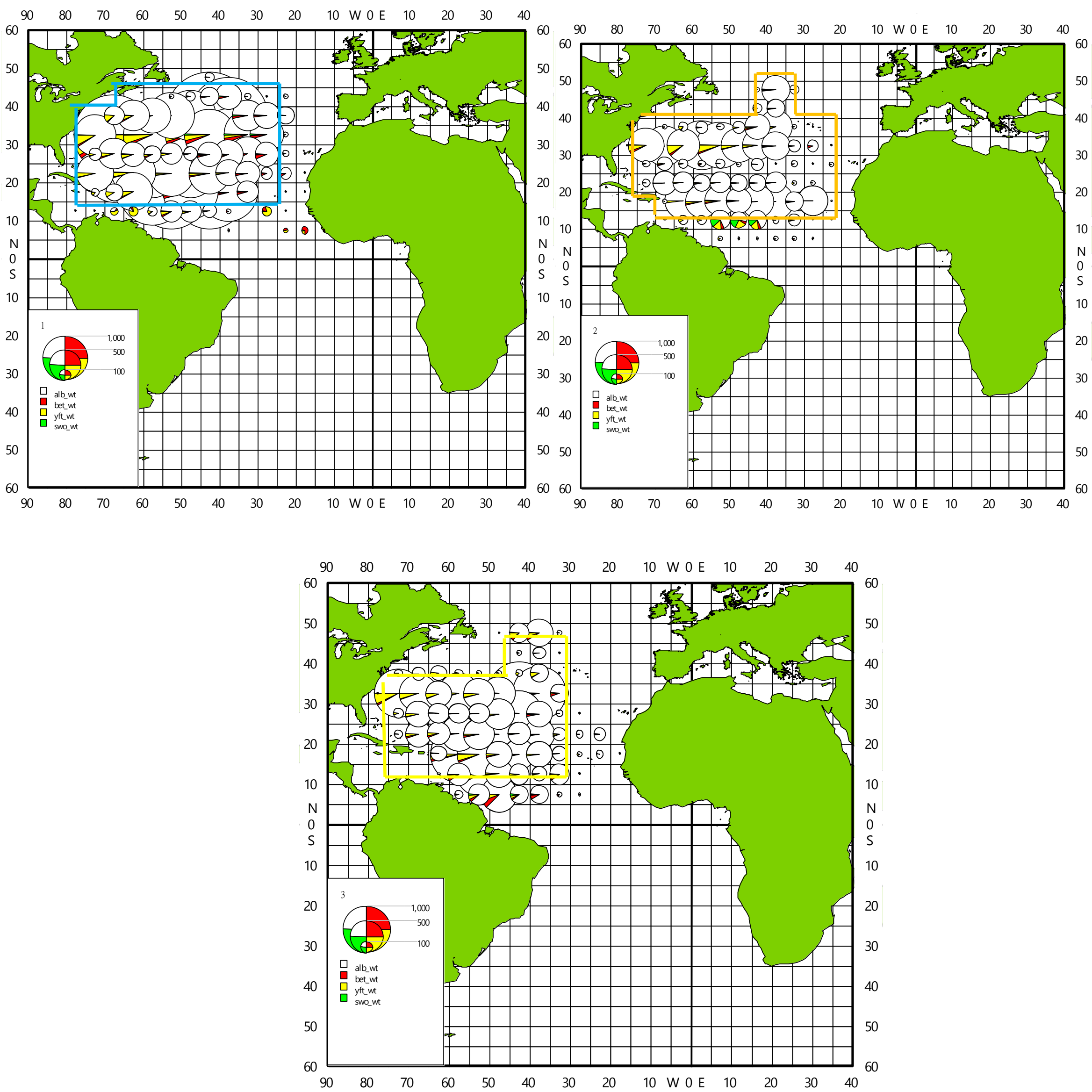

Figure 5. Geographic distribution, by 5º-square block, of catch in weight of four major species (from logbooks), caught by Chinese Taipei longliners in the North Atlantic Ocean for periods of 1981-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower). Four major species are: albacore (ALB in white), bigeye tuna (BET in red), yellowfin tuna (YFT in yellow) and swordfish (SWO in green).

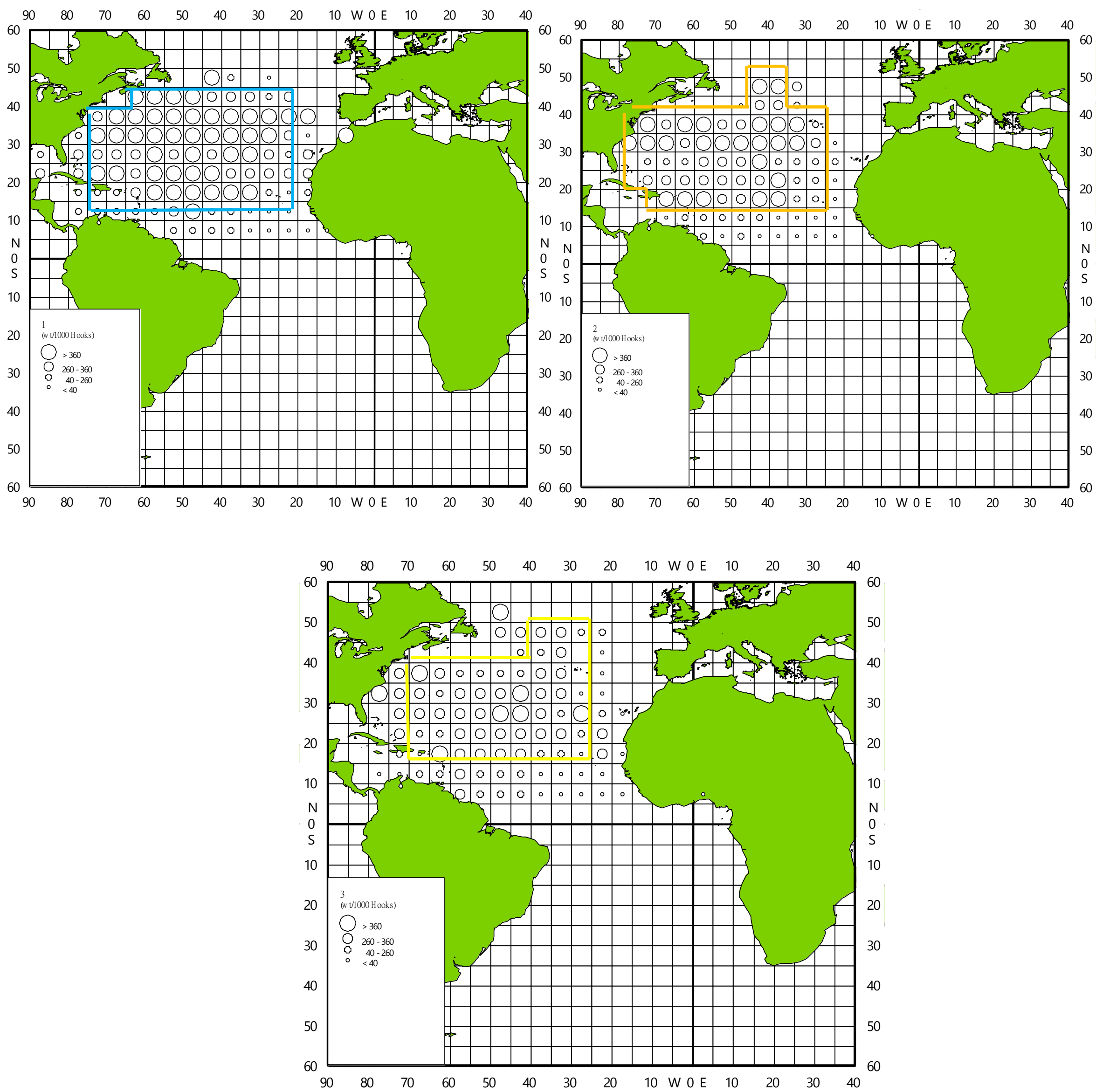

Figure 6. Yearly nominal CPUE (Wt./1000 Hooks from task2) of albacore caught by Chinese Taipei longliners in the North Atlantic Ocean for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower).

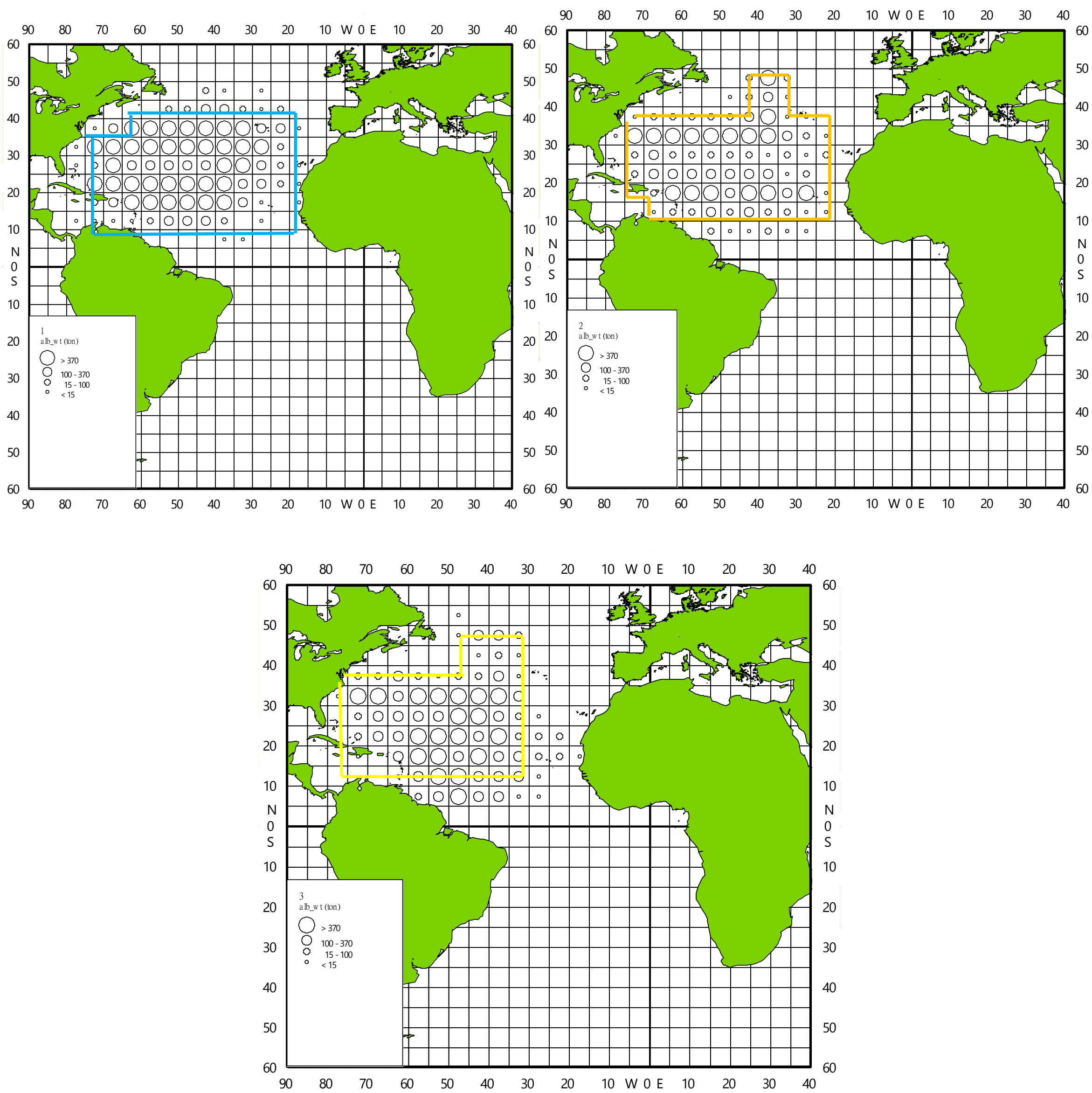

Figure 7. Yearly catch in weight (from Task II) of albacore caught by Chinese Taipei longliners in the North Atlantic Ocean for periods of 1967-1987 (upper left), 1987-1999 (upper right), and 1999-2015 (lower).

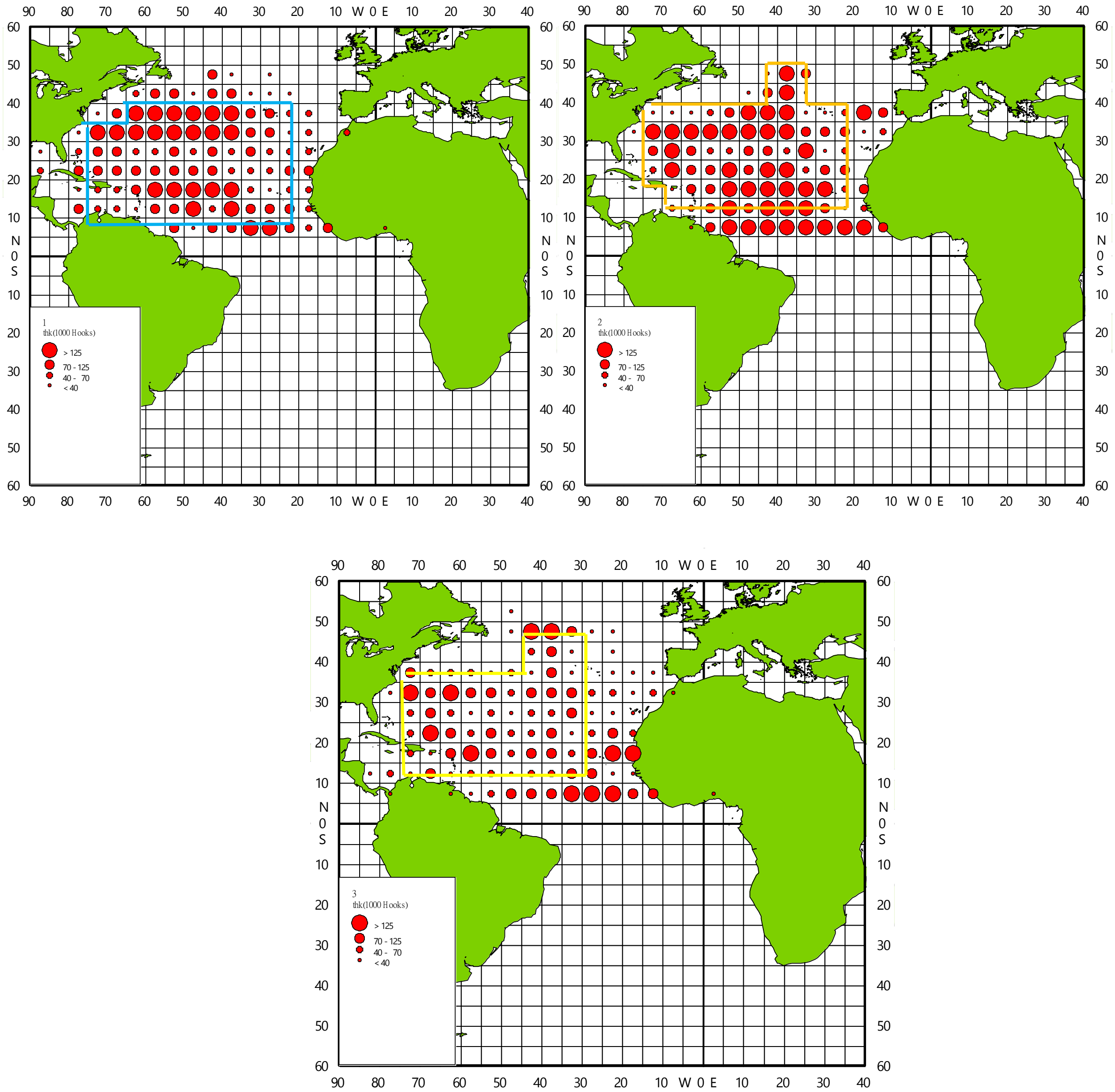

Figure 8. Yearly fishing efforts (Number of hooks from task2) cast by Chinese Taipei longliners in the North Atlantic Ocean for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower).

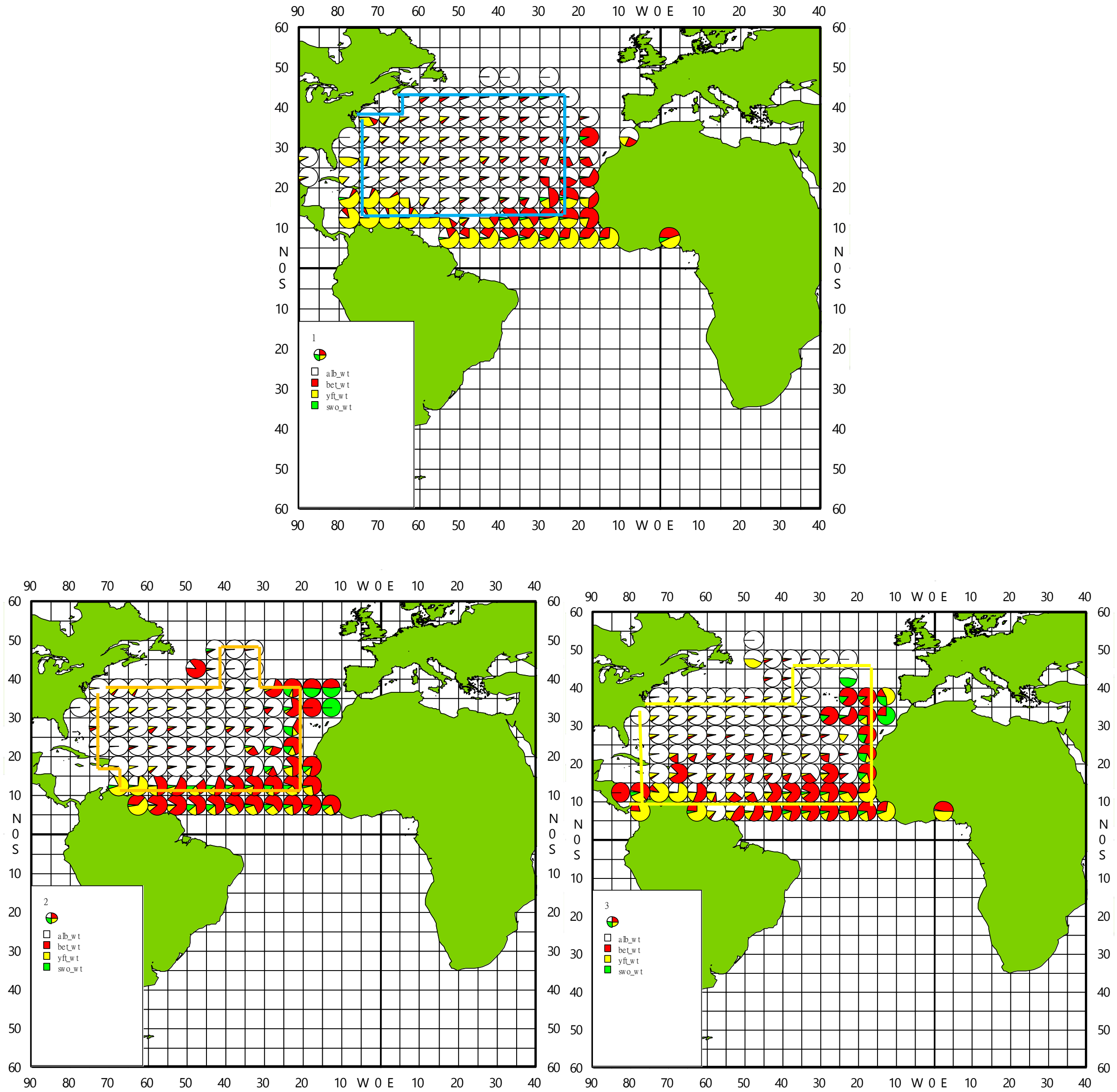

Figure 9. Geographic distribution of yearly four major species composition (from Task II) caught by Chinese Taipei longliners for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower).

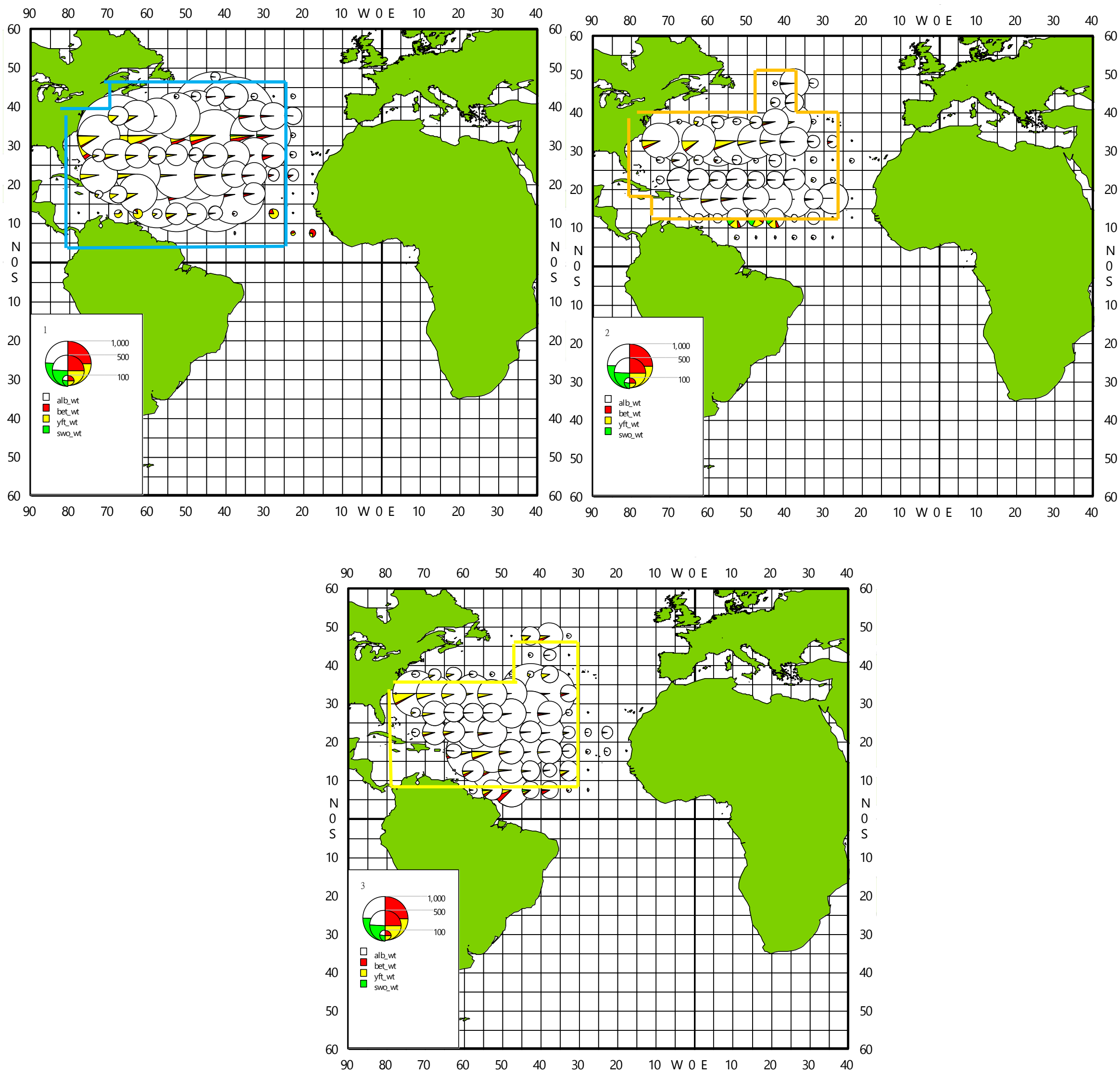

Figure 10. Geographic distribution of yearly catch composition of four major species (from Task II) caught by Chinese Taipei longliners for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower).

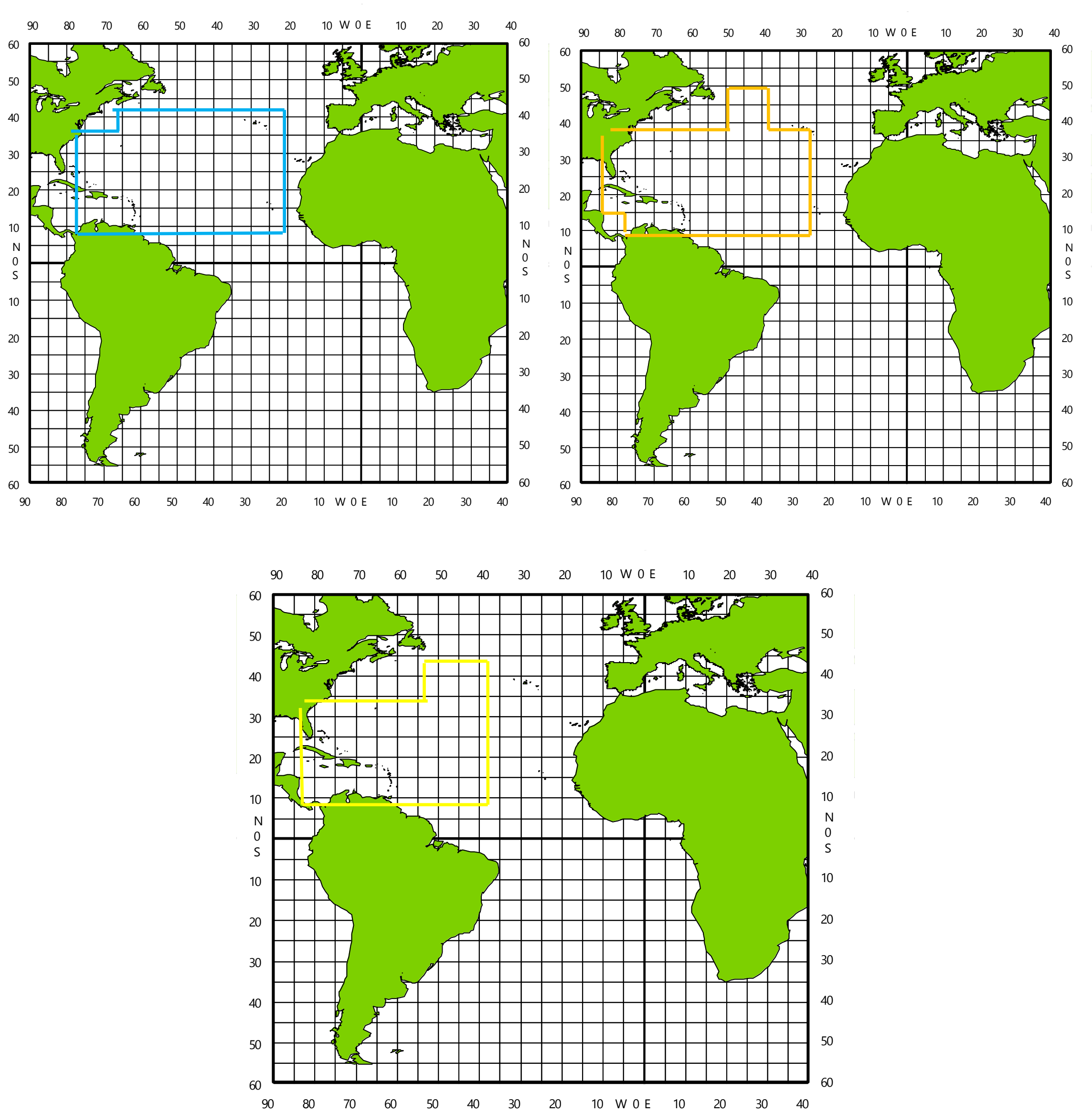

Figure 11. There were 58, 53 and 51, by 5º-square block, subareas proposed by this paper for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower) respectively for CPUE standardization on albacore resource in the North Atlantic Ocean.

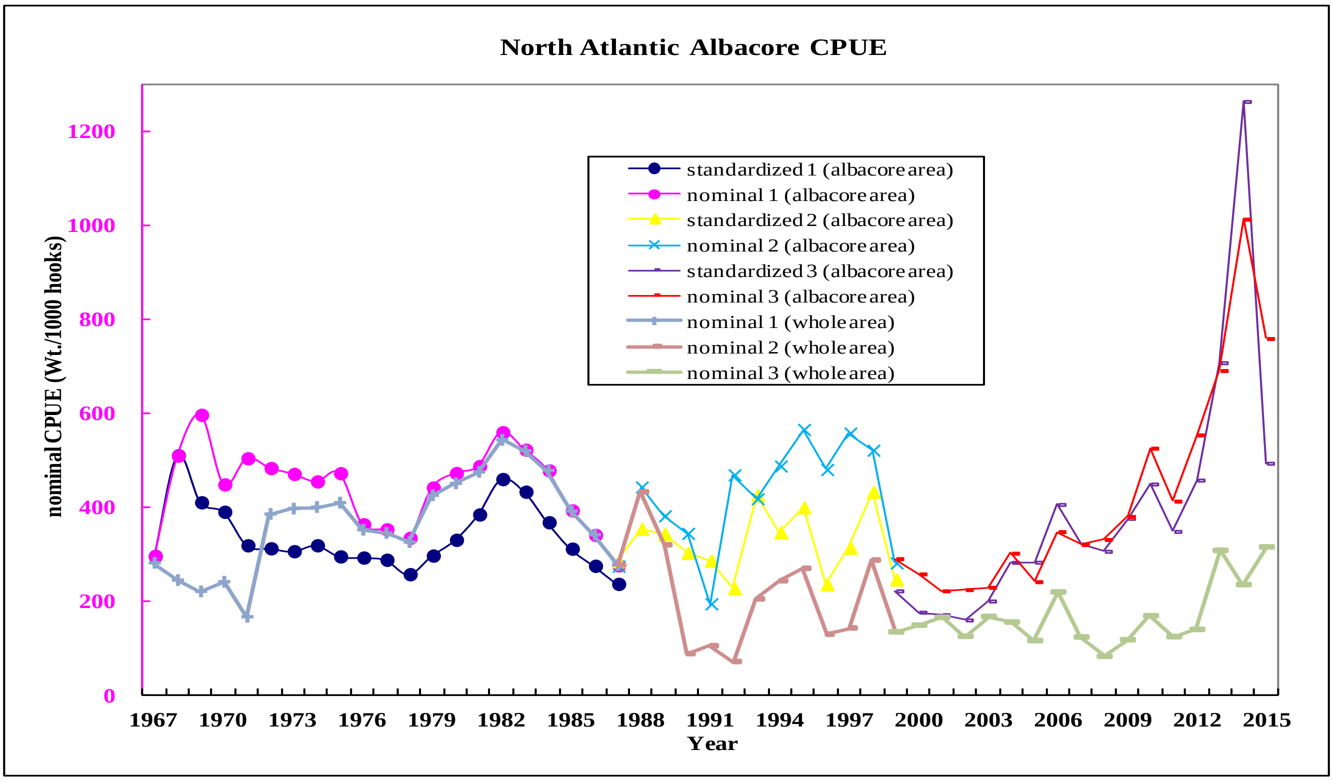

Figure 12. Yearly nominal and standardized CPUE (Wt./1000 hooks) trends of North Atlantic albacore based on Chinese Taipei longline fishery task2 data set from 1967 to 2015.

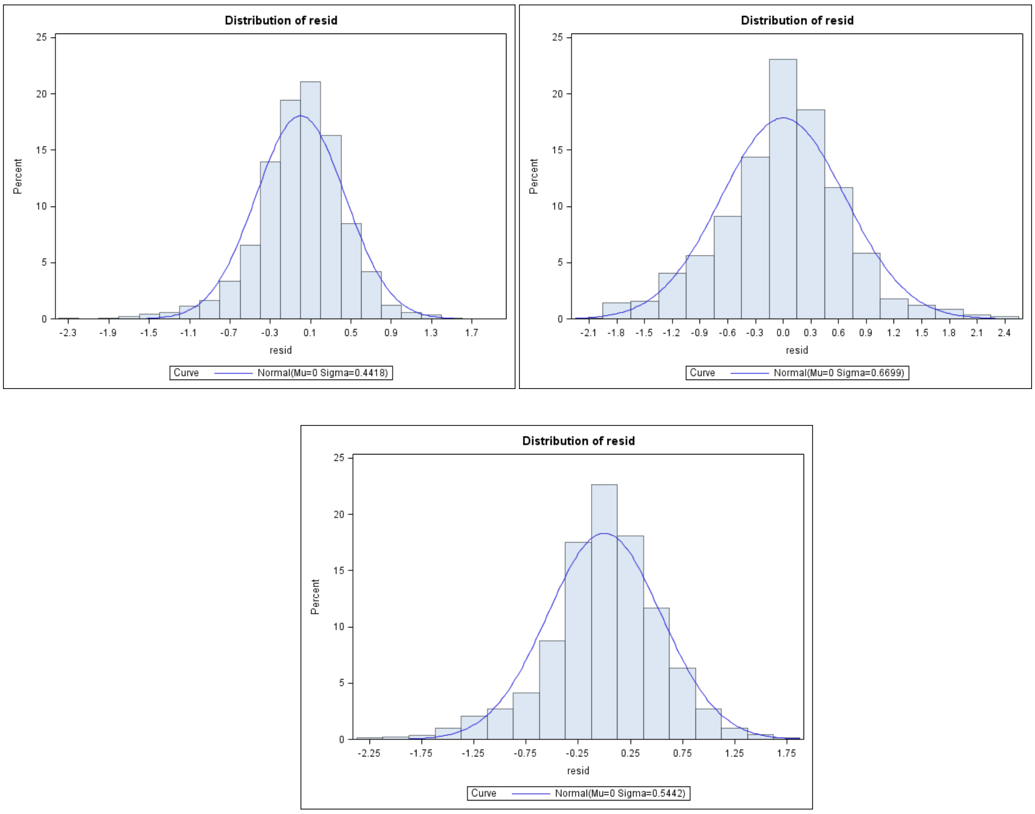

Figure 13. Distributions of normalized residuals obtained for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower) from yearly GLM models.

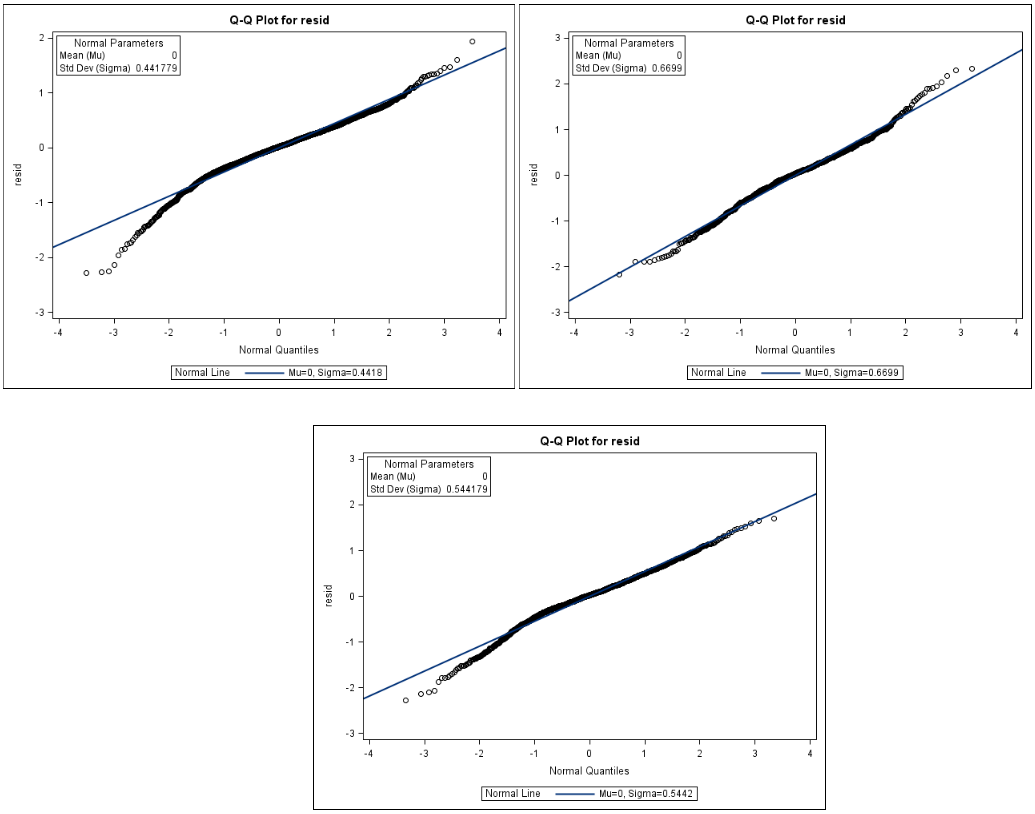

Figure 14. The Q-Q plots for residuals obtained for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower) from yearly GLM models.

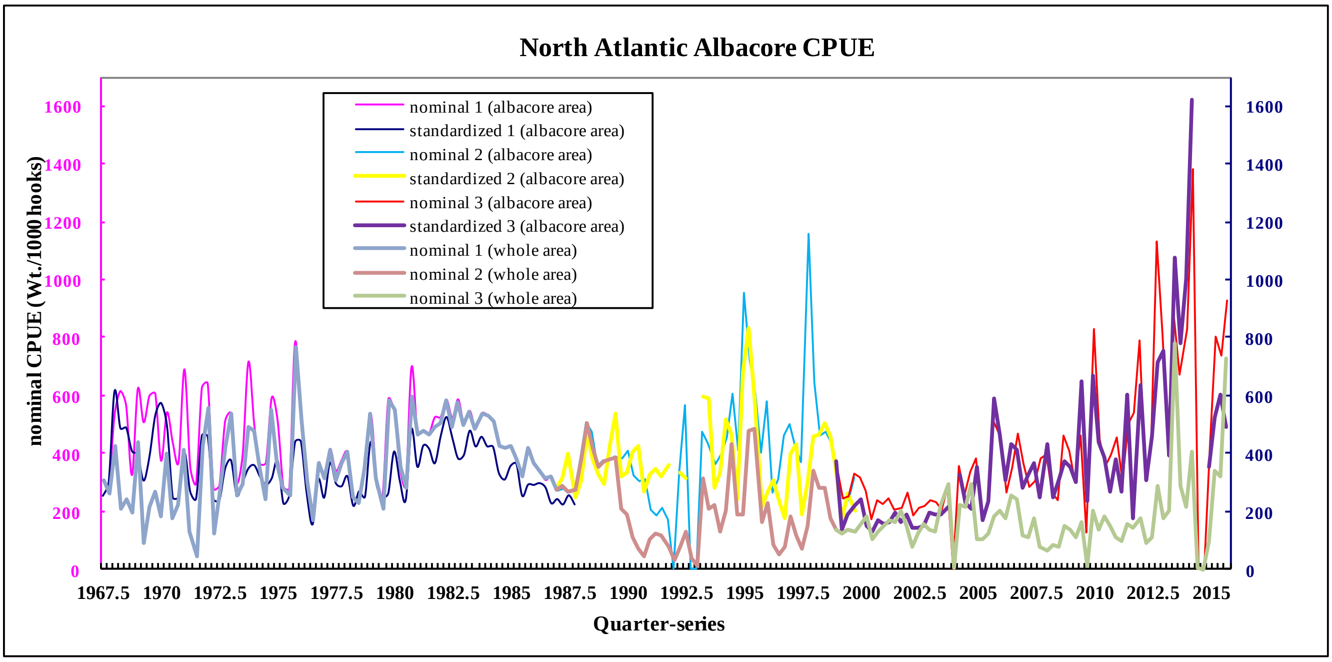

Figure 15. Quarterly nominal and standardized CPUE (Wt./1000 hooks) trends of North Atlantic albacore based on Chinese Taipei longline fishery Task II data set from 1967 to 2015.

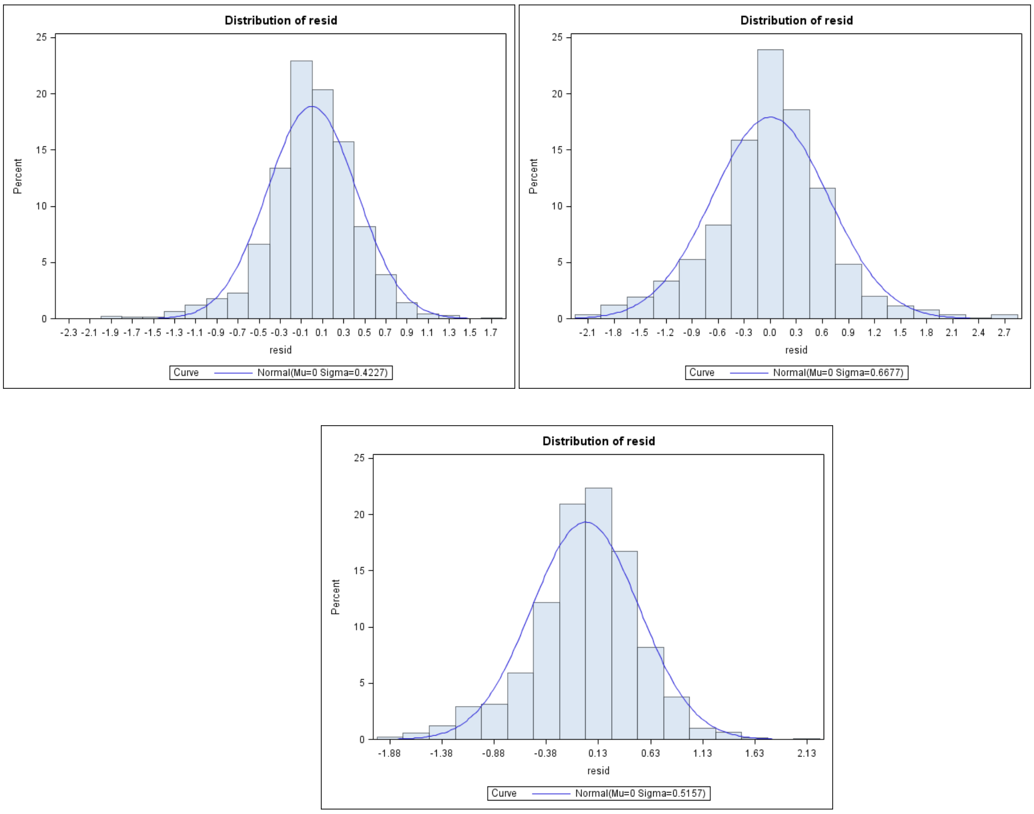

Figure 16. Distributions of normalized residuals obtained for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower) from quarterly GLM models.

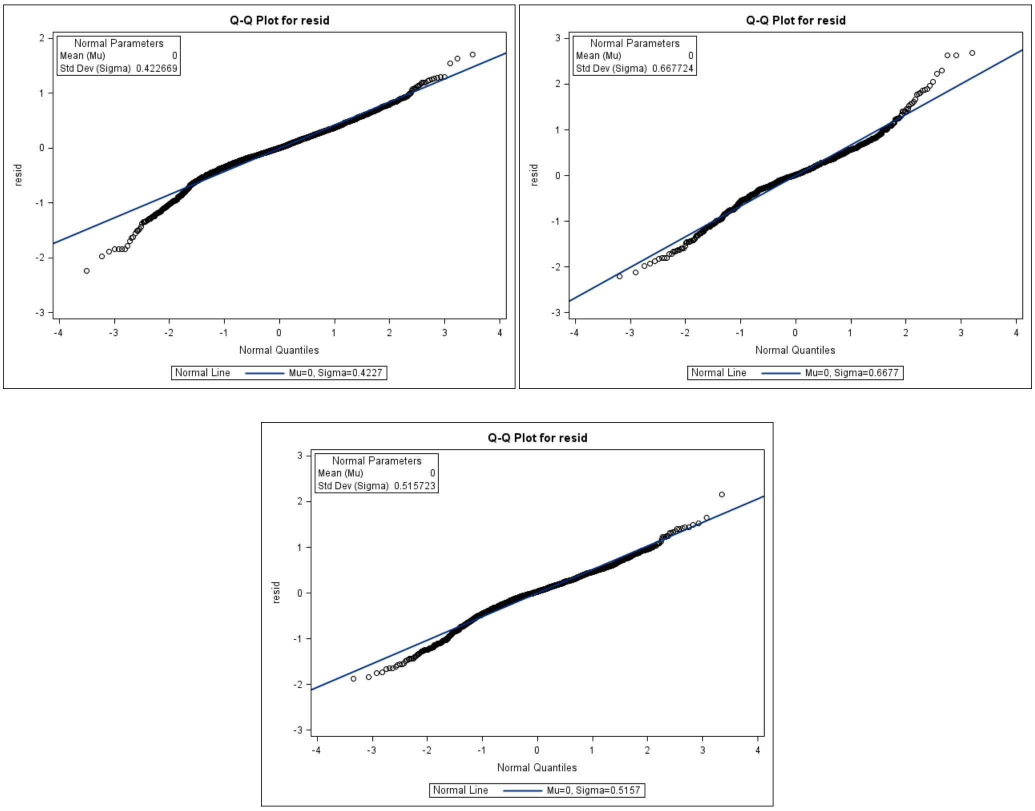

Figure 17. The Q-Q plots for residuals obtained for periods of 1967-1987 (upper left), 1987-1999 (upper right) and 1999-2015 (lower) from quarterly GLM models.