SCRS/2016/079 Collect. Vol. Sci. Pap. ICCAT, 73(4): 1516-1538 (2017)

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

Feng-Chen Chang[1]

SUMMARY

Both the logbooks (since 1981) and the Task II (since 1967) data sets of Chinese Taipei longliners were scrutinized, by decadal period 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 better abundance indices for albacore resources. This paper used only those Chinese Taipei fisheries data sets within proposed sampling areas for the generalized linear model (GLM) standardization analysis and hopefully able to minimize most noises of non-albacore-targeting data. In appropriate albacore sampling areas, standardized abundance indices of South Atlantic albacore, dating from 1967 to 2015, based on Chinese Taipei longline catch and effort statistics by using the GLM were carried out in present study. CPUE, both yearly and quarterly, trends obtained indicated that the abundance in weight of appropriate South Atlantic albacore sampling areas declined from late 1960s to 1990, then increased till mid-1990s, and leveled off since early 2000s up to 2015. Quarterly trend, as compared to its respective yearly trend, often appeared a significant peak per year implied a consistent recruitment pattern of the resource.

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, par décennie 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 appropriées d'échantillonnage 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 l'analyse 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. Dans les zones appropriées d'échantillonnage du germon, la présente étude a mis au point des indices d'abondance standardisés du germon de l'Atlantique Sud, correspondant à la période 1967-2015, en se fondant sur les statistiques de prise et d'effort des palangriers du Taipei chinois, à l'aide d'un modèle linéaire généralisé (GLM). Les tendances de la CPUE, à la fois annuelles et trimestrielles, ainsi obtenues ont indiqué que l'abondance en poids des zones appropriées d'échantillonnage du germon de l'Atlantique Sud avait chuté à partir de la fin des années 60 jusqu'en 1990, puis avait augmenté jusqu'au milieu des années 90, pour se stabiliser depuis le début des années 2000 jusqu'en 2015. La tendance trimestrielle, comparée à sa tendance annuelle respective, a souvent fait apparaître un pic considérable par an, ce qui implique un schéma de recrutement constant de cette ressource.

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 por década y 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 adecuadas para obtener mejores índices de abundancia para los recursos de atún blanco. En este documento se utilizaron 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 generalizado (GLM) y se espera poder minimizar la mayoría de los ruidos de los datos no dirigidos al atún blanco. Para las zonas de muestreo apropiadas, en este estudio se calcularon los índices de abundancia estandarizados de atún blanco del Atlántico sur para el periodo 1967

[1] Overseas Fisheries Development Council, Taipei 106, Chinese Taipei; E-mail: fengchen@ofdc.org.tw; d93241008@ntu.edu.tw

a 2015, basados en las estadísticas de captura y esfuerzo de los palangreros de Taipei Chino utilizando GLM. Las tendencias de CPUE, tanto anuales como trimestrales, obtenidas así indicaban que la abundancia en peso de las zonas apropiadas de muestreo de atún blanco del sur descendió desde finales de los sesenta hasta 1990, se incrementó hasta mediados de los noventa, y se estabilizó desde principios de los años 2000 hasta 2015. La tendencia trimestral, cuando se compara con su tendencia anual respectiva, mostraba a menudo un pico importante por año, lo que implica un patrón de reclutamiento constante de este recurso.

KEYWORDS

Albacore, CPUE standardization, GLM, longline, South 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. Chinese Taipei longline fishery, followed Japanese footstep, has become one of the major fishing fleets utilizing this resource since 1960s. According to the ICCAT report, annual catch of South Atlantic albacore ranged from 25,000 mt to 35,000 mt in the last decade. Chinese Taipei catch of South Atlantic albacore comprised of 70% or more of the total (**Figure 1**). As one of the fishing nations that utilized this resource, it is equally our responsibility to acquire the catch and effort statistics for the purpose of monitoring its status.

Chinese Taipei longliners in the Atlantic Ocean were mainly composed of two types of fishing gears, i.e., regular longliner and deep longliner. The regular longliner, which commenced since 1960s and was also called traditional longliner, was mainly targeting albacore. Since mid-1980s, another type of longliner or so called deep longliner, which equipped with –70 degree centigrade or more freezing capability, was mainly targeting bigeye and yellowfin tunas. Unfortunately, it was not possible until mid-1990s when the logbook reporting system was able to distinguish their major identities by the addition of 'the number of hooks per basket used' in new reporting logbooks. Nevertheless, historic task2 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 South Atlantic Ocean (South of 5ºN latitude) as subarea factor in the Generalized Linear Model (GLM), had been carried out for Chinese Taipei longliners data dating from 1967 to 2012 (Chang and Yeh, 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 task2 (since 1967) data sets of Chinese Taipei longliners were scrutinized, by decadal period and 5º-square block, for the geographical distribution characters of four major tuna species (albacore, bigeye tuna, yellowfin tuna, and swordfish) and identified the most 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 area for the GLM standardization analysis 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

Task I 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 South Atlantic albacore was showed in **Figure 1**. A historical high South Atlantic albacore catch in 1987 which was 28,790 t. The catch decreased after 1988 and fluctuated between 6,700 t to 21,000 t.

(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 most appropriate albacore area which is applied to the task2 data.

(3) Task II from 1967 to 2015

The task2 data, aggregated by month and 5° statistical block from 1967 to 2015, were compiled. The logbook and task2 data were the major sources of data used in this analysis and provided by Overseas Fisheries Development Council of Chinese Taipei. Nominal CPUE was defined as catch in weight per 1,000 hooks.

2.2 The appropriate albacore sampling subareas

Although the Atlantic water mass is generally considered having the North Atlantic mid-ocean gyre and South Atlantic mid-ocean gyre, the delineation of North Atlantic albacore from South Atlantic albacore is set at 5°N latitude. Furthermore, the habitat of South Atlantic albacore is currently designated and separated from the Indian Ocean by the 20°E longitude. As of the entire habitat for South Atlantic albacore, it is thus designated currently as from 5°N southward and set 20°E as its eastward boundary condition.

In order to find the most appropriate albacore area 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 each decadal period by Chinese Taipei longline fishery were used to examine.

2.3 Models of GLM

A constant, which was obtained by averaging all Chinese Taipei longliners' nominal albacore CPUE in the most appropriate albacore area of South Atlantic Ocean and divided by 10, was 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 most appropriate albacore area, the GLM with normal error structure (Robson, 1966; Gavaris, 1980; Kimura, 1981) was used in present study to standardize yearly and quarterly CPUE series of the South Atlantic albacore. Factors used in the yearly standardization are year, quarter, subareas by 5° latitude x 5° longitude, effects of bycatch which includes bigeye tuna, yellowfin tuna and swordfish, and interactions. Factors used in the quarterly standardization, however, are quarter-series, subareas by 5° latitude x 5° longitude, and effects of bycatch which includes bigeye tuna, yellowfin tuna and swordfish. The nominal CPUE values of those bycatch species were calculated and coded by quantile. The GLM models constructed in present study for yearly and quarterly standardizations are as follows:

Yearly generalized linear model with normal error structure:

$LOG(CPUE_{ijklmnop}+c)=\mu+YEAR_i+QUARTER_j+SUBAREA_k+CODEBET_l+CODEYFT_m+CODESWO_n+QUARTER*CODEBET_o+QUARTER*CODEYFT_p+\xi_{ijklmnop}$

where
LOG: natural logarithm;
$CPUE_{ijklmnop}$: nominal albacore CPUE (catch in weight per 1000 hooks) in year *i*, quarter *j*, subarea *k*, bycatch of BET_l, YFT_m, SWO_n, $QUARTER*CODEBET_o$, and $QUARTER*CODEYFT_p$;
μ: intercept;
c: constant (10% of the overall mean of nominal albacore CPUE);
$YEAR_i$: main effect of year *i*;
$QUARTER_j$: effect of quarter *j*;
$SUBAREA_k$: effect of subarea *k*;
$CODEBET_l$: effect of bycatch (bigeye tuna);
$CODEYFT_m$: effect of bycatch (yellowfin tuna);
$CODESWO_n$: effect of bycatch (swordfish);
$QUARTER*CODEBET_o$: effect of interaction on quarter and bycatch (bigeye tuna);
$QUARTER*CODEYFT_p$: effect of interaction on quarter and bycatch (yellowfin tuna);
$\xi_{ijklmnop}$: error term with distribution character of $N(0,\sigma^2)$.

Quarterly generalized linear model with normal error structure:

$LOG(CPUE_{iklmn}+c)=\mu+QUARTER\text{-}SERIES_i+SUBAREA_k+CODEBET_l+CODEYFT_m+CODESWO_n+\xi_{iklmn}$

where
LOG: natural logarithm;
$CPUE_{iklmn}$: nominal albacore CPUE (catch in weight per 1000 hooks) in quarter-series *i*, subarea *k*, and bycatch of BET_l, YFT_m, SWO_n;
μ: intercept;
c: constant (10% of the overall mean of nominal albacore CPUE);
$QUARTER\text{-}SERIES_i$: main effect of quarter-series *i*;
$SUBAREA_k$: effect of subarea *k*;
$CODEBET_l$: effect of bycatch (bigeye tuna);
$CODEYFT_m$: effect of bycatch (yellowfin tuna);
$CODESWO_n$: effect of bycatch (swordfish);
ξ_{iklmn}: error term with distribution character of $N(0,\sigma^2)$.

SAS Ver. 9.4 statistical package was used in both cases to obtain 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 result of cluster analysis based on the logbook catches in weight of albacore, bigeye tuna, yellowfin tuna and swordfish from 1981 to 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, i.e., albacore (cluster 1); albacore, bigeye and yellowfin tunas (cluster 2); albacore (cluster 3); and bigeye and yellowfin tunas (cluster 4). The cluster 1 and cluster 3 can be treated as the albacore fleet. **Figures 2-4** showed the geographical distribution maps of the albacore fleet, albacore mostly distributed in subtropical and temperate waters of the South Atlantic Ocean. After confirmation operating distribution of the albacore fleet from logbooks, thus it can supplement the most appropriate albacore area which is applied to the Task II data.

For elucidating geographical distribution characteristics of South Atlantic albacore resource, dating from 1967 to 2015, for each decadal period of geographic distribution map of averaging nominal albacore CPUE in weight was shown in **Figure 5**. As shown in **Figure 5**, a significant area aggregation with different level of catch rate was observed. In particular, an aggregation with higher catch rate appeared between 10°S and 45°S of the South Atlantic Ocean. The same pattern was also observed in **Figures 6-9**, which was obtained exactly the same procedure used to obtain **Figure 5**. In **Figures 2-9**, the area (10°S-45°S/55°W-20°E excepting for 10°S-15°S/10°W-15°E) was proposed as the most appropriate albacore area (**Figure 10**). These figures showed the most appropriate albacore area located in subtropical and temperate waters of the South Atlantic Ocean was always the most dominate fishing ground of albacore by Chinese Taipei longline fishery.

3.2 Standardization CPUE

A constant 35.5240758, which was obtained by averaging all Chinese Taipei longliners' nominal albacore CPUE reported from 1967 to 2015 in the most appropriate albacore area of the South Atlantic Ocean and divided by 10.

The bycatch of bigeye tuna, yellowfin tuna and swordfish was included and coded by quantile. The four quantile intervals of nominal CPUE in the most appropriate albacore area, were (1) 0-0.998582, 0.998582-10.654193, 10.654193-38.232096, and greater than 38.232096 for bigeye tuna; (2) 0, greater than 0 to 1.87721, 1.87721-10.49587, and greater than 10.49587 for yellowfin tuna; and (3) 0, greater than 0 to 2.27556, 2.27556-9.05347, and greater than 9.05347 for swordfish.

To divide appropriately the South Atlantic albacore's entire habitat into subareas was one of the attempts used in present study for providing corrections stemmed from area contrast. 89 subareas (**Figure 10**), by 5° latitude x 5° longitude, were thus used in present study based on Chinese Taipei longline catch statistics.

The ANOVA tables in the most appropriate albacore area, as shown in **Tables 2-3**, which were provided by SAS solver, indicated that (1) factors assigned both in yearly model and in quarter-series model were statistically significant; (2) factors of year/quarter-series and subarea played the most important roles in explanation of its orthogonal variation to the total; (3) comparatively, factor bycatch of yellowfin tuna played a less significant role as its sum of squares were relatively low, although still significant; (4) the determination coefficient R-square approached 36% in both cases indicated the explanatory resultant by the two models were significant.

In the most appropriate albacore area, the yearly nominal CPUE trend and its respective yearly standardized CPUE series thus obtained were tabulated in **Table 4** and plotted in **Figure 11**. The yearly standardized CPUE series showed a continuous decline from the beginning of the Chinese Taipei longline fishery to 1990, then increased till mid-1990s, and leveled off since early 2000s up to 2015. The normalized residual pattern from this model was shown in **Figure 12**. As shown in **Figure 12**, main distribution of residuals ranged from –1.65 to +1.65 and obviously centered at zero as mode. The Q-Q plot of those residuals was also shown in **Figure 13** indicating the fitting was not far from normal distribution.

In the most appropriate albacore area, the quarterly nominal CPUE trend and its respective quarterly standardized CPUE series thus obtained were tabulated in **Table 5** and plotted in **Figure 14**. The quarterly standardized CPUE series showed a continuous decline from late 1960s to 1990 with higher fluctuation, then increased till mid-1990s, and leveled off since early 2000s up to 2015. The trend appeared in quarterly CPUE series was very similar with those obtained in yearly CPUE trend. Although quarterly trend having more fluctuations, it was very interesting to point out that every four quarters always appeared a high peak strongly implied that a consistent recruitment may have coming in every year. The normalized residual pattern from this model was shown in **Figure 15**. As shown in **Figure 15**, main distribution of residuals also ranged from –1.65 to +1.65 and obviously centered at zero as mode. The Q-Q plot of those residuals was shown in **Figure 16** indicating the fitting was not far from normal distribution.

3.3 Discussion

Comparisons were made visually as in **Figure 11** and **Figure 14** among the yearly and quarterly nominal CPUE series respectively, which were calculated in the most appropriate albacore area and in whole areas (Chang and Yeh, 2014). They were similar to those in whole areas of the South Atlantic Ocean from 1976 to 1989. 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. The proposed appropriate albacore sampling subareas appeared their own significance in this regard.

The proposed albacore area and subareas (**Figure 10**) were the main fishing ground of albacore for Chinese Taipei longline fishery, had own characteristics and represented meaning. The most appropriate albacore sampling subareas were proposed mainly for minimizing those non-albacore-targeting noises. We hope, through such manipulations, give a more persuasive resultant CPUE trend than current endeavors.

Acknowledgments

We are grateful for the Fisheries Agency and Overseas Fisheries Development Council of Chinese Taipei fisheries managerial sectors for their financial supports and tremendous efforts devoted to fisheries catch and effort statistical data collection and compilation.

References

Chang, F. C. and Yeh, S. Y. 2015. CPUE standardization, using proper albacore subareas and dating from 1967 to 2013, on albacore caught by Chinese Taipei longliners fishing in the South Atlantic Ocean. Collect. Vol. Sci. Pap. ICCAT, 71(5): 2438-2457.

Chang, F. C. and Yeh, S. Y. 2014. Standardized CPUE of South Atlantic albacore (*Thunnus alalunga*) based on Chinese Taipei longline catch and effort statistics dating from 1967 to 2012. Collect Vol. Sci. Pap. ICCAT 70(3): 1234-1246.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. Aquat. Sci., 37: 2272-2275.

ICCAT. 1996. Report of the bluefin tuna methodology session (Madrid, Spain, April 16 to 19, 1996).

ICCAT. 2013. Report of the 2013 North and South Atlantic albacore stock assessment meeting (Sukarrieta, Spain, June 17 to 24, 2013).

Kimura, D. K. 1981. Standardized measures of relative abundance based on modeling log (CPUE), and their application to Pacific Ocean perch (*Sebastes alutus*), J. Cons. Int. Explore, Mer., 39:211-218.

Report for biennial period, 2012-13, PART II (2013) - Vol. 2, English version, SCRS.

Report for biennial period, 2014-15, PART I (2014) - Vol. 2, English version, SCRS.

Report for biennial period, 2014-15, PART II (2015) - Vol. 2, English version, SCRS.

Robson, D. S. 1996. Estimation of the relative fishing power of individual ships. ICNAF Res. Bull., 3:5-15.

Wu, C. L. and Yeh, S. Y. 2002. Geographic distribution and area demarcation on the fisheries resource of south Atlantic albacore. ACTA Oceanogra. Chinese Taipei. 40(1): 81-92.

Table 1. The result of cluster analysis based on the logbook catches in weight (kg) of albacore, bigeye tuna, yellowfin tuna and swordfish from 1981 to 2015.

cluster	ALB_wt	BET_wt	YFT_wt	SWO_wt
1	60,752	1,094	744	480
2	2,558	6,105	1,257	648
3	27,584	1,016	699	408
4	343	25,559	2,125	1,302

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

Table 2. Analysis of variance on standardizing South Atlantic albacore (in the most appropriate albacore area) yearly CPUE using Chinese Taipei longline fishery task2 data set from 1967 to 2015 by the GLM procedure.

Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	166	1934.01284	11.65068	35.96	<.0001
Error	10714	3471.37579	0.32400		
Corrected Total	10880	5405.38863			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.35779	9.87712	0.56921	5.76295

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	48	789.01768	16.43787	50.73	<.0001
quarter	3	42.04694	14.01565	43.26	<.0001
subarea	88	357.67566	4.06450	12.54	<.0001
codebet	3	184.03983	61.34661	189.34	<.0001
codeyft	3	19.71126	6.57042	20.28	<.0001
codeswo	3	97.61751	32.53917	100.43	<.0001
quarter*codebet	9	36.64615	4.07179	12.57	<.0001
quarter*codeyft	9	36.78780	4.08753	12.62	<.0001

Table 3. Analysis of variance on standardizing South Atlantic albacore (in the most appropriate albacore area) quarterly CPUE using Chinese Taipei longline fishery Task II data set from 1967 to 2015 by the GLM procedure.

Dependent Variable: Logcpuew_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	290	2132.74960	7.35431	23.8	<.0001
Error	10590	3272.63903	0.30903		
Corrected Total	10880	5405.38863			

R-Square	Coeff Var	Root MSE	Logcpuew_alb Mean
0.39456	9.64620	0.55591	5.76295

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yq	193	1125.01934	5.82912	18.86	<.0001
subarea	88	352.96208	4.01093	12.98	<.0001
codebet	3	186.18215	62.06072	200.82	<.0001
codeyft	3	17.05619	5.68540	18.4	<.0001
codeswo	3	97.36637	32.45546	105.02	<.0001

Table 4. Yearly nominal and standardized CPUE trends of the most appropriate South Atlantic albacore area based on Chinese Taipei longline fishery task2 data set from 1967-2015 by the GLM procedure.

Year	Nominal CPUE	Standardized CPUE	CV
1967	840.66	801.35	0.04918
1968	1161.02	791.72	0.01079
1969	812.47	743.27	0.00691
1970	682.97	599.70	0.00653
1971	814.97	629.15	0.00708
1972	565.58	415.40	0.00694
1973	455.21	319.23	0.00847
1974	484.84	343.32	0.00692
1975	560.29	405.04	0.00746
1976	391.12	374.69	0.00645
1977	528.10	449.76	0.00600
1978	501.49	384.15	0.00578
1979	444.41	352.29	0.00664
1980	493.29	361.37	0.00594
1981	436.82	321.20	0.00619
1982	424.66	301.33	0.00585
1983	405.34	294.83	0.00709
1984	489.47	368.20	0.00801
1985	407.33	300.71	0.00663
1986	427.68	295.30	0.00600
1987	337.09	263.46	0.00615
1988	284.41	195.45	0.00861
1989	268.38	165.61	0.00917
1990	282.27	177.62	0.00913
1991	275.30	197.55	0.00785
1992	320.15	214.57	0.00946
1993	289.59	218.20	0.00735
1994	342.95	282.08	0.00699
1995	376.64	276.07	0.00716
1996	491.08	292.35	0.00673
1997	473.56	308.64	0.00660
1998	432.21	281.76	0.00739
1999	301.75	197.97	0.00603
2000	272.01	174.60	0.00582
2001	303.86	218.39	0.00670
2002	268.82	175.16	0.00660
2003	248.92	153.28	0.00906
2004	357.31	202.27	0.01193
2005	297.56	253.89	0.00669
2006	286.69	202.06	0.00642
2007	444.90	239.13	0.00699
2008	437.01	248.35	0.00737
2009	449.35	262.41	0.00732
2010	457.39	286.47	0.00727
2011	376.53	240.72	0.00710
2012	416.80	250.93	0.00736
2013	376.86	270.34	0.00710
2014	332.98	180.64	0.00796
2015	438.26	263.05	0.00766

Table 5. Quarterly nominal and standardized CPUE trends of the most appropriate South Atlantic albacore area based on Chinese Taipei longline fishery task2 data set from 1967-2015 by the GLM procedure.

Year*Quarter	Nominal CPUE	Standardized CPUE	CV
19673	955.90	1062.37	0.05641
19674	469.32	613.25	0.08616
19681	731.14	435.91	0.03708
19682	1439.22	1645.45	0.01955
19683	1130.51	1178.51	0.01456
19684	304.69	285.84	0.02509
19691	767.50	647.35	0.01764
19692	1075.97	736.43	0.01525
19693	837.83	878.31	0.01140
19694	630.84	696.80	0.01081
19701	698.52	524.20	0.01395
19702	1061.47	861.72	0.01520
19703	848.26	875.02	0.01065
19704	381.39	432.78	0.01049
19711	436.46	435.84	0.01472
19712	1234.23	1119.82	0.01381
19713	1054.77	993.83	0.01194
19714	389.48	415.06	0.01256
19721	525.11	469.01	0.01513
19722	713.26	620.71	0.01291
19723	594.23	450.77	0.01090
19724	260.74	281.35	0.01356
19731	439.68	277.63	0.01684
19732	641.93	621.68	0.01566
19733	490.08	435.07	0.01518
19734	227.35	195.00	0.01572
19741	370.90	245.71	0.01547
19742	609.92	447.43	0.01124
19743	591.21	511.28	0.01112
19744	284.51	262.16	0.01453
19751	494.28	380.61	0.01607
19752	808.58	657.94	0.01405
19753	612.42	497.08	0.01142
19754	268.37	264.16	0.01515
19761	356.71	325.13	0.01334
19762	521.05	540.10	0.01127
19763	421.98	512.94	0.01085
19764	213.21	248.43	0.01261
19771	451.37	432.38	0.01157
19772	663.00	703.33	0.01140
19773	557.74	487.39	0.01002
19774	329.45	337.42	0.01142
19781	448.62	336.46	0.01056
19782	607.83	517.52	0.00978
19783	500.26	419.62	0.01055
19784	344.33	349.34	0.01169
19791	419.13	362.15	0.01188
19792	546.60	413.44	0.01264
19793	420.36	362.61	0.01249
19794	319.24	315.64	0.01243
19801	506.18	366.08	0.01142
19802	671.96	500.48	0.01161
19803	450.77	357.58	0.01007
19804	334.77	323.04	0.01082
19811	467.99	366.08	0.01082
19812	485.02	384.78	0.01172
19813	399.84	331.48	0.01032
19814	387.43	276.42	0.01346
19821	442.43	332.80	0.01014
19822	499.96	360.53	0.01051
19823	369.84	320.88	0.00957
19824	342.86	240.84	0.01353
19831	346.86	249.51	0.01121
19832	440.75	319.72	0.01423
19833	432.26	330.31	0.01332
19834	442.61	379.31	0.01541
19841	508.75	387.95	0.01702
19842	658.36	531.50	0.01488
19843	394.84	336.11	0.01440
19844	463.06	332.72	0.01445
19851	393.47	301.88	0.01178
19852	457.47	372.13	0.01284
19853	390.02	305.96	0.01135
19854	361.83	290.19	0.01348
19861	430.22	297.32	0.01058
19862	503.80	339.45	0.01078
19863	391.93	333.03	0.01071
19864	316.93	256.55	0.01200
19871	368.78	281.04	0.01075
19872	370.90	305.78	0.01113
19873	283.07	259.72	0.01173
19874	296.47	242.90	0.01180
19881	258.79	177.18	0.01212
19882	297.02	232.14	0.01708
19883	233.74	199.39	0.01700
19884	409.74	305.86	0.02591
19891	366.84	196.70	0.01892
19892	252.81	160.15	0.01617
19893	227.90	209.52	0.01710
19894	234.44	146.01	0.01703
19901	286.80	191.20	0.01541
19902	330.26	235.71	0.01596
19903	233.79	183.90	0.01534
19904	295.00	128.04	0.02757
19911	276.92	209.57	0.01534
19912	261.52	175.02	0.01408
19913	262.00	217.53	0.01452
19914	303.81	209.83	0.01473
19921	291.79	213.78	0.01751
19922	347.26	265.82	0.01607
19923	328.77	244.28	0.01696
19924	290.66	129.55	0.02303
19931	258.01	115.22	0.01936
19932	341.38	296.05	0.01505
19933	297.48	228.56	0.01441
19934	274.46	238.39	0.01063
19941	373.27	288.26	0.01201
19942	399.73	314.60	0.01330
19943	259.81	276.06	0.01273
19944	282.21	283.57	0.01439
19951	417.16	326.76	0.01841
19952	441.72	328.31	0.01333
19953	303.10	241.31	0.01206
19954	402.50	294.47	0.01175
19961	621.92	286.04	0.01303
19962	466.21	314.32	0.01140
19963	371.09	284.62	0.01183
19964	575.60	321.02	0.01381
19971	563.33	301.02	0.01118
19972	490.10	307.65	0.01287
19973	395.54	333.93	0.01333
19974	462.04	310.59	0.01185
19981	398.30	309.93	0.01386
19982	546.59	339.65	0.01368
19983	442.28	309.63	0.01322
19984	286.62	200.66	0.01438
19991	239.85	171.75	0.01085
19992	342.63	178.33	0.01187
19993	311.05	224.20	0.01029
19994	302.11	225.47	0.01115
20001	240.88	157.23	0.01041
20002	316.58	177.40	0.01008
20003	246.58	184.85	0.01104
20004	278.79	212.84	0.01170
20011	323.10	244.17	0.01054
20012	302.30	156.14	0.01334
20013	310.99	249.00	0.01283
20014	271.85	227.08	0.01366
20021	277.34	204.98	0.01098
20022	269.92	162.44	0.01166
20023	235.80	166.93	0.01148
20024	316.33	199.74	0.01677
20031	246.67	163.16	0.01577
20032	267.73	153.19	0.01578
20033	226.88	193.63	0.01758
20034	251.05	103.66	0.02052
20041	221.07	169.58	0.01936
20042	650.64	258.53	0.02973
20043	396.83	286.75	0.01921
20044	333.96	113.13	0.02902
20051	257.32	244.11	0.01114
20052	353.62	233.96	0.01383
20053	331.64	262.98	0.01205
20054	256.45	276.44	0.01327
20061	287.94	225.01	0.01091
20062	342.66	220.00	0.01222
20063	258.20	214.37	0.01184
20064	217.40	157.74	0.01272
20071	284.98	165.76	0.01304
20072	636.67	374.14	0.01303
20073	474.87	318.80	0.01233
20074	271.10	185.21	0.01342
20081	335.81	242.70	0.01360
20082	516.50	281.51	0.01272
20083	444.73	285.69	0.01189
20084	279.31	173.92	0.02026
20091	343.56	235.26	0.01293
20092	489.53	267.62	0.01315
20093	547.90	363.89	0.01313
20094	290.94	220.60	0.01612
20101	347.26	239.87	0.01244
20102	490.28	274.64	0.01333
20103	513.72	416.01	0.01253
20104	463.42	266.06	0.01701
20111	353.83	247.86	0.01235
20112	429.09	296.90	0.01318
20113	359.10	240.71	0.01182
20114	304.98	193.67	0.01692
20121	419.35	198.01	0.01359
20122	420.29	288.02	0.01229
20123	464.71	340.14	0.01393
20124	283.40	237.05	0.01542
20131	352.10	186.27	0.01515
20132	419.02	304.73	0.01347
20133	367.52	306.34	0.01271
20134	359.40	285.92	0.01232
20141	213.89	120.35	0.01561
20142	397.51	189.77	0.01591
20143	327.30	230.69	0.01264
20144	331.30	231.77	0.01621
20151	322.65	186.37	0.01600
20152	443.11	229.61	0.01427
20153	406.94	345.78	0.01303
20154	576.90	330.41	0.01432

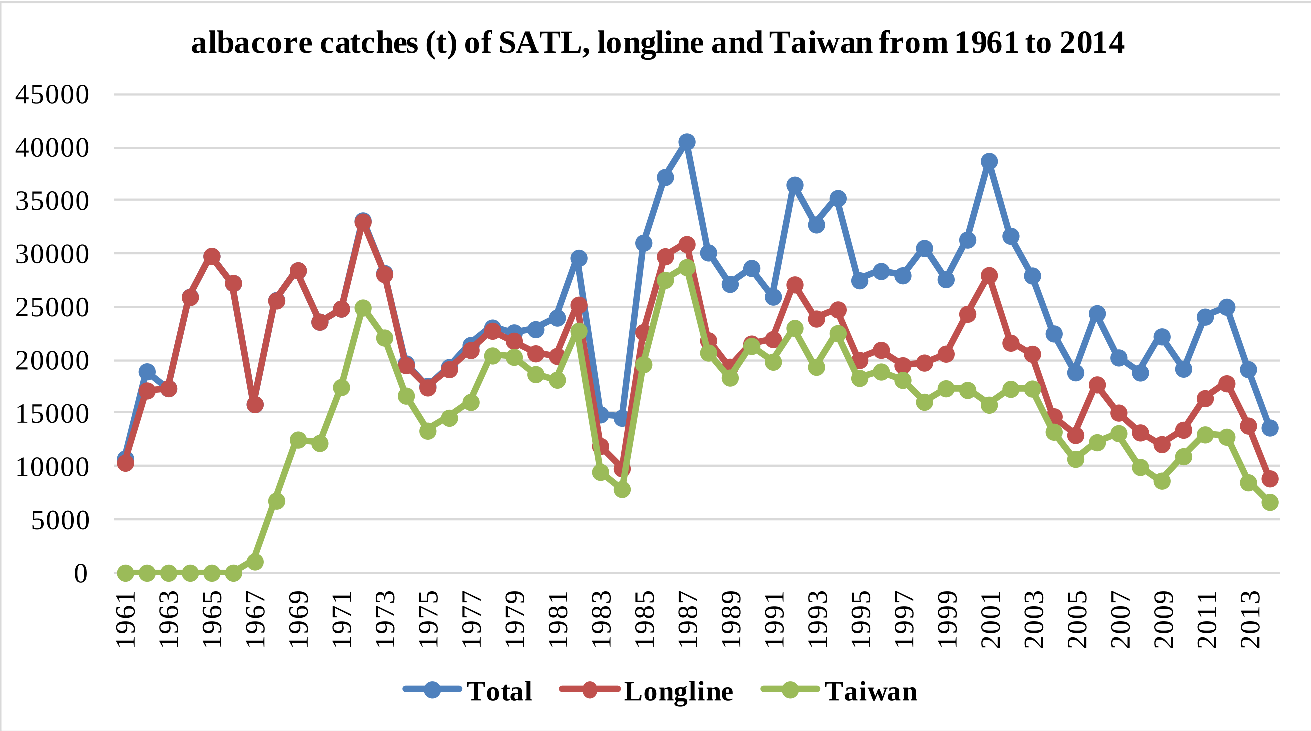

Figure 1. Historical albacore catch of Chinese Taipei longline fishing vessels in the South Atlantic Ocean, 1961-2014.
Sources: ICCAT (task 1) and OFDC.

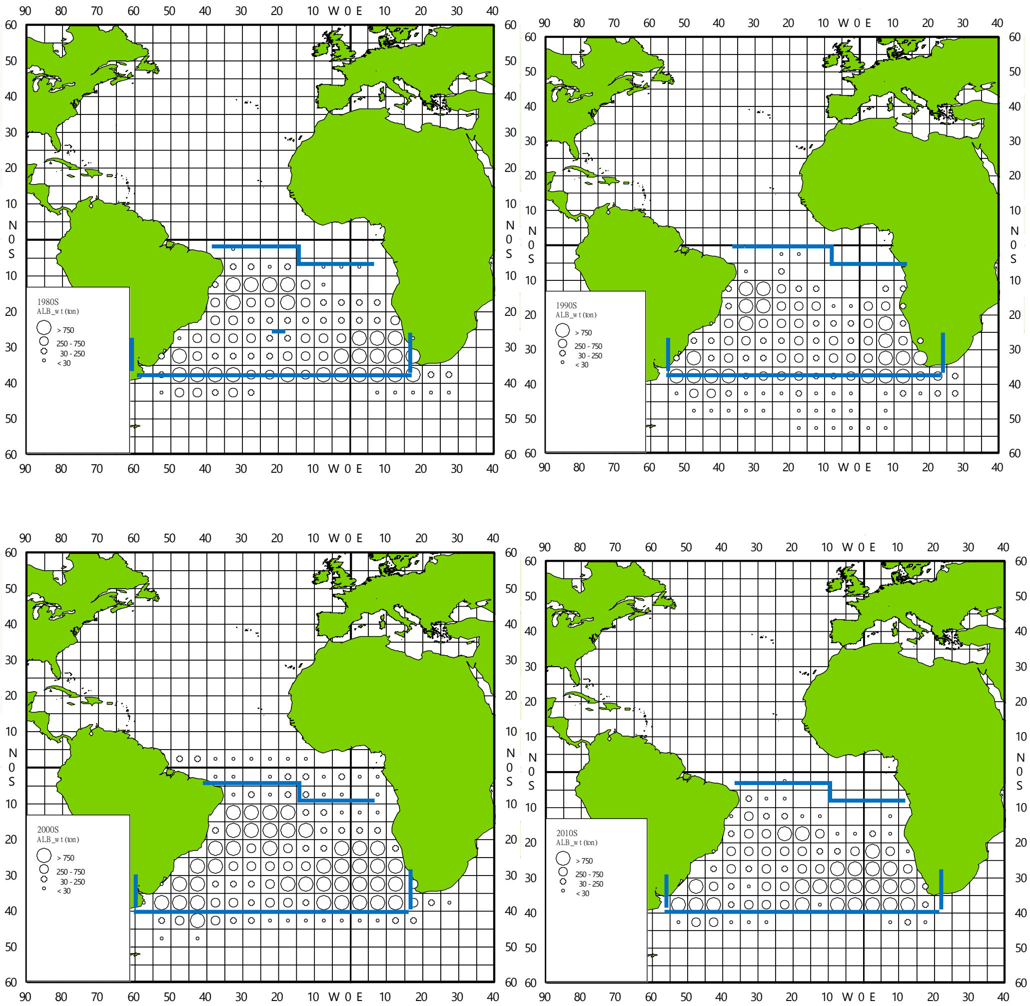

Figure 2. Geographic distribution, by 5º-square block, of catch in weight (from logbooks) of albacore caught by Chinese Taipei longliners in the South Atlantic Ocean for periods of 1981-1989 (Upper-Left), 1990-1999 (Upper-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower-Right).

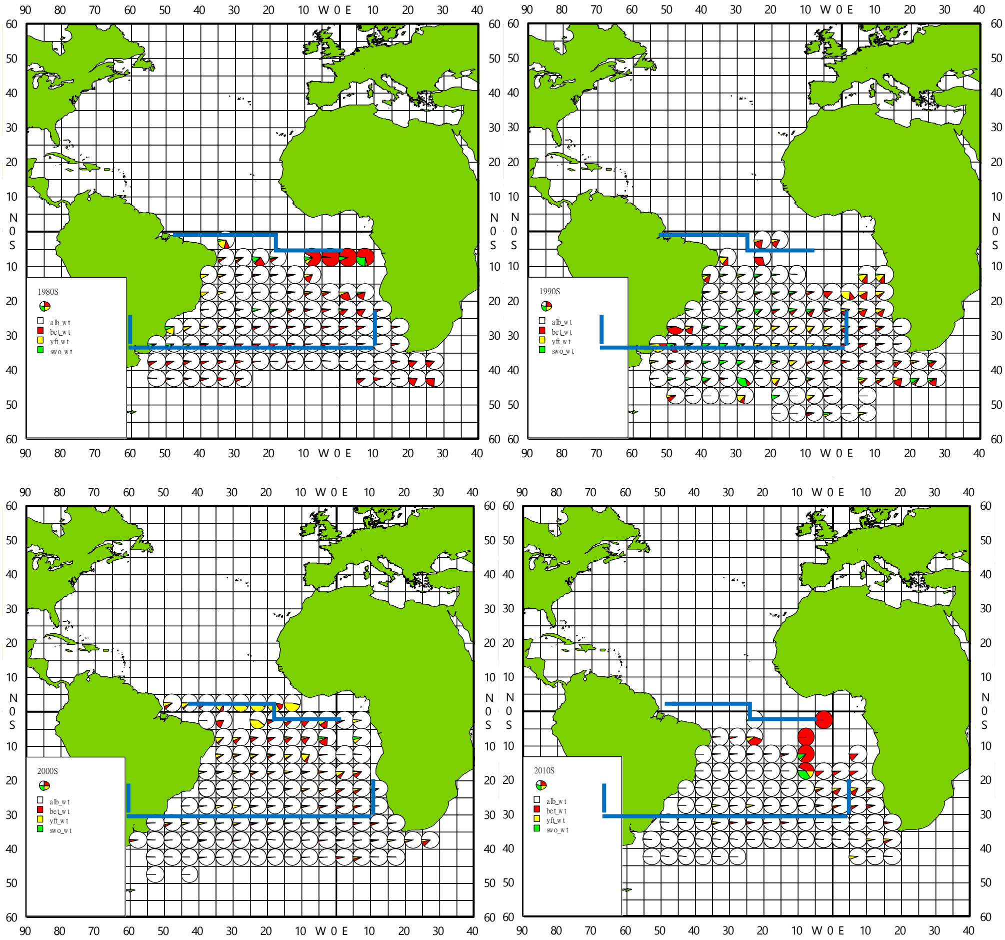

Figure 3. Geographic distribution, by 5º-square block, of four major species composition, in terms of catch in weight (from logbooks), caught by Chinese Taipei longliners in the South Atlantic Ocean for periods of 1981-1989 (Upper-Left), 1990-1999 (Upper-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower- Right). Four major species are: albacore (ALB in white), bigeye tuna (BET in red), yellowfin tuna (YFT in yellow) and swordfish (SWO in green).

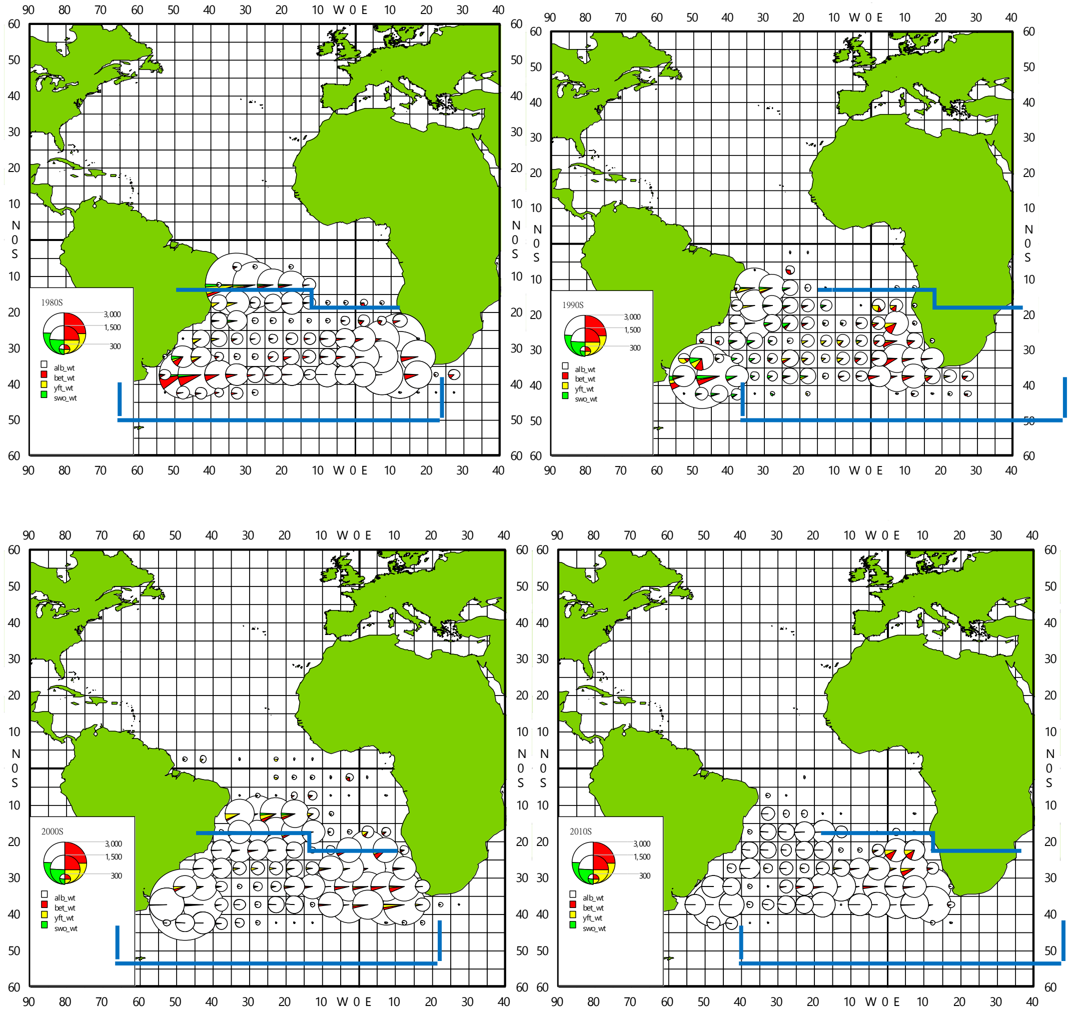

Figure 4. Geographic distribution, by 5º-square block, of catch in weight of four major species (from logbooks), caught by Chinese Taipei longliners in the South Atlantic Ocean for periods of 1981-1989 (Upper-Left), 1990-1999 (Upper-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower-Right). Four major species are: albacore (ALB in white), bigeye tuna (BET in red), yellowfin tuna (YFT in yellow) and swordfish (SWO in green).

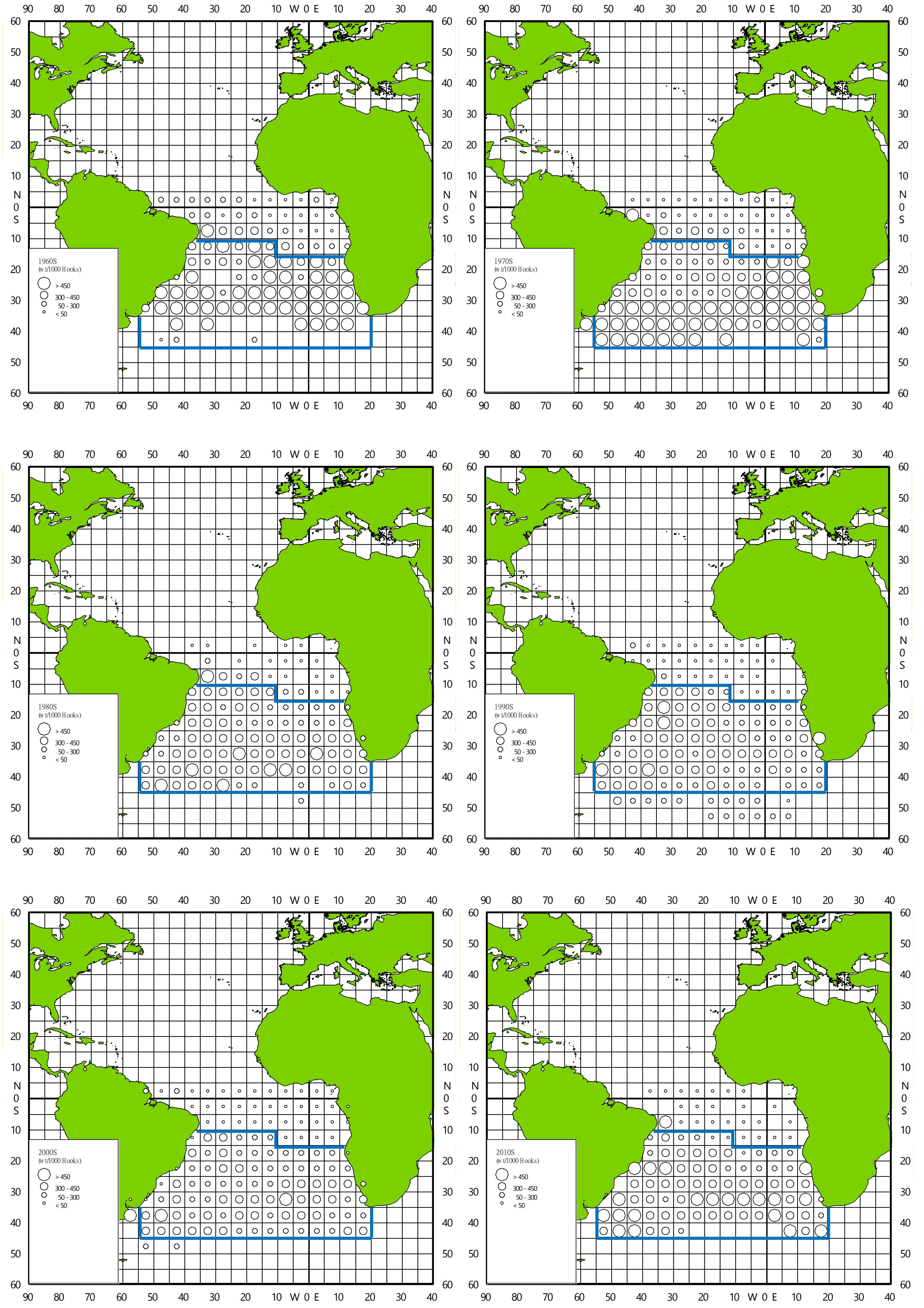

Figure 5. Yearly nominal CPUE (Wt./1000 Hooks from task2) of albacore caught by Chinese Taipei longliners in the South Atlantic Ocean for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower-Right).

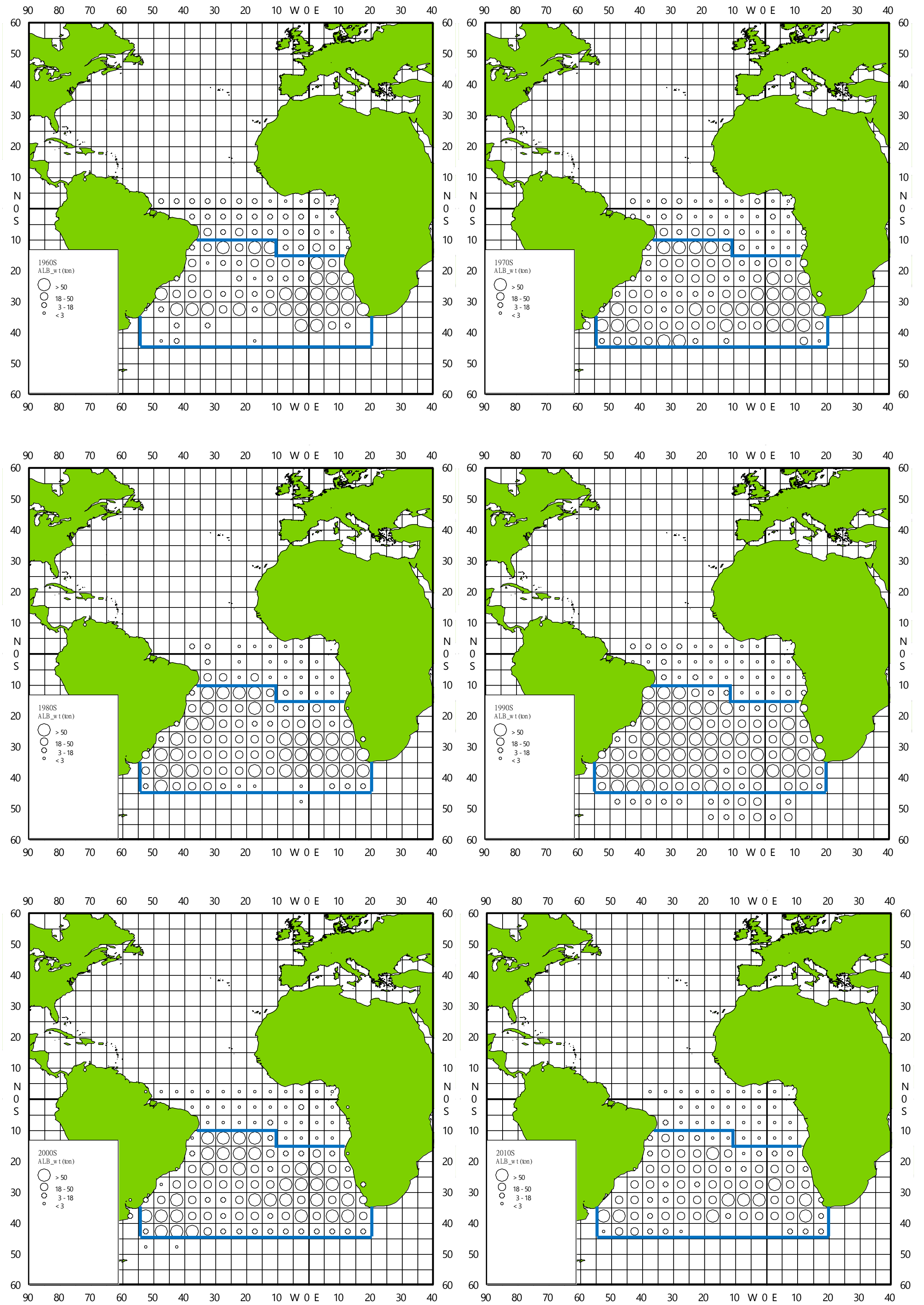

Figure 6. Yearly catch in weight (from task2) of albacore caught by Chinese Taipei longliners in the South Atlantic Ocean for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower-Right).

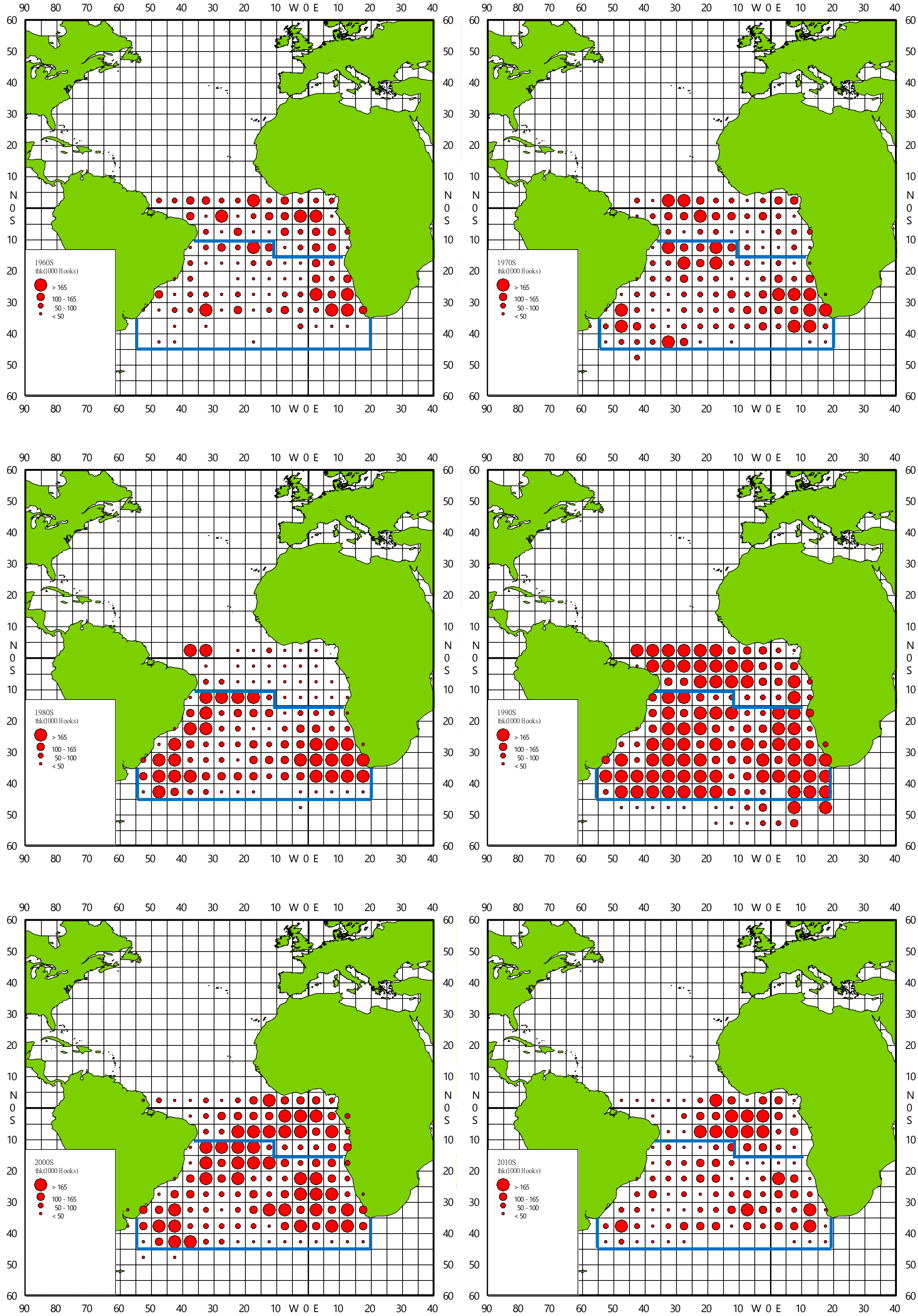

Figure 7. Yearly fishing efforts (Number of hooks from task2) cast by Chinese Taipei longliners in the South Atlantic Ocean for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower-Right).

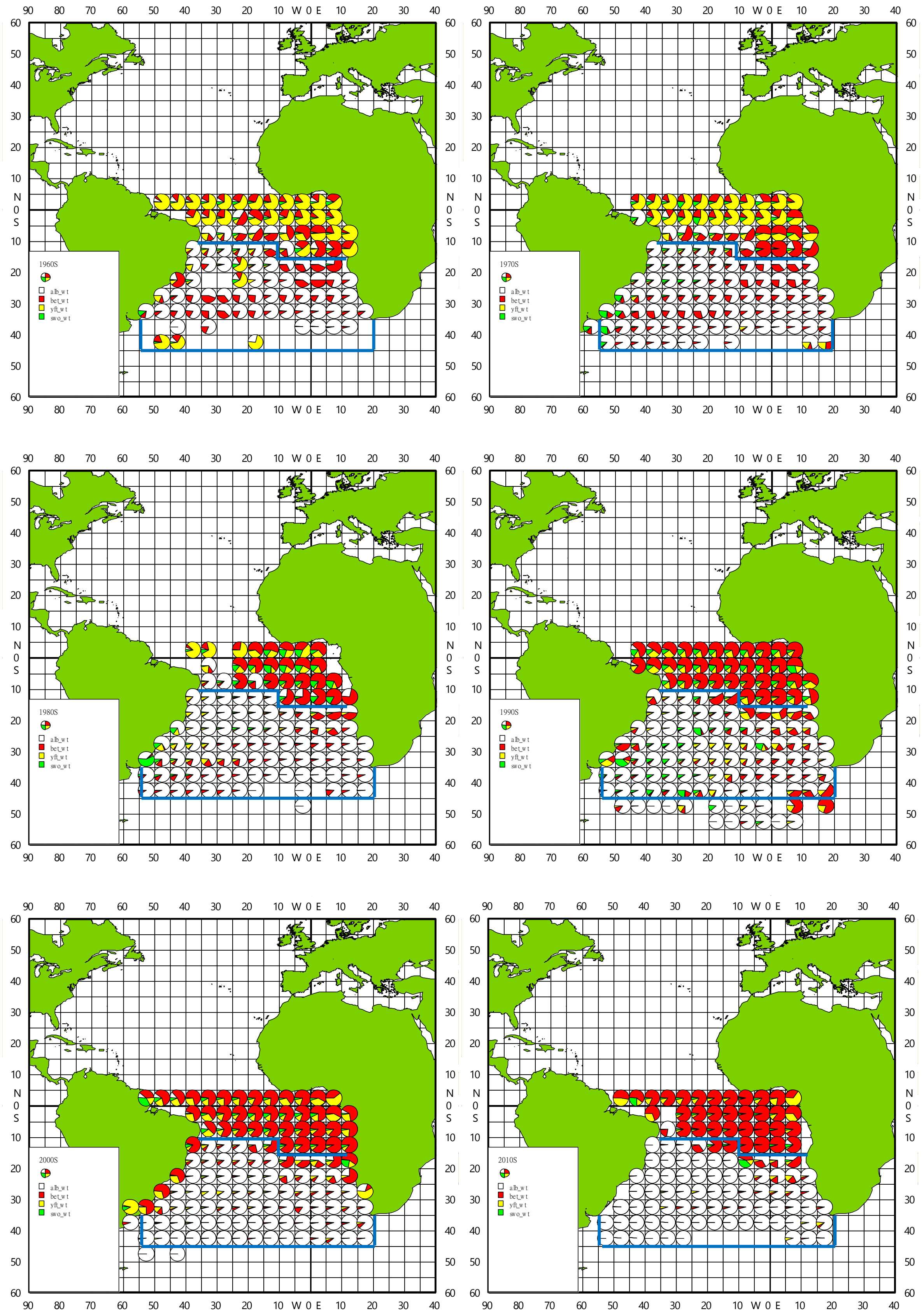

Figure 8. Geographic distribution of yearly four major species composition (from task2) caught by Chinese Taipei longliners for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower-Right).

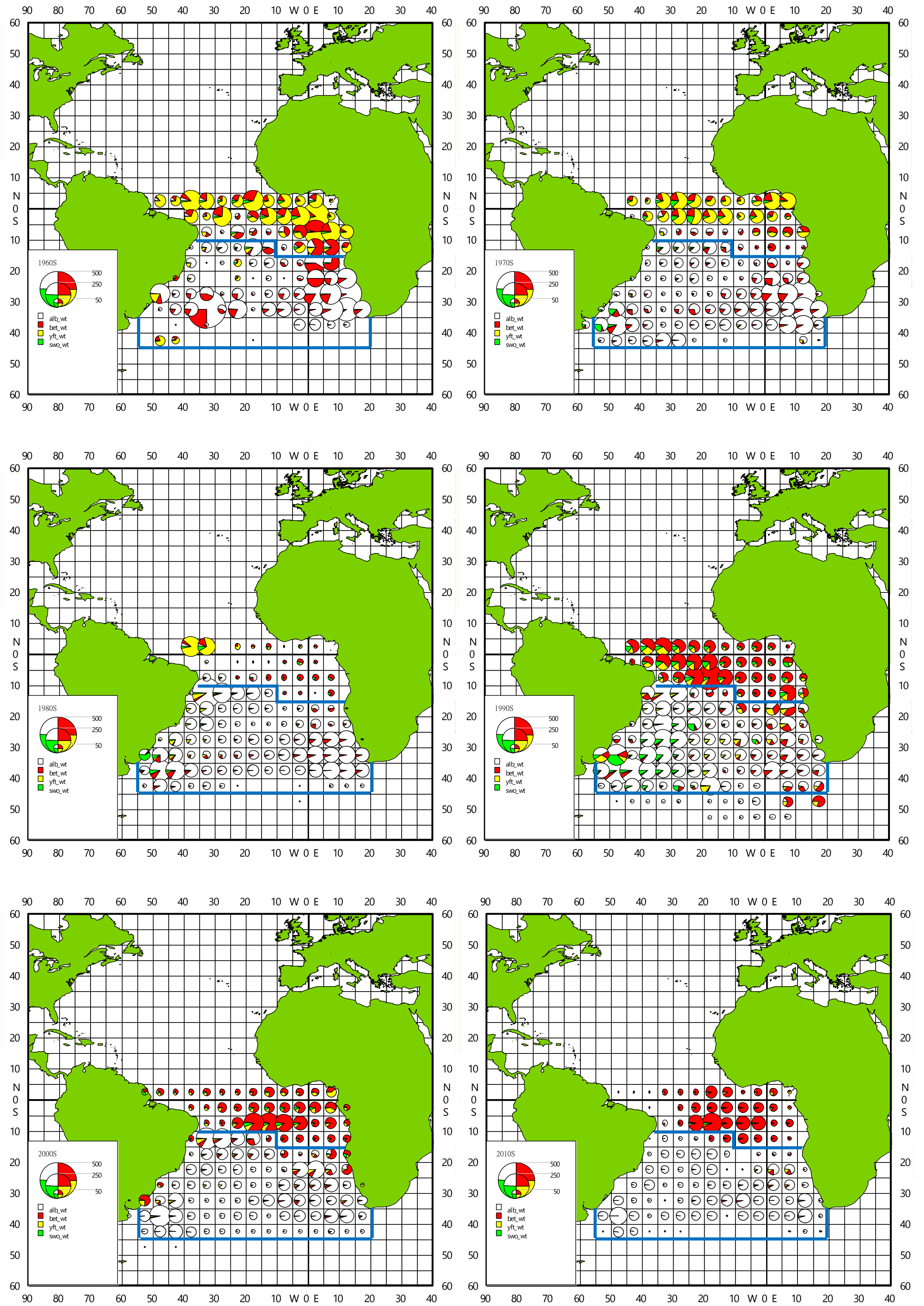

Figure 9. Geographic distribution of yearly catch composition of four major species (from task2) caught by Chinese Taipei longliners for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2015 (Lower-Right).

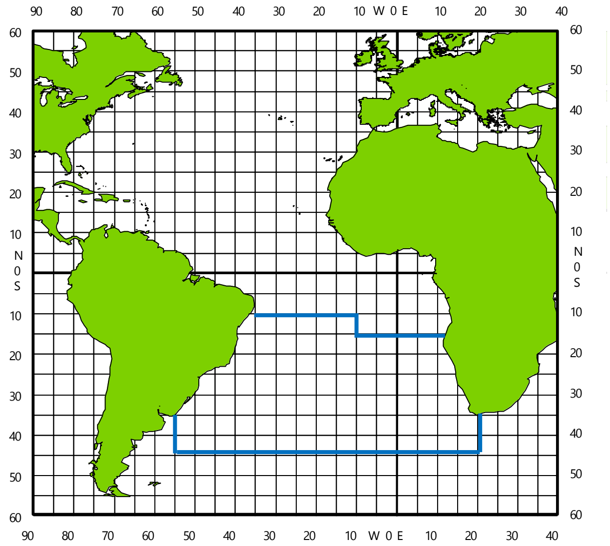

Figure 10. The 89, by 5º-square block, subareas (encircled by blue lines) thus proposed by this paper for CPUE standardization on albacore resource in the South Atlantic Ocean.

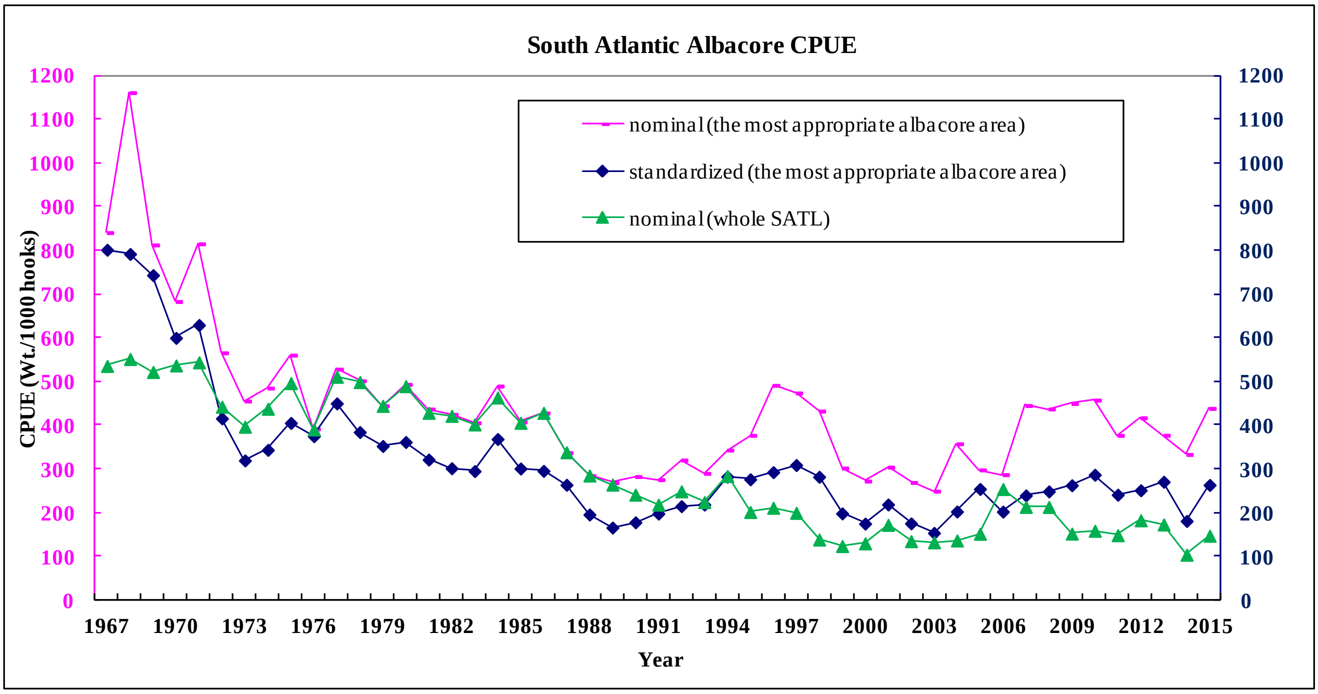

Figure 11. Yearly nominal and standardized CPUE (Wt./1000 Hooks) trends of South Atlantic albacore based on Chinese Taipei longline fishery task2 data set from 1967 to 2015.

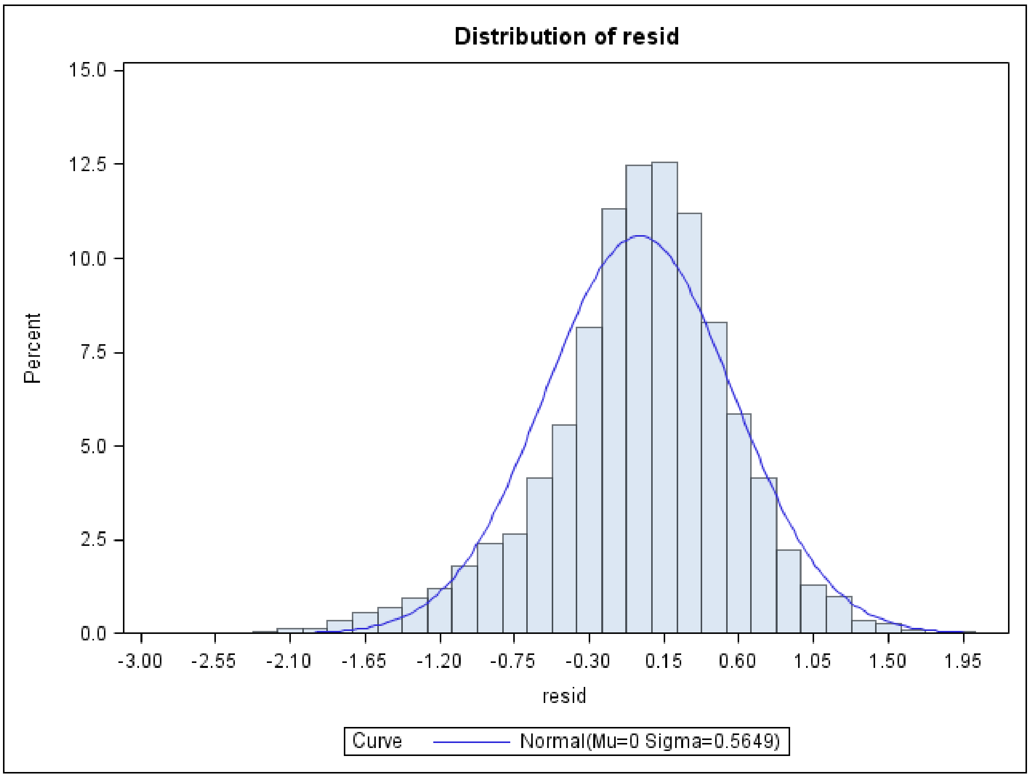

Figure 12. Distribution of normalized residual obtained from yearly GLM model.

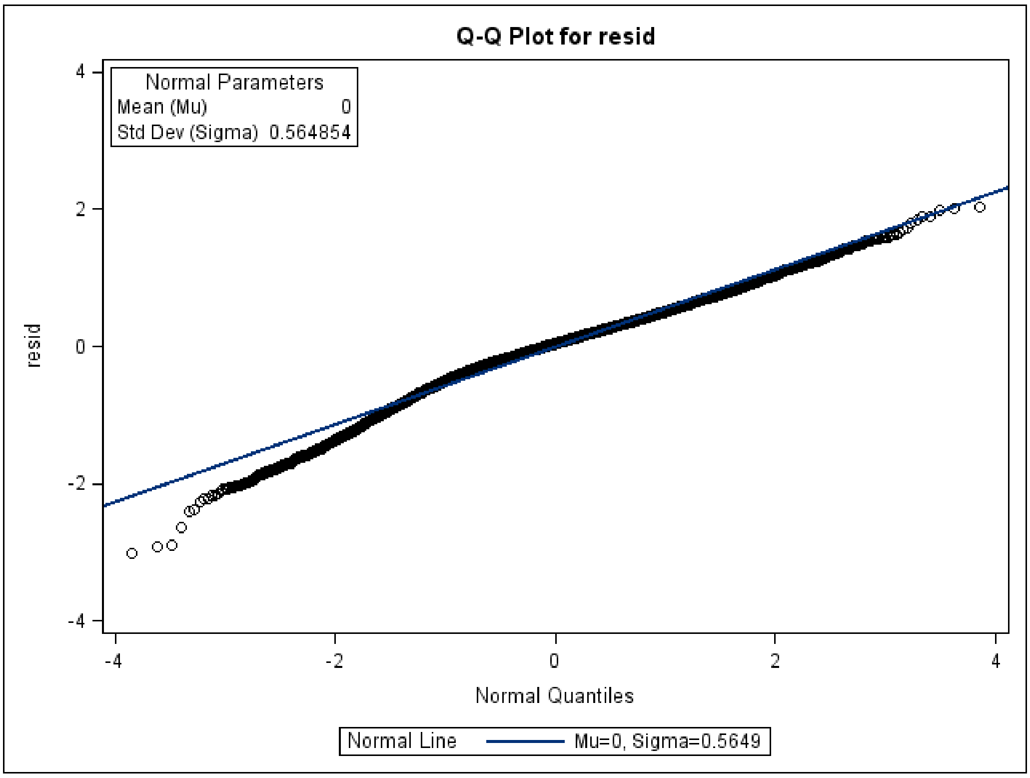

Figure 13. The Q-Q plot for residuals obtained from yearly GLM model.

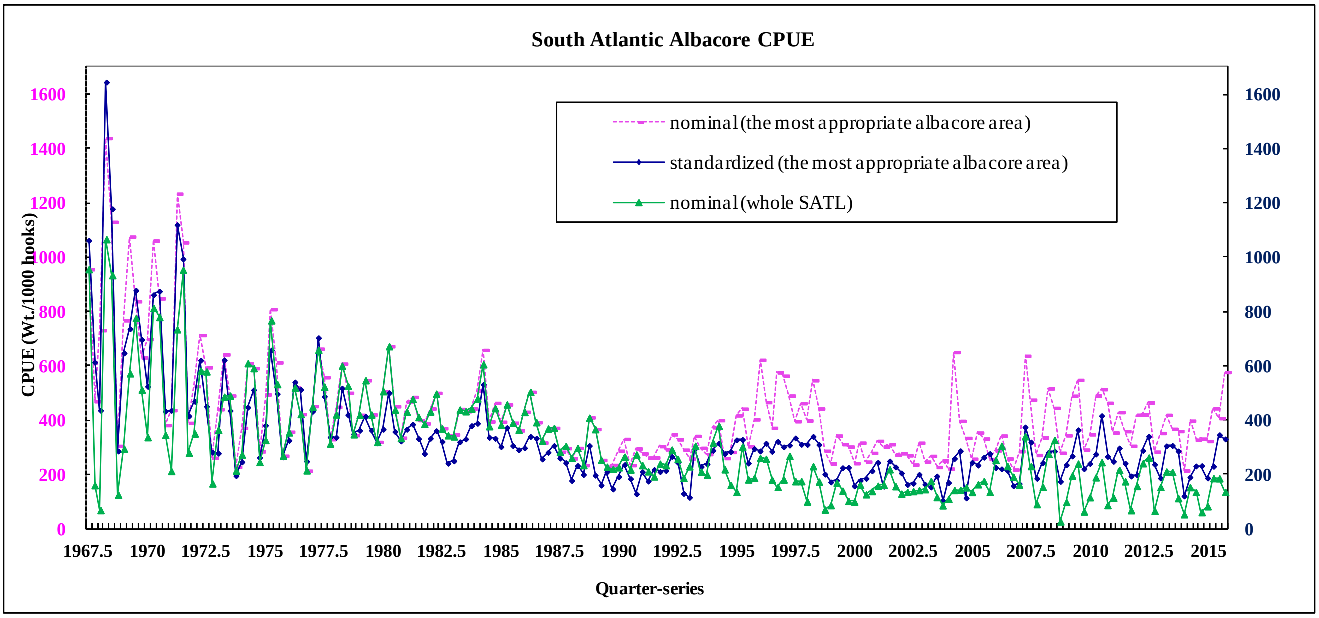

Figure 14. Quarterly nominal and standardized CPUE (Wt./1000 Hooks) trends of South Atlantic albacore based on Chinese Taipei longline fishery task2 data set from 1967 to 2015.

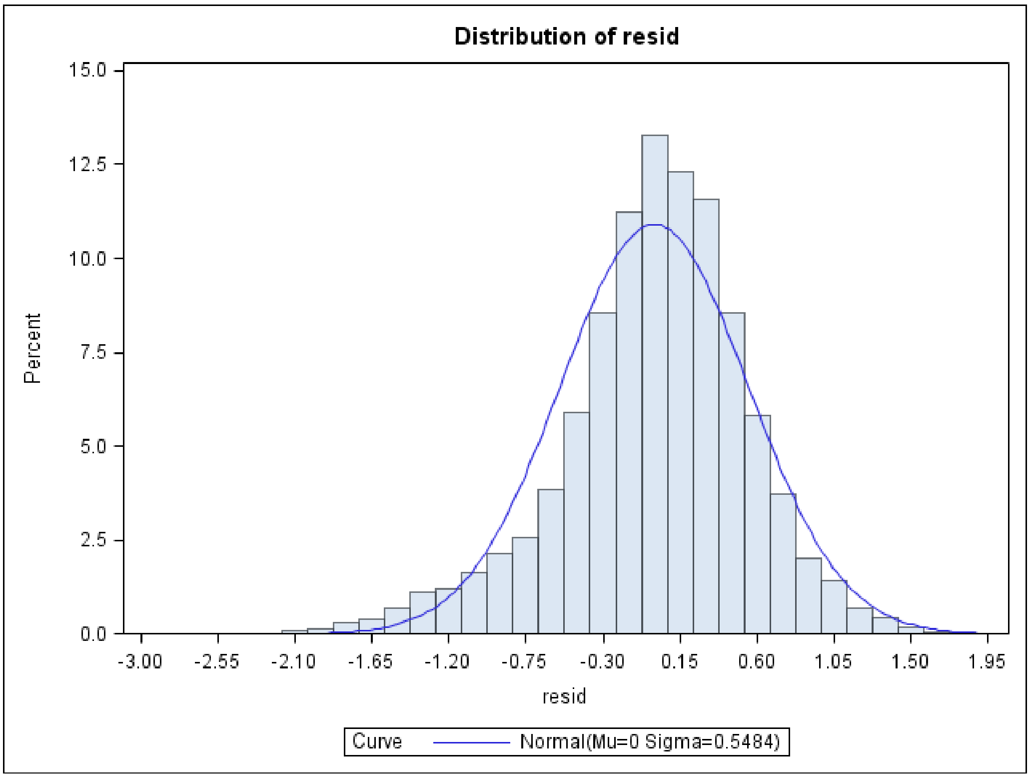

Figure 15. Distribution of normalized residual obtained from quarterly GLM model.

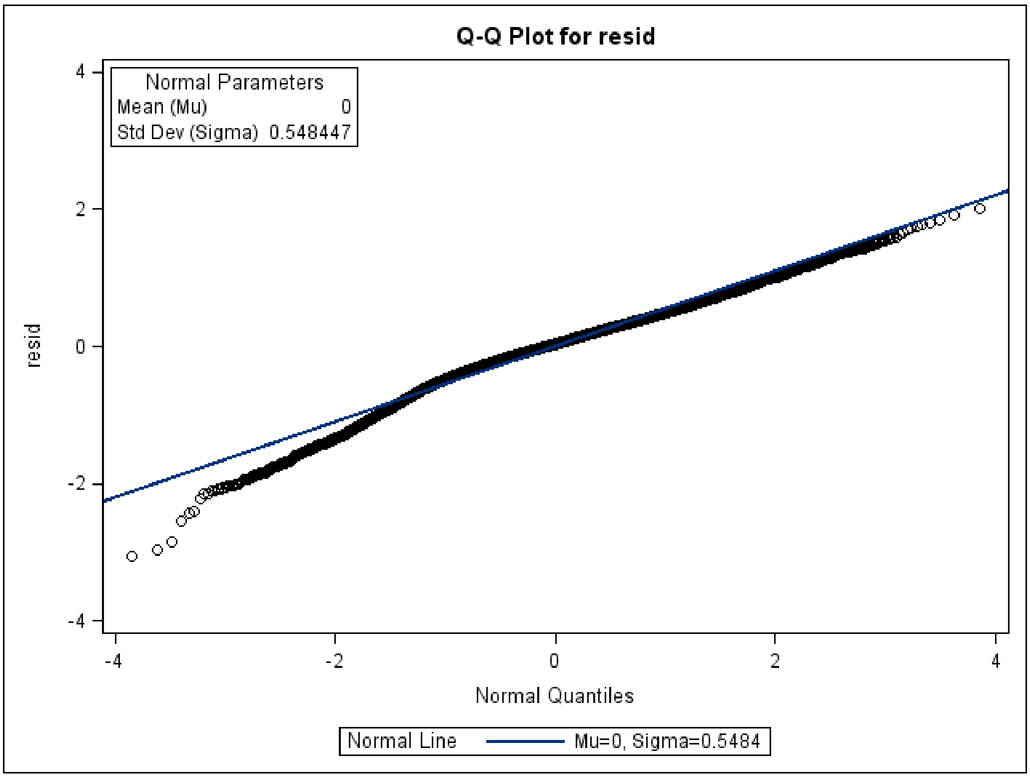

Figure 16. The Q-Q plot for residuals obtained from quarterly GLM model.