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CPUE STANDARDIZATION, USING PROPER ALBACORE SUBAREAS AND DATING FROM 1967 TO 2013, ON ALBACORE CAUGHT BY TAIWANESE LONGLINERS FISHING IN THE SOUTH ATLANTIC OCEAN

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SUMMARY

Both the logbooks (since 1981) and the Task2 (since 1967) data sets of Taiwanese 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 Taiwanese fisheries data sets within the proposed sampling area for the Generalized Linear Model (GLM) standardization analysis and hopefully able to minimize most noises of non-albacore-targeting data. The most appropriate sampling area for South Atlantic albacore thus identified was from 10°S to 45°S and from 55°W to 20°E, yet excluding the small block of 10°S-15°S/10°W-15°E. In the most appropriate albacore area, standardized abundance indices of South Atlantic albacore, dating from 1967 to 2013, based on Taiwanese longline catch and effort statistics by using the GLM procedure were carried out in present study. Factors as year, quarter, subareas by 5° latitude x 5° longitude, bycatch effects of bigeye tuna, yellowfin tuna, swordfish and interactions were used to obtain the yearly standardized Catch Per Unit Effort (CPUE) trend from 1967 to 2013. The quarterly standardized CPUE series from the 3rd quarter of 1967 to the 3rd quarter of 2013 were also obtained by using quarter-series, subareas by 5° latitude x 5° longitude, bycatch effects of bigeye tuna, yellowfin tuna, and swordfish as factors of concern. CPUE, both yearly and quarterly, trends thus obtained indicated that the abundance in number of the most appropriate South Atlantic albacore area declined from late 1960s to 1990, then increased till mid 1990s, and leveled off since early 2000s up to 2013. Quarterly trend, as compared to its respective yearly trend, often appeared a significant peak per year implied a consistent recruitment pattern of this 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 la zone d'échantillonnage la plus indiquée 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 de la zone d'échantillonnage proposée 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. La zone d'échantillonnage la plus appropriée pour le germon de l'Atlantique Sud ayant donc été identifiée s'étendait de 10ºS à 45ºS et de 55ºW à 20ºE, exception faite du petit bloc se trouvant à 10°S-15°S/10°W-15°E. Dans la zone d'échantillonnage du germon la plus appropriée, la présente étude a mis au point des indices d'abondance standardisés du germon de l'Atlantique Sud, correspondant à la période 1967-2013, en se fondant sur les statistiques de prise et d'effort des palangriers du Taipei chinois, à l'aide d'une procédure de modèle linéaire généralisé (GLM). Les facteurs, tels que année, trimestre, sous-zone par 5º de latitude et 5º de longitude, effets de la prise accessoire du thon obèse, de l'albacore et de l'espadon et interactions ont été utilisés en vue d'obtenir la tendance de la prise par unité d'effort (CPUE) standardisée annuelle de 1967 à 2013. On a également obtenu la série de CPUE standardisée trimestrielle à partir du troisième trimestre de 1967 jusqu'au troisième trimestre de 2013, en utilisant des séries trimestrielles, sous-zone par 5º de latitude et 5º de longitude et effets de la prise accessoire du thon obèse, de l'albacore et de l'espadon comme facteurs de préoccupation. Les tendances de la CPUE, à la fois annuelles et trimestrielles, ainsi obtenues ont indiqué que l'abondance en nombre de la zone la plus appropriée de germons 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 2013. 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.

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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 bloques cuadrados de 5º, para determinar la distribución geográfica de cuatro especies principales de túnidos (atún blanco, patudo, rabil y pez espada) y se identificaron las subáreas de muestreo más adecuadas para obtener mejores índices de abundancia para el atún blanco. Este documento utilizaba solo los conjuntos de datos de las pesquerías de Taipei Chino dentro del área de muestreo propuesta 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. El área de muestreo más adecuada para el atún blanco del Atlántico sur identificada se extendía de 10ºS a 45ºS y de 55ºW a 20ºE, excluyendo el pequeño bloque en 10°S-15°S/10°W-15°E. En la zona de muestreo más adecuada para el atún blanco, se realizaron los índices de abundancia estandarizados para el atún blanco del Atlántico sur, entre 1967 y 2013, basándose en las estadísticas de captura y esfuerzo del palangre de Taipei Chino y utilizando un procedimiento GLM. Factores como el año, trimestre, subárea por 5º latitud x 5º longitud, efectos de captura fortuita de patudo, rabil y pez espada e interacciones, fueron utilizados para obtener la tendencia de la CPUE estandarizada anual desde 1967 hasta 2013. Se obtuvieron también las series de CPUE estandarizadas trimestralmente desde el tercer trimestre de 1967 hasta el tercer trimestre de 2013 utilizando series trimestrales, subáreas por 5º latitud x 5º longitud y efectos de captura fortuita de patudo, rabil y pez espada como factores de inquietud. Las tendencias de CPUE, tanto anuales como trimestrales, obtenidas así indicaban que la abundancia en número de la zona más adecuada del 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 2013. 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

CPUE standardization, albacore, longline, South Atlantic, GLM

Introduction

In the Atlantic Ocean, two stocks of albacore (*Thunnus alalunga*), separated by 5°N latitude, were assumed for the fishery management. Taiwanese 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. Taiwanese catch of South Atlantic albacore comprised of 70% or more of the total. 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.

Taiwanese 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 Task 2 data series compiled by Taiwanese 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.

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 Taiwanese 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 true albacore abundance. Undertaking this problem, as the first 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 2 (since 1967) data sets of Taiwanese 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 true albacore resource. This paper used only those Taiwanese 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.

Materials and methods

The logbooks data, aggregated by per vessel's year-monthly catch from 1981 to 2013, 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 Task 2 data.

The Task 2 data, aggregated by month and 5° statistical block from 1967 to 2013, were compiled. The logbook and Task 2 data were the major sources of data used in this analysis and provided by Overseas Fisheries Development Council of Taiwan. Nominal CPUE was defined as catch in number per 1,000 hooks.

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 Taiwanese longline fishery, distribution maps of the average of albacore CPUE, albacore catch, effort, proportion of catch by species, and amount of catch by species for each decadal period by Taiwanese longline fishery were used to examine.

A constant, which was obtained by averaging all Taiwanese 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 (Anon., 1997).

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:

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

where
LOG: natural logarithm;
$CPUE_{ijklmnop}$: nominal albacore CPUE (catch in number 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:

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

where
LOG: natural logarithm;

$CPUE_{iklmn}$: nominal albacore CPUE (catch in number 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. 9.3 statistical package was used in both cases to obtain solutions.

Results and discussion

The result of cluster analysis based on the logbook catches in weight of albacore, bigeye tuna, yellowfin tuna and swordfish from 1981 to 2013 showed a clear separation of 4 clusters (**Table 1**). Taiwanese 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 1-3** 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 2 data.

For elucidating geographical distribution characteristics of South Atlantic albacore resource, dating from 1967 to 2013, for each decadal period of geographic distribution map of averaging nominal albacore CPUE in number was shown in **Figure 4**. As shown in **Figure 4**, 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 5-8**, which was obtained exactly the same procedure used to obtain **Figure 4**. In **Figures 1-8**, 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 9**). 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 Taiwanese longline fishery.

A constant 2.44201781, which was obtained by averaging all Taiwanese longliners' nominal albacore CPUE reported from 1967 to 2013 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) 0-0.0297128, 0.0297128-0.2948911, 0.2948911-1.1042164, and greater than 1.1042164 for bigeye tuna; (2) 0, greater than 0 to 0.0518568, 0.0518568-0.3002336, and greater than 0.3002336 for yellowfin tuna; and (3) 0, greater than 0 to 0.0398601, 0.0398601-0.1513186, and greater than 0.1513186 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 9**), by 5° latitude x 5° longitude, were thus used in present study based on Taiwanese 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 42% 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 10**. The yearly standardized CPUE series showed a continuous decline from the beginning of the Taiwanese longline fishery to 1990, then increased till mid 1990s, and leveled off since early 2000s up to 2013. The normalized residual pattern from this model was shown in **Figure 11**. As shown in **Figure 11**, 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 12** 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 13**. 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 2013. 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 14**. As shown in **Figure 14**, 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 15** indicating the fitting was not far from normal distribution.

Comparisons were made visually as in **Figure 10** and **Figure 13** 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 proposed appropriate albacore sampling subareas appeared their own significance in this regard.

The proposed albacore area and subareas (**Figure 9**) were the main fishing ground of albacore for Taiwanese longline fishery, had own characteristics and represented meaning. The most appropriate albacore sampling subareas were proposed mainly for minimizing those non-targeting-albacore noises. We hope, through such manipulations, give a more persuasive resultant CPUE trend than current endeavors.

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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 from 1981 to 2013.

cluster	ALB_wt	BET_wt	YFT_wt	SWO_wt
1	61,610	1,113	745	495
2	3,331	4,671	1,185	586
3	28,238	1,023	703	430
4	372	22,450	2,312	1,357

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 Taiwanese longline fishery Task 2 data set from 1967 to 2013 by the GLM procedure.

Dependent Variable: Logcpuen_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	164	2392.99972	14.59146	46.72	<.0001
Error	10222	3192.72953	0.31234		
Corrected Total	10386	5585.72925			

R-Square	Coeff Var	Root MSE	Logcpuen_alb Mean
0.42841	18.24482	0.55887	3.06319

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	46	723.19954	15.72173	50.34	<.0001
quarter	3	73.49113	24.49704	78.43	<.0001
subarea	88	581.00121	6.60229	21.14	<.0001
codebet	3	170.48723	56.82908	181.95	<.0001
codeyft	3	15.70673	5.23558	16.76	<.0001
codeswo	3	85.23568	28.41189	90.96	<.0001
quarter*codebet	9	17.11357	1.90151	6.09	<.0001
quarter*codeyft	9	22.89302	2.54367	8.14	<.0001

Table 3. Analysis of variance on standardizing South Atlantic albacore (in the most appropriate albacore area) quarterly CPUE using Taiwanese longline fishery Task 2 data set from 1967 to 2013 by the GLM procedure.

Dependent Variable: Logcpuen_alb

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	282	2552.87488	9.05275	30.16	<.0001
Error	10104	3032.85437	0.30016		
Corrected Total	10386	5585.72925			

R-Square	Coeff Var	Root MSE	Logcpuen_alb Mean
0.45704	17.88568	0.54787	3.06319

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yq	185	1018.69723	5.50647	18.34	<.0001
subarea	88	585.22675	6.65030	22.16	<.0001
codebet	3	158.00787	52.66929	175.47	<.0001
codeyft	3	16.02275	5.34092	17.79	<.0001
codeswo	3	86.36924	28.78975	95.91	<.0001

Table 4. Yearly nominal and standardized CPUE trends of the most appropriate South Atlantic albacore area based on Taiwanese longline fishery Task2 data set from 1967-2013 by the GLM procedure.

Year	Nominal CPUE	Standardized CPUE
1967	61.7855	55.9131
1968	76.7870	48.8746
1969	49.7227	43.6831
1970	40.7257	35.0259
1971	52.1412	39.8361
1972	37.6298	26.3649
1973	30.5103	20.8817
1974	30.8229	21.3968
1975	37.6286	26.8077
1976	29.4302	28.8829
1977	35.7796	30.0502
1978	36.3138	27.0249
1979	31.7434	25.2104
1980	32.7988	23.6207
1981	28.8751	19.6396
1982	29.7169	18.6988
1983	28.8564	19.2493
1984	31.0394	22.7121
1985	30.3395	20.1981
1986	32.0526	19.0030
1987	24.5143	17.0924
1988	19.7825	12.5031
1989	17.2731	11.8615
1990	20.6147	11.9261
1991	16.9429	12.3851
1992	20.7895	13.4700
1993	20.1504	14.4005
1994	23.7536	17.8371
1995	27.9051	20.2266
1996	33.2481	20.3963
1997	33.9832	22.1840
1998	29.8200	18.4930
1999	22.2509	14.4652
2000	18.9327	12.0397
2001	20.8074	15.8190
2002	16.7972	11.4352
2003	15.1594	9.2764
2004	21.2218	12.7613
2005	18.6753	15.4769
2006	20.5751	12.5938
2007	33.0420	15.6244
2008	34.2312	16.8175
2009	34.3899	17.1644
2010	33.8952	19.3530
2011	28.9001	16.1779
2012	31.7045	16.7004
2013	33.8805	17.0437

Table 5. Quarterly nominal and standardized CPUE trends of the most appropriate South Atlantic albacore area based on Taiwanese longline fishery Task 2 data set from 1967-2013 by the GLM procedure.

Year*Quarter	Nominal CPUE	Standardized CPUE
19673	68.3534	72.5423
19674	33.0978	37.8319
19681	48.3562	28.5160
19682	95.1866	92.7943
19683	74.7689	70.4199
19684	20.1515	19.8775
19691	46.9704	38.2130
19692	65.8489	39.4176
19693	51.2747	49.1323
19694	38.6070	44.0679
19701	41.6529	30.8778
19702	63.2955	42.1371
19703	50.5817	47.6952
19704	22.7427	27.6987
19711	27.9245	31.6209
19712	78.9655	56.1016
19713	67.4839	58.5494
19714	24.9188	28.3565
19721	34.9377	30.5154
19722	47.4561	33.3180
19723	39.5363	28.2617
19724	17.3479	20.1688
19731	29.4694	17.0164
19732	43.0245	35.2798
19733	32.8474	26.1768
19734	15.2381	15.1757
19741	23.5790	16.2882
19742	38.7744	25.4749
19743	37.5847	29.5870
19744	18.0869	18.9172
19751	33.1953	25.4092
19752	54.3039	37.5955
19753	41.1296	32.1389
19754	18.0238	19.9838
19761	26.8411	24.8466
19762	39.2063	38.8196
19763	31.7523	36.8276
19764	16.0428	21.6583
19771	30.5806	27.8893
19772	44.9194	41.9125
19773	37.7882	32.1802
19774	22.3205	25.1759
19781	32.4857	24.1149
19782	44.0140	32.7435
19783	36.2249	28.1558
19784	24.9337	27.6728
19791	29.9376	24.9876
19792	39.0429	26.0325
19793	30.0259	26.0767
19794	22.8028	25.9389
19801	33.6553	23.9336
19802	44.6783	28.4747
19803	29.9714	23.1589
19804	22.2588	23.6604
19811	30.9191	22.0127
19812	38.9565	25.4461
19813	29.8584	20.6855
19814	15.7370	14.7727
19821	29.8442	22.0663
19822	41.0364	23.9685
19823	25.6739	19.4024
19824	14.2239	12.6727
19831	24.9659	16.8480
19832	37.2901	21.3570
19833	30.9674	22.6998
19834	18.5986	20.2130
19841	26.8225	22.6479
19842	54.2116	35.9884
19843	31.2735	22.2707
19844	18.8697	17.9539
19851	28.8621	20.5417
19852	39.6748	26.5297
19853	31.7002	21.0596
19854	15.4914	16.8017
19861	31.9921	19.6396
19862	41.8987	24.1430
19863	29.8827	21.5054
19864	14.7266	14.6998
19871	25.8926	18.2373
19872	30.1874	20.7630
19873	21.7751	17.3359
19874	14.1550	14.5633
19881	17.2680	10.6650
19882	24.0039	16.6937
19883	18.3505	13.5576
19884	16.5717	16.8529
19891	16.9126	12.4750
19892	21.0579	11.3738
19893	19.3040	16.7913
19894	11.0707	10.1627
19901	14.1132	12.1053
19902	29.9281	16.1331
19903	19.7102	13.2059
19904	12.4467	7.2300
19911	15.4684	12.0004
19912	18.4586	11.6799
19913	17.3632	15.0515
19914	16.1834	12.4475
19921	16.5662	12.9841
19922	25.3125	18.7254
19923	21.6478	15.3250
19924	16.1443	7.4827
19931	16.5304	6.7066
19932	26.7889	20.3451
19933	26.3991	17.3083
19934	15.5165	14.3968
19941	23.2696	18.4110
19942	30.5066	20.4867
19943	19.5670	18.5880
19944	14.0789	15.7641
19951	33.6908	23.2676
19952	39.0167	25.7704
19953	24.6083	18.4005
19954	22.2693	20.1044
19961	34.9624	19.7532
19962	38.2182	22.7826
19963	29.8488	21.1644
19964	27.8283	20.8730
19971	32.9948	21.0812
19972	40.9347	22.9237
19973	33.1754	25.7114
19974	24.2567	20.6816
19981	22.8556	19.2614
19982	39.5022	22.2984
19983	35.9976	21.2930
19984	14.6741	13.3768
19991	16.3133	12.3024
19992	28.6008	13.4181
19993	25.1533	17.8594
19994	15.8550	14.8198
20001	14.2752	10.7915
20002	25.9822	12.3640
20003	19.5659	13.8853
20004	14.6042	13.5695
20011	18.7631	16.6012
20012	26.2955	12.5722
20013	23.9487	19.8974
20014	13.5624	15.3784
20021	15.4970	13.9751
20022	20.3267	10.4847
20023	15.7938	11.4183
20024	14.5371	12.4068
20031	11.3261	9.0871
20032	21.4174	9.7337
20033	15.5625	12.6834
20034	11.0408	6.6201
20041	10.4060	9.4222
20042	46.0404	18.0365
20043	26.7678	20.1888
20044	15.4266	7.6510
20051	14.3752	14.4415
20052	26.4455	15.0656
20053	22.9443	17.0087
20054	12.1185	16.0341
20061	17.3311	12.2856
20062	29.5507	15.4764
20063	18.9243	15.1915
20064	9.4103	9.1895
20071	19.8220	10.2677
20072	52.6191	27.3006
20073	35.3441	22.6051
20074	12.1358	10.5345
20081	20.6712	14.1377
20082	43.0692	20.4710
20083	36.7919	21.6668
20084	16.9734	11.4324
20091	22.3747	14.2453
20092	42.7449	18.8249
20093	43.0537	26.2257
20094	14.2717	13.4141
20101	23.4036	14.3754
20102	42.9633	20.8985
20103	39.8192	31.4225
20104	19.7439	15.7555
20111	20.9524	14.1714
20112	38.0728	22.6031
20113	29.5586	18.7930
20114	12.8661	11.1759
20121	30.7344	12.4399
20122	35.0484	20.3411
20123	35.8249	25.4420
20124	13.0792	13.9363
20131	27.4892	12.5028
20132	41.9379	23.9031
20133	31.3854	21.5223

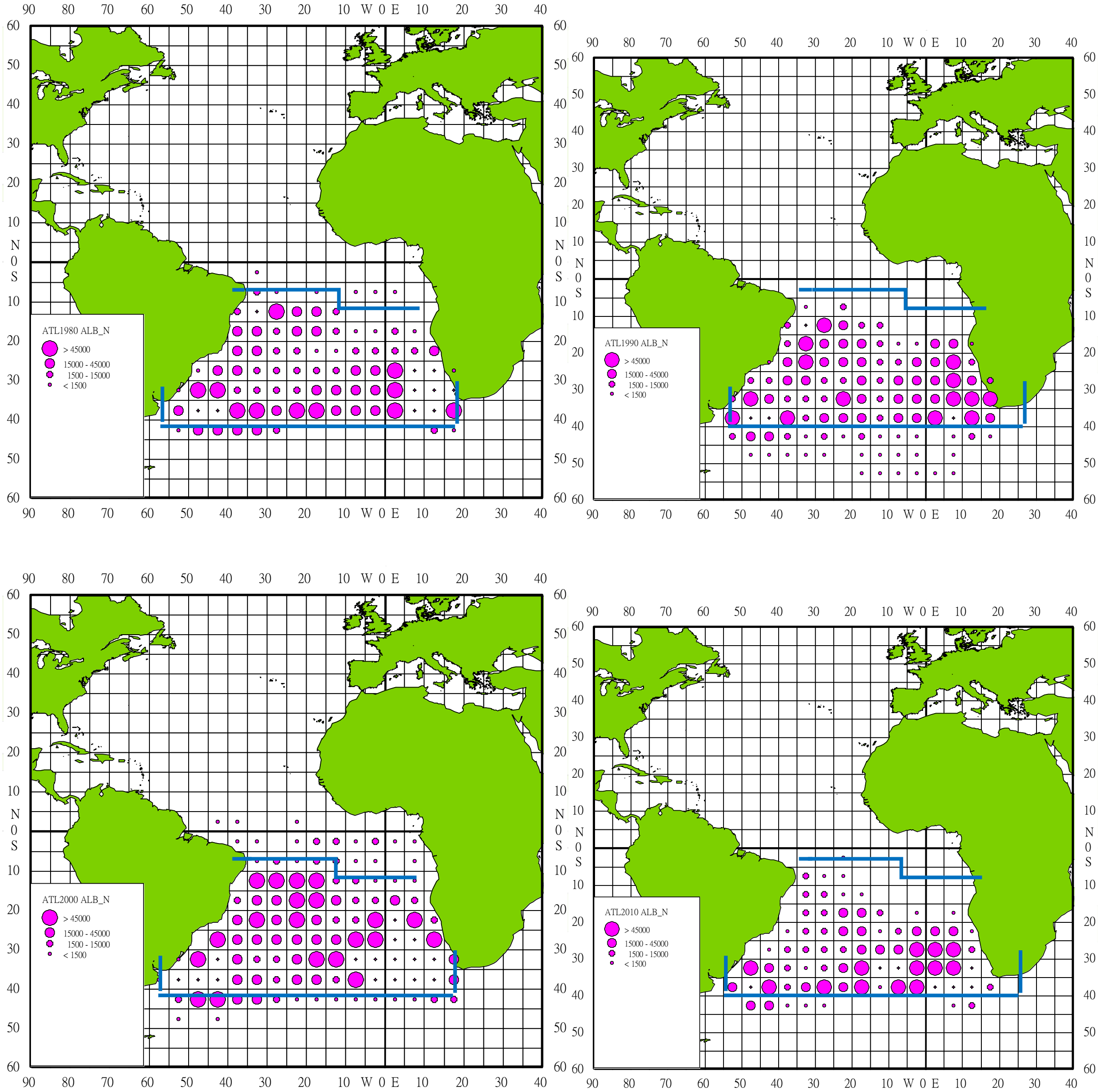

Figure 1. Geographic distribution, by 5^{o}-square block, of catch in number (from logbooks) of albacore caught by Taiwanese longliners in the South Atlantic Ocean for periods of 1981-1989 (Upper-Left), 1990-1999 (Upper-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower-Right).

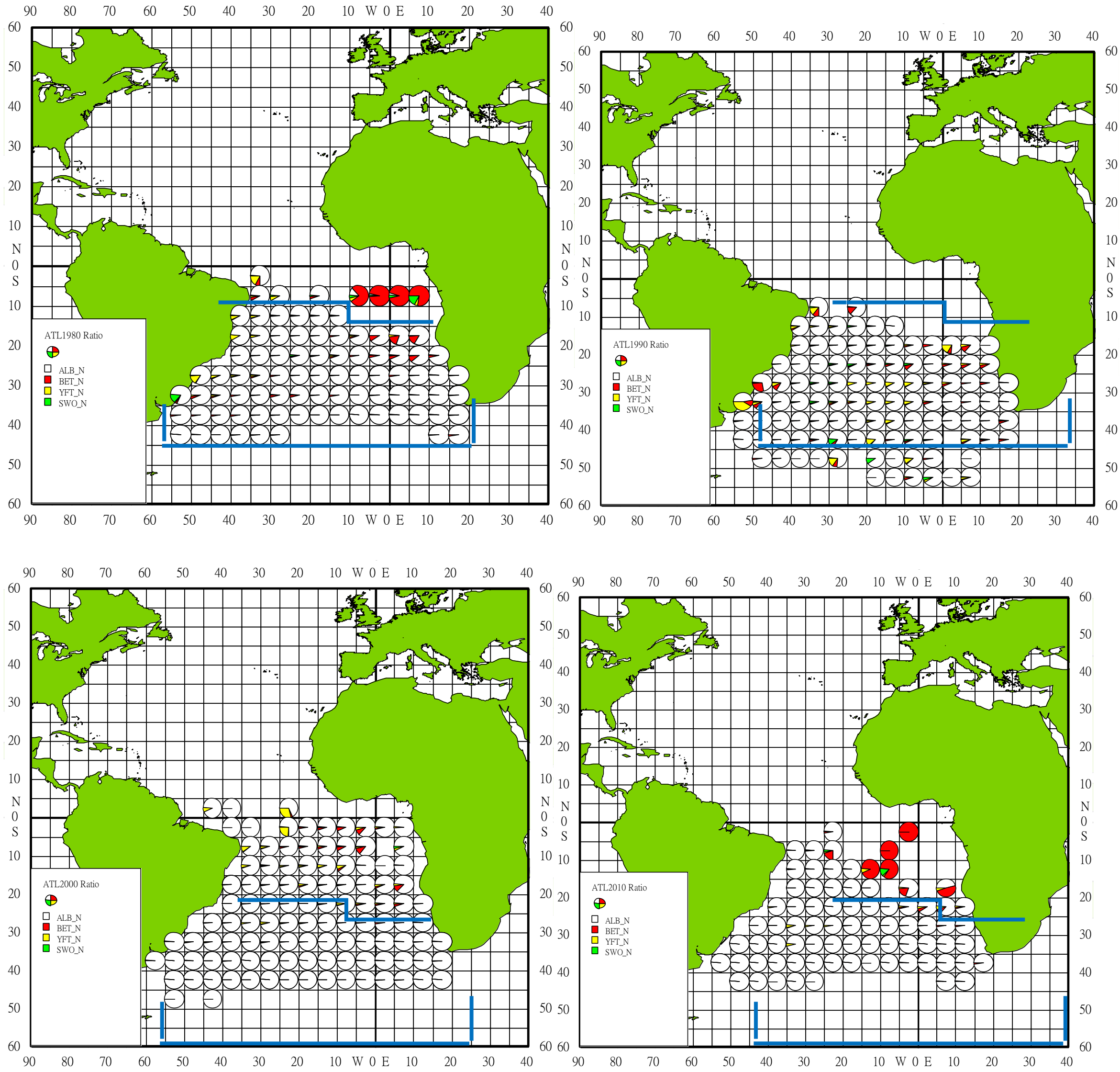

Figure 2. Geographic distribution, by 5º-square block, of four major species composition, in terms of catch in number (from logbooks), caught by Taiwanese longliners in the South Atlantic Ocean for periods of 1981-1989 (Upper-Left), 1990-1999 (Upper-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower- Right). Four major species are: albacore (ALB in white), bigeye tuna (BET in red), yellowfin tuna (YFT in yellow) and swordfish (SWO in green).

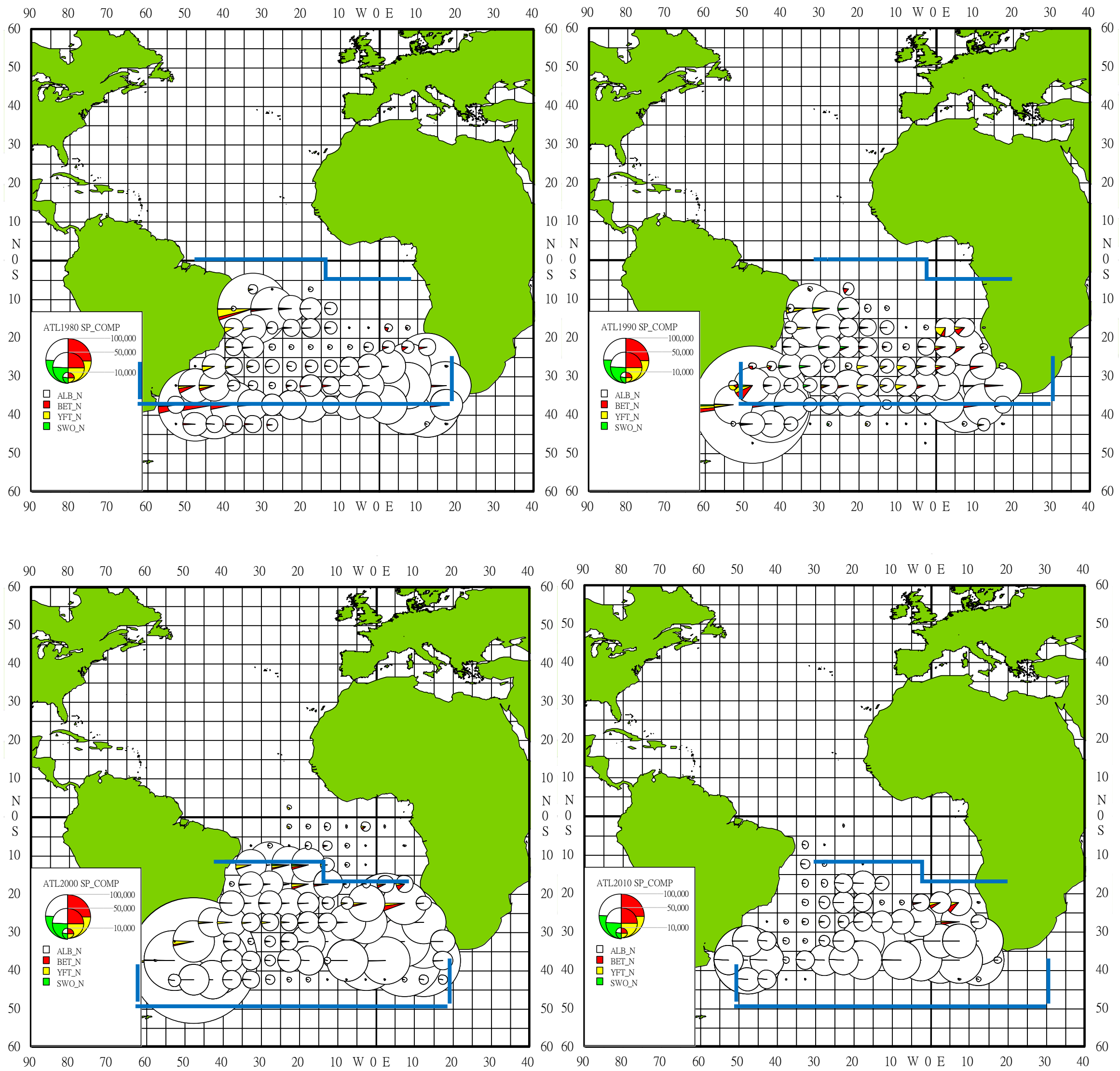

Figure 3. Geographic distribution, by 5o-square block, of catch in number of four major species (from logbooks), caught by Taiwanese longliners in the South Atlantic Ocean for periods of 1981-1989 (Upper-Left), 1990-1999 (Upper-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower-Right). Four major species are: albacore (ALB in white), bigeye tuna (BET in red), yellowfin tuna (YFT in yellow) and swordfish (SWO in green).

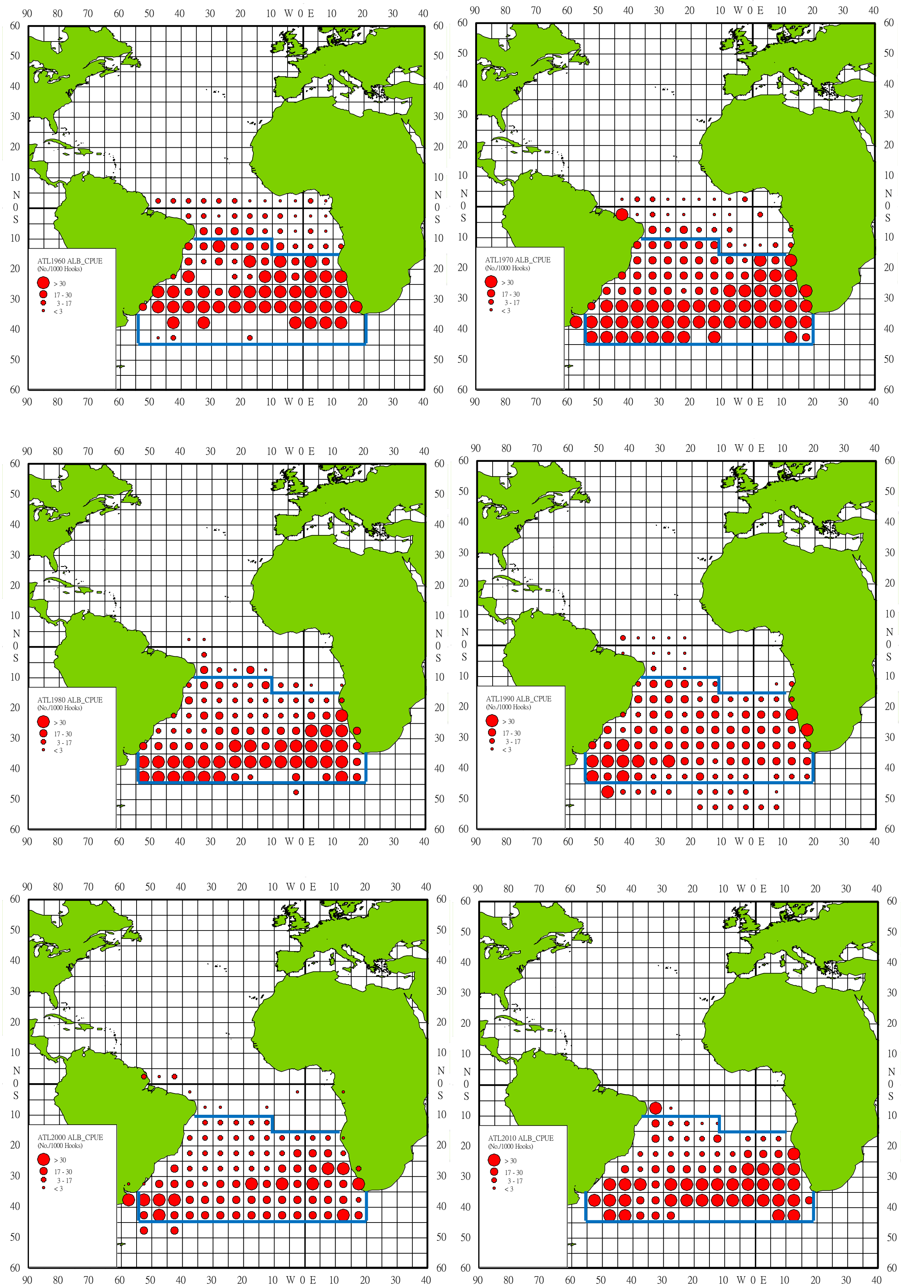

Figure 4. Yearly nominal CPUE (No./1000 Hooks from Task 2) of albacore caught by Taiwanese longliners in the South Atlantic Ocean for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower-Right).

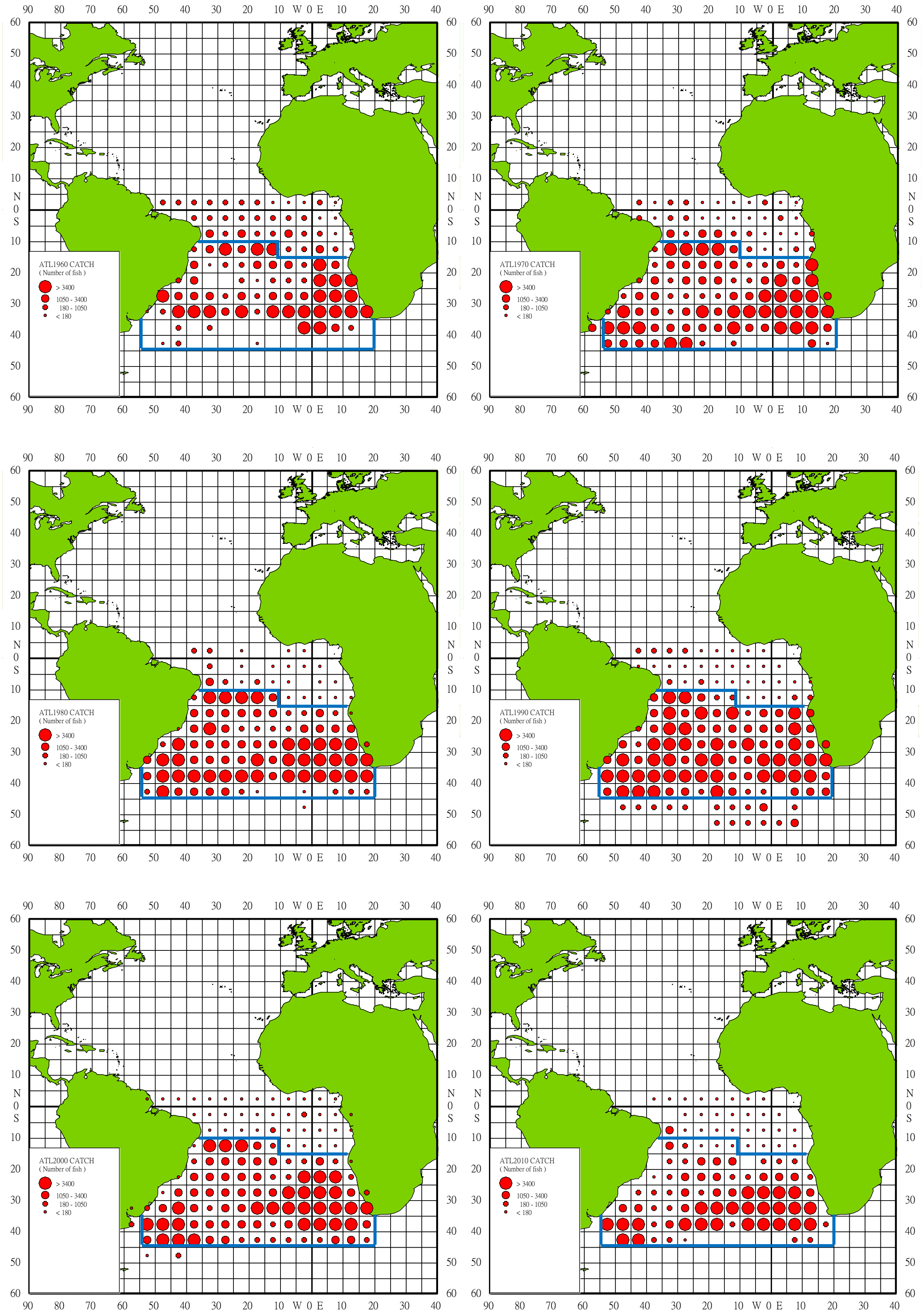

Figure 5. Yearly catch in number (from Task 2) of albacore caught by Taiwanese longliners in the South Atlantic Ocean for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower-Right).

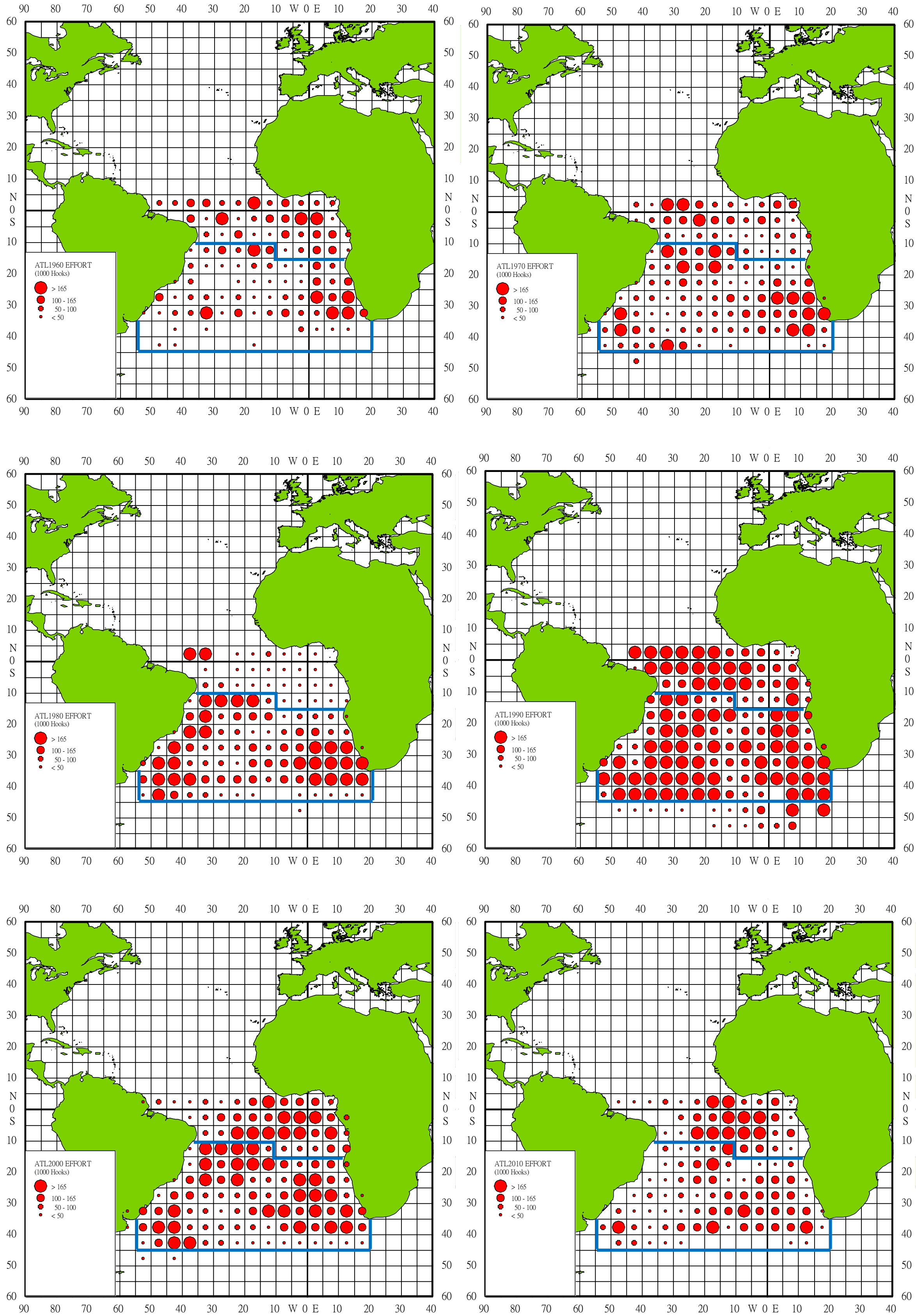

Figure 6. Yearly fishing efforts (Number of hooks from Task 2) cast by Taiwanese longliners in the South Atlantic Ocean for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower-Right).

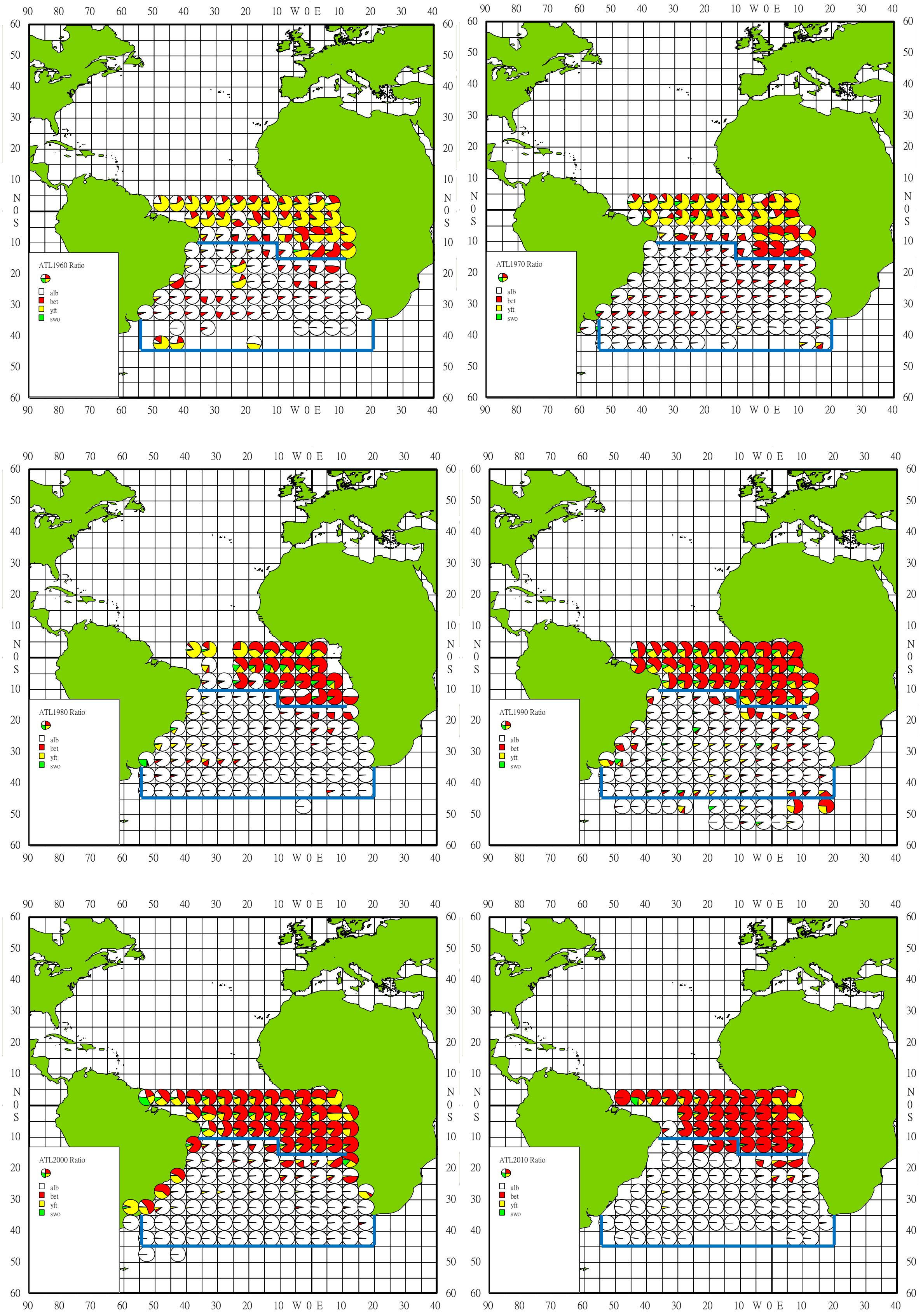

Figure 7. Geographic distribution of yearly four major species composition (from Task 2) caught by Taiwanese longliners for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower-Right).

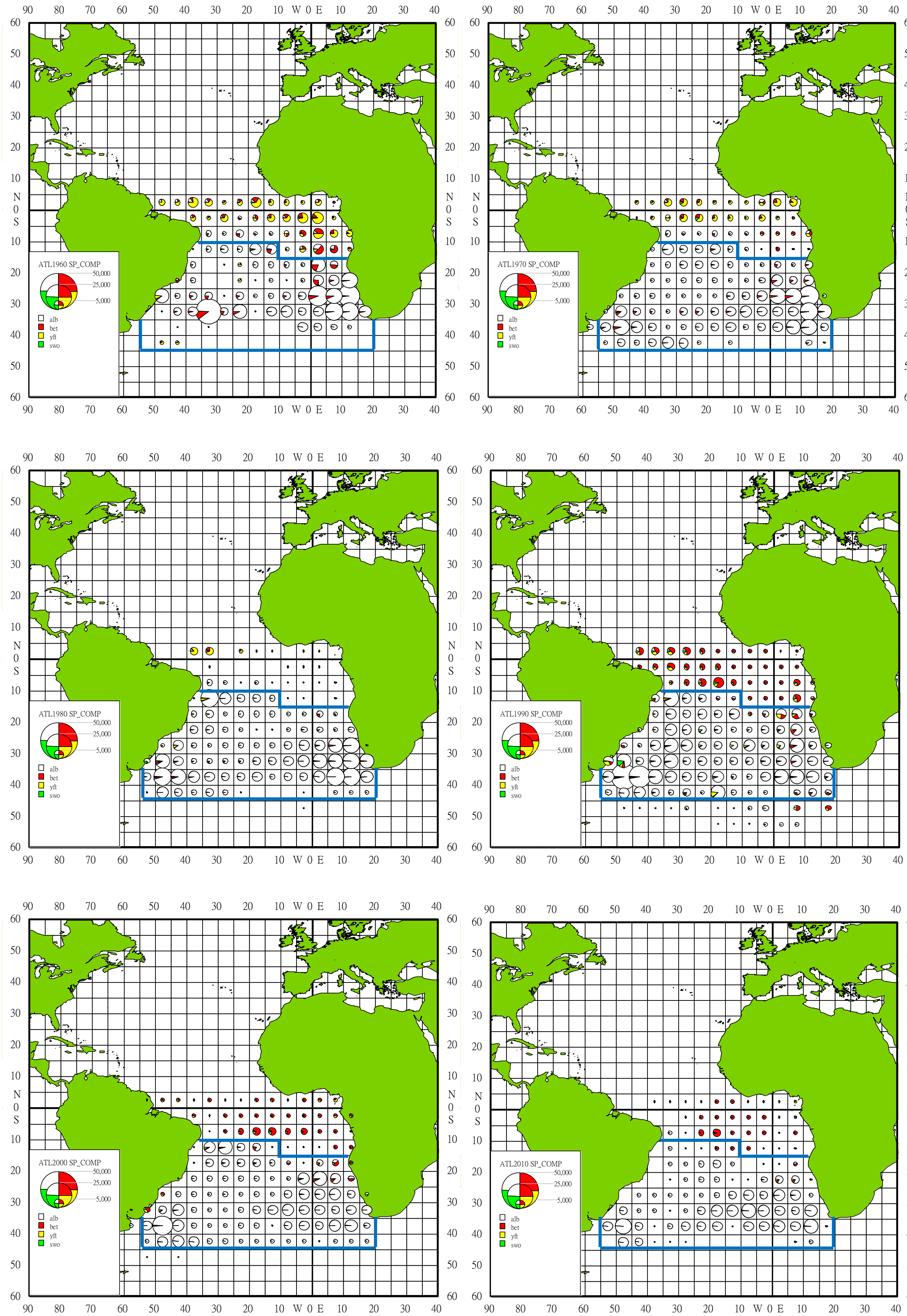

Figure 8. Geographic distribution of yearly catch composition of four major species (from Task 2) caught by Taiwanese longliners for periods of 1967-1969 (Upper-Left), 1970-1979 (Upper-Right), 1980-1989 (Mid-Left), 1990-1999 (Mid-Right), 2000-2009 (Lower-Left), and 2010-2013 (Lower-Right).

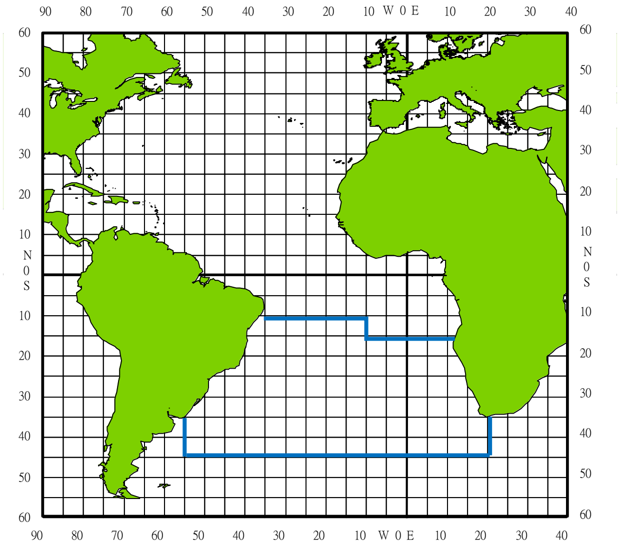

Figure 9. The 89, by 5o-square block, subareas (encircled by blue lines) thus proposed by this paper for CPUE standardization on albacore resource in the South Atlantic Ocean.

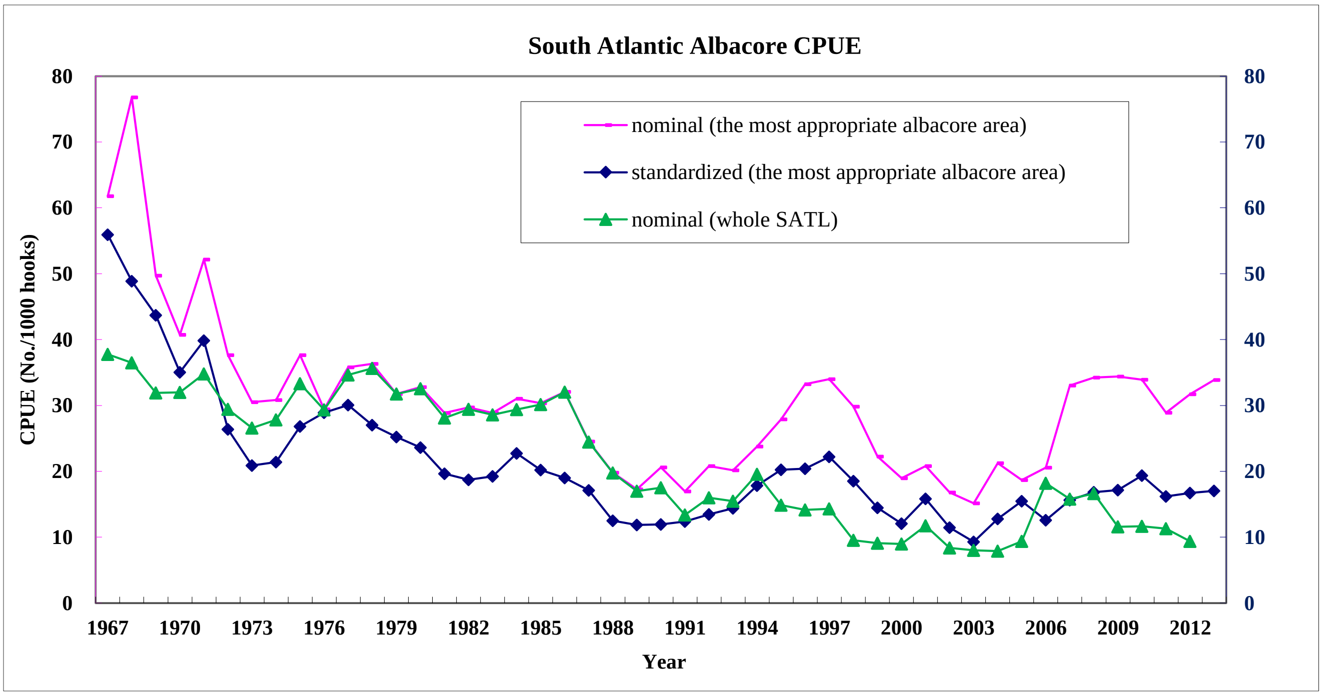

Figure 10. Yearly nominal and standardized CPUE (No./1000 Hooks) trends of South Atlantic albacore based on Taiwanese longline fishery Task 2 data set from 1967 to 2013.

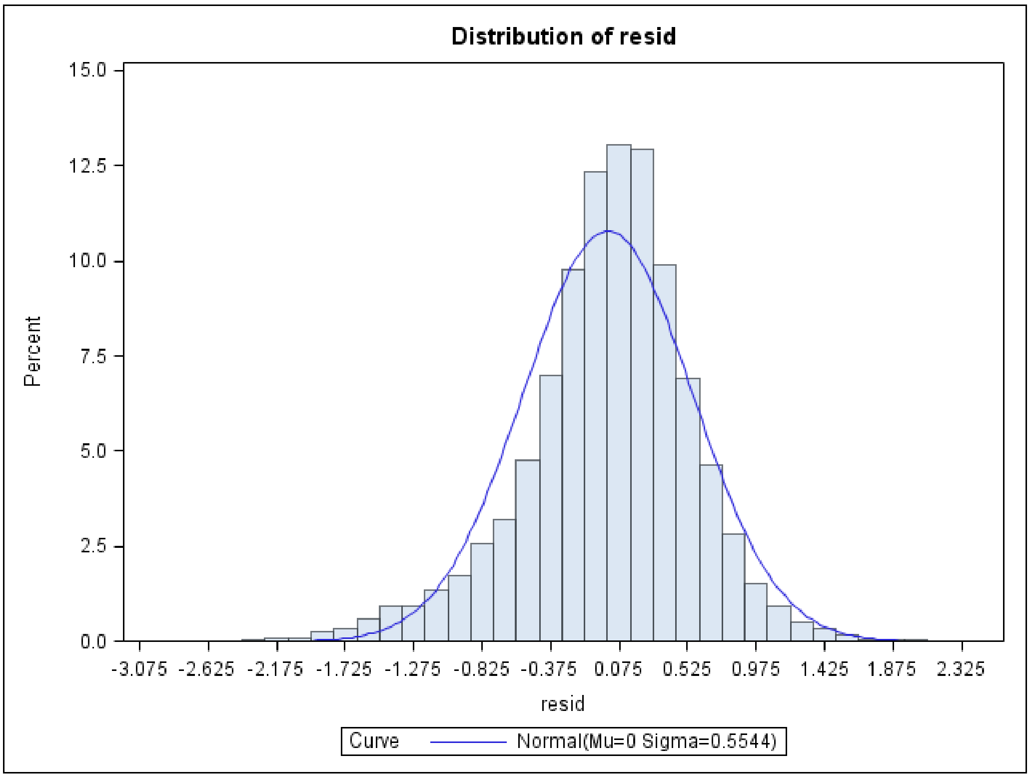

Figure 11. Distribution of normalized residual obtained from yearly GLM model.

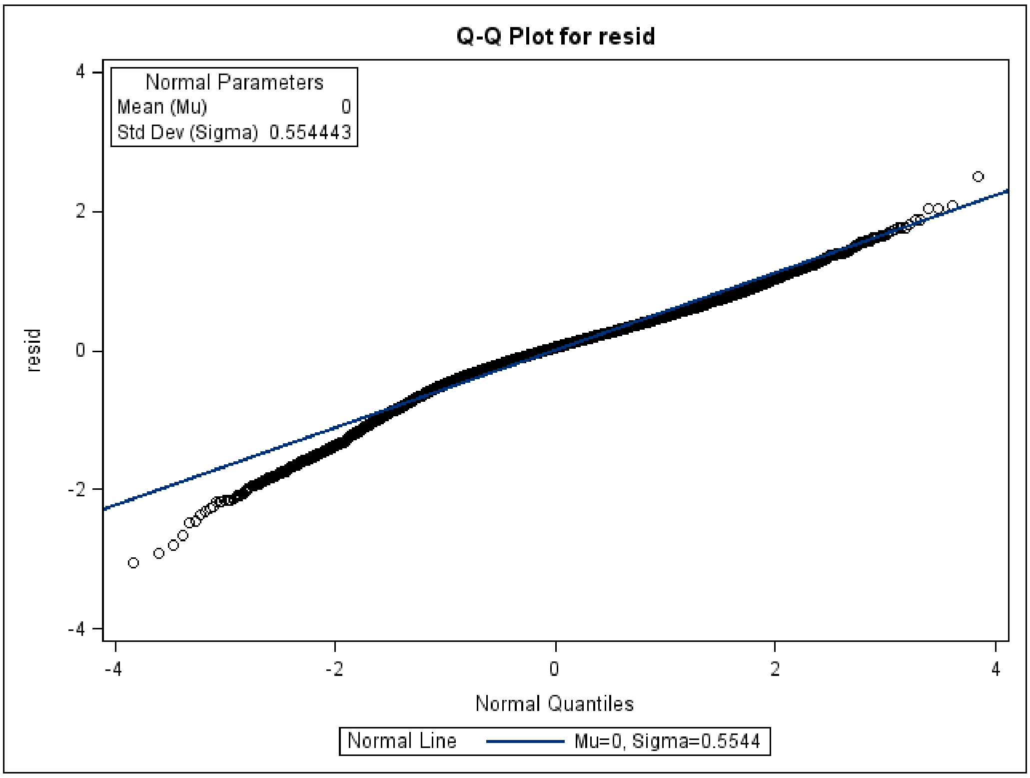

Figure 12. The Q-Q plot for residuals obtained from yearly GLM model.

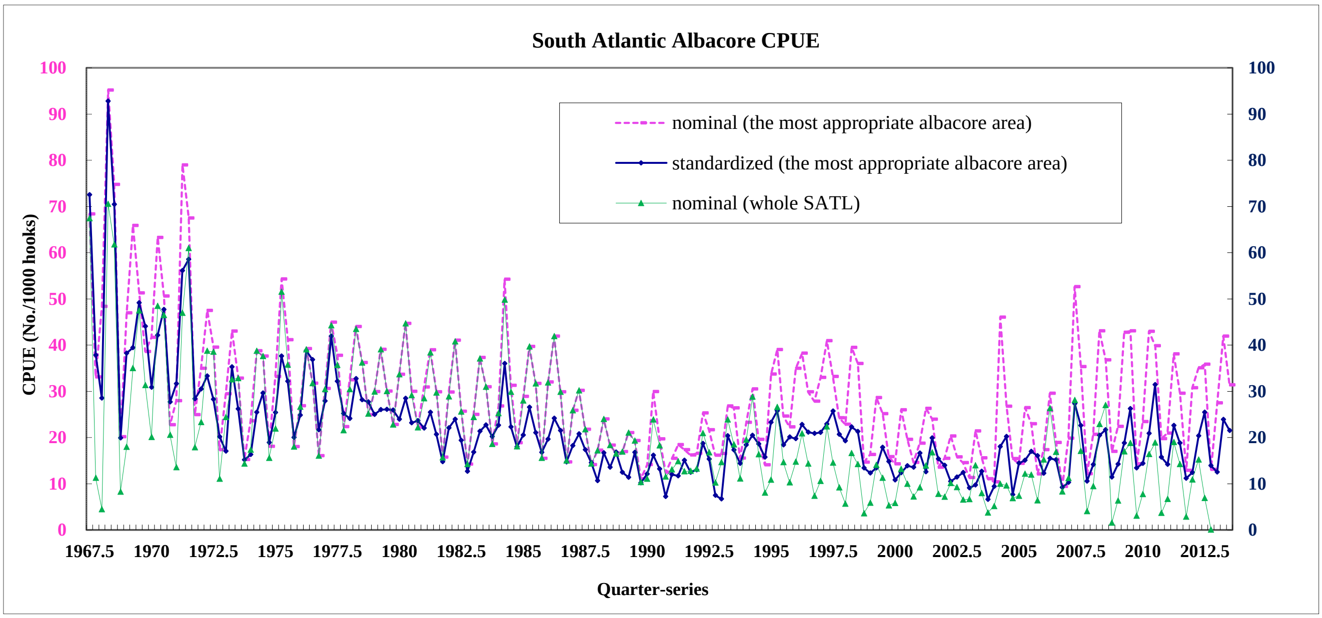

Figure 13. Quarterly nominal and standardized CPUE (No. /1000 Hooks) trends of South Atlantic albacore based on Taiwanese longline fishery Task 2 data set from 1967 to 2013.

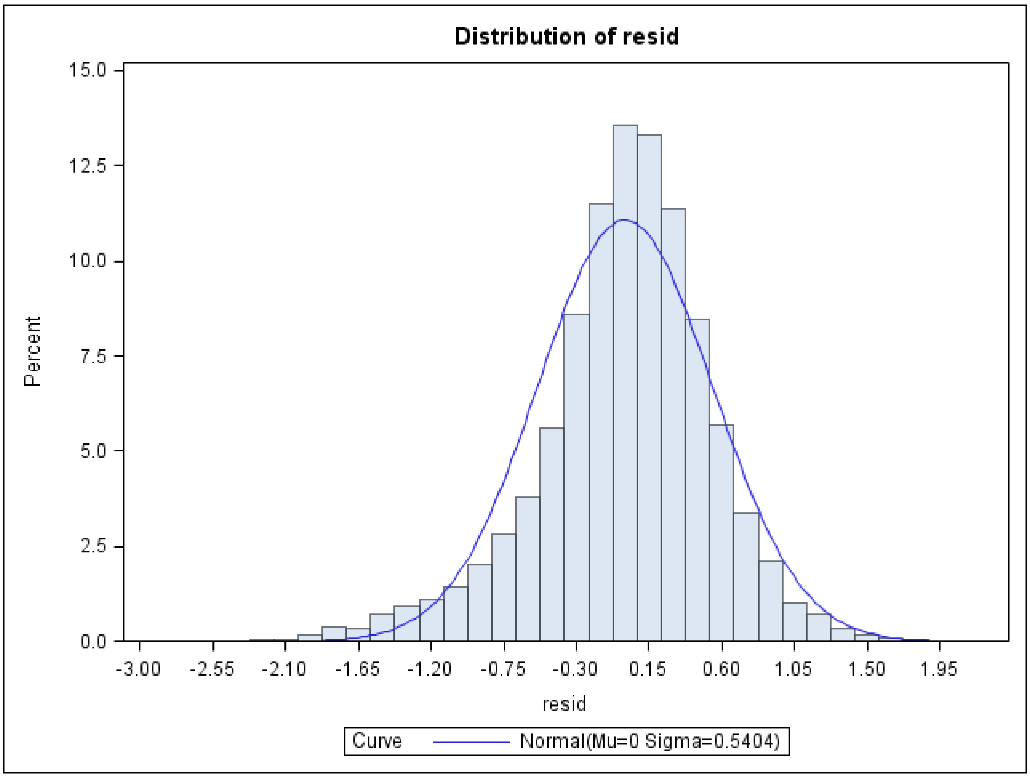

Figure 14. Distribution of normalized residual obtained from quarterly GLM model.

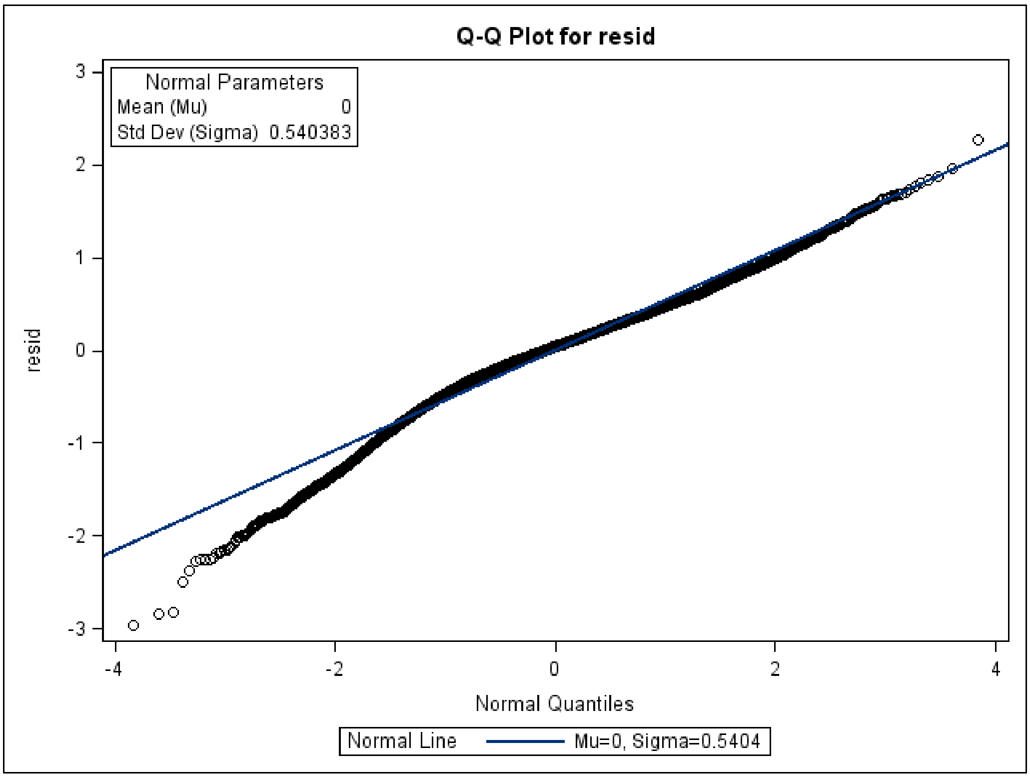

Figure 15. The Q-Q plot for residuals obtained from quarterly GLM model.