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STANDARDIZED NORTHERN ATLANTIC ALBACORE (*THUNNUS ALALUNGA*) CPUE, FROM 1967 TO 2005, BASED ON TAIWANESE LONGLINE CATCH AND EFFORT STATISTICS

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SUMMARY

Nominal catch per unit effort (number of fish caught per thousand hooks) of north Atlantic albacore (Thunnus alalunga) *compiled from Taiwanese longliners from 1967 to 2005 was used to elucidate the historic abundance fluctuations of this resource by generalized linear model (GLM) procedure. Three subareas are identified thus used in this study. Both yearly and quarterly standardization procedure were carried out in this study. Yearly and quarterly standardized CPUE series from the 3rd quarter of 1967 to the 4th quarter of 2005 were also obtained by using quarter-series, subarea, bycatch effects of bigeye tuna, yellowfin tuna, and swordfish as factors of concern. The standardized yearly CPUE series shows a continuous decline of CPUE from mid 1980s to 2001. The CPUE went up gradually until 2002.*

RÉSUMÉ

*La capture nominale par unité d'effort (nombre de poissons capturés pour mille hameçons) du germon de l'Atlantique Nord (*Thunnus alalunga*) compilée à partir des palangriers du Taïpei chinois, de 1967 à 2005, a été utilisée pour élucider les fluctuations historiques de l'abondance de cette ressource au moyen de la procédure de modèle linéaire généralisé (GLM). Trois sous-zones ont été identifiées et utilisées dans la présente étude. Une procédure de standardisation annuelle et trimestrielle a été menée à bien dans cette étude. Des séries de CPUE standardisée annuellement et trimestriellement du 3ème trimestre de 1967 au 4ème trimestre de 2005 ont également été obtenues en utilisant des effets de trimestre-série, sous-zone, prise accessoire du thon obèse, de l'albacore et de l'espadon comme facteurs présentant un intérêt particulier. La série de CPUE standardisée annuellement dégage une baisse continue de la CPUE depuis le milieu des années 1980 jusqu'en 2001. La CPUE a graduellement augmenté jusqu'en 2002.*

RESUMEN

*La captura por unidad de esfuerzo nominal (número de peces capturados por mil anzuelos) del atún blanco del Atlántico norte (*Thunnus alalunga*) recopilada en los palangreros de Taipei Chino desde 1967 hasta 2005 se utilizó para deducir las fluctuaciones en la abundancia histórica de este recurso mediante un procedimiento de modelo lineal generalizado (GLM). Se identifican tres subáreas que se utilizan en este estudio. En este estudio se llevaron a cabo procedimientos de estandarización tanto anuales como trimestrales. Se obtuvieron también series de CPUE estandarizadas anuales y trimestrales desde el 3er trimestre de 1967 hasta el 4º trimestre de 2005 utilizando series trimestrales, subárea, y efectos de la captura fortuita de patudo, rabil y pez espada como factores de inquietud. Las series de CPUE estandarizadas anualmente muestran un descenso continuo de la CPUE desde mediados de los 80 hasta 2001. La CPUE aumentó gradualmente hasta 2002.*

KEYWORDS

Catch per unit effort, albacore, abundance

1. Introduction

In the Atlantic Ocean, two stocks of albacore (*Thunnus alalunga*), separated by 5° N latitude, were assumed for the fishery management. To northern Atlantic albacore, Taiwan is one of the fishing nations that utilized this

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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 composed mainly of two types of fishing gears, i.e., regular longliner and deep longliner. The regular longliner, which is also called traditional longliner, is mainly targeting on albacore. Since the mid-1980s, deep longliner equipped with -70ºC freezing capability emerged and mainly targeting on bigeye and yellowfin tunas. Unfortunately, it was not until mid-1990s when the logbook reporting system was able to distinguish their major identity by the addition of "the number of hooks per basket used" in new reporting logbook. Historic task2 data series compiled by Taiwanese Fisheries Managerial Sector and reported to the ICCAT since late-1960s thus become one of the important data sources to investigate the long-term abundance fluctuation of this resource.

The main purposes of this study were thus to standardize the North Atlantic albacore abundance indices, based on Taiwanese 1967-2005 task2 data series, by using Generalized Linear Models (GLM) with identifiable factors as year, quarter, fishing locations, by-catch information for the purpose of minimizing the aforementioned incompatibility may have aroused in the data set, which were collected over a rather vast area-time-fishery spectra.

2. Materials and methods

The task2 data, aggregated by month and by 5° statistical block from 1967 to 2005 in this paper, were provided by Overseas Fisheries Development Council. CPUE is defined as the catch in number per 1,000 hooks.

Three subareas used in the models were shown in **Figure 1** (Yang and Yeh, 2004). The character of subareas from the data set reflects that subarea-1 is the main fishing areas of albacore, subarea-3 for bigeye tuna, and subarea-2 for a mixing areas of albacore and bigeye tuna.

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 north Atlantic albacore. Factors used in the yearly standardization are year, quarter, subarea, the effect of by-catch, including bigeye tuna and yellowfin tuna. Factors used in the quarterly standardization, however, are quarter-series, subarea, the effect of by-catch, including bigeye tuna and yellowfin tuna. The nominal CPUE values of those by-catch species were calculated and coded by quartile. GLM models thus constructed for both yearly and quarterly standardizations are as follows:

Yearly generalized linear model with normal error structure:

$$Log\ (U_{ijklm} + C) = \mu + Y_i + Q_j + A_k + BE_l + YF_m + \varepsilon_{ijklm}$$

where *Log*: natural logarithm;

U_{ijklm} : nominal CPUE (catch in number per 1000 hooks) in year (*i*), quarter (*j*), subarea (*k*), bigeye tuna (*l*) and yellowfin tuna(*m*)

μ : intercept, or overall mean for correction

C: a constant, C =1.48, 10% of the overall mean albacore nominal CPUE

Y_i: the effect of the *i* year

Q_j: the effect of the *j* quarter

A_k: the effect of the *k* subarea;

BE_l: the bycatch effect of bigeye tuna by the quantiles of CPUE (no./1000hs)

(BE_l=1 when BE_l <=0.07, BE_l=2 when BE_l between 0.7 and 0.39, BE_l=3 when BE_l between 0.39 and 2.79, BE_l=4 when 2.79<= BE_l)

YF_m: the bycatch effect of yellowfin tuna by the quantiles of CPUE (no./1000hs)

(YF_m=1 when YF_m <=0.1, YF_m=2 when YF_m between 0.1 and 0.49, YF_m=3 when YF_m between 0.49 and 1.74, YF_m=4 when 1.74<= YF_m)

ε :: error term assumed normal distribution as $N(0,\sigma^2)$.

Quarterly generalized linear model with normal error structure:

$$Log\ (U_{jklm} + C) = \mu + YQ_j + A_k + BE_l + YF_m + \varepsilon_{jklm}$$

where *Log*: natural logarithm;

U_{jklm} : nominal CPUE (catch in number per 1000 hooks) in quarter-series (*i*), subarea (*k*), bigeye tuna (*l*) and yellowfin tuna(*m*)

μ : intercept, or overall mean for correction
C: a constant, C =1.48, 10% of the overall mean albacore nominal CPUE
YQ_j : the effect of the *j* quarter-series
A_k: the effect of the *k* subarea;
BE_l: the bycatch effect of bigeye tuna by the quantiles of CPUE (no./1000hs)
(where BE_l=1 when BE_l <=0.07, BE_l=2 when BE_l between 0.7 and 0.39, BE_l=3 when BE_l between 0.39 and 2.79, BE_l=4 when 2.79<= BE_l)
YF_m: the bycatch effect of yellowfin tuna by the quantiles of CPUE (no./1000hs)
(where YF_m=1 when YF_m <=0.1, YF_m=2 when YF_m between 0.1 and 0.49,YF_m=3 when YF_m between 0.49 and 1.74, YF_m=4 when 1.74<= YF_m)
ε :: error term assumed normal distribution as $N(0,\sigma^2)$.

All analyses are conducted by software, SAS. Factors are accepted as its statistical significance at $p<0.0001$. The reduced model is examined until all factors in the model are significant. **Tables 1** and **2,** and **Figures 4, 5, 7,** and **8.**

3. Results and discussion

3.1 Adding a constant in nominal CPUE

To solve the problem from the natural logarithm of zero albacore's catch rate, the constant 1.48, derived from 10% of the grand mean of albacore CPUE, was added to each nominal CPUE. The methodology on how to decide an appropriate adding constant during GLM analysis was discussed in Bluefin Species Group (ICCAT, 1996).

3.2 Geographical distributions

Figure 2 reveals the main distribution ocean of North Atlantic albacore. The subarea-1 is targeting on albacore, subarea-2 is the mixing area both albacore and bigeye tuna. The subarea-3 is targetting on bigeye tuna.

After the mid-1980s, some Taiwanese longliners equipped with super cold freezer and shifted their target species from albacore to the bigeye tuna, which inhabit the tropical waters. Moreover, the fishing efforts in the tropical waters increased on a large scale in recent decade to meet the demands of the sashimi market. Almost all efforts exerted in these waters can be considered as non-albacore-directed efforts, because albacore is the less expected catch species than bigeye tuna.

On the other hand, Yang and Yeh (2004) applied the cluster analysis to classify the North Atlantic Ocean into three subareas in relation to catch rates among the main tuna species caught. The results clearly demonstrated that the fishery structure of subarea-1 was quite different from the other two subarea-2 and subarea-3, which were the traditional albacore fishing grounds and the main distribution waters for the northern Atlantic Albacore. Subarea-3 was the main fishing ground for Taiwanese deep longline fleets for harvesting bigeye tuna. Thus, it can be concluded that in recent decade the increased efforts from subarea-3 were mostly exerted by deep longliners, which targeted on tropical tunas instead albacore.

3.3 Standardized catch per unit effort

The model was constructed by GLM procedure according to whether the standardized CPUE was estimated. The ANOVA results revealed that the main effects were significant at $p<0.0001$ levels. As the mean square for bigeye tuna was the highest than other main factors, it may suggest that the bigeye tuna has played an important role for Taiwanese longline fisheries. On the ANOVA result, it demonstrated that the effect of subareas accounted for some of the variations in the models. Because the fishing strategy is closely related with the fishing locality, an appropriate separation of subarea will be important.

In **Table 3** and **Figure 3**, the nominal CPUE and the standardized yearly CPUE, derived from the GLM procedure, are tabulated. The standardized CPUE series shows a continuous decline of CPUE from mid-1980s to 2001. The CPUE went up gradually until 2002.

Figures 4 and **7** show the standardized residual patterns by year (**Figure 4**) and by quarter series (**Figure 7**), generally showing normally distributed patterns, especially the distribution of standardized residual, which is concentrated around 0 and few below -1.65 that can be considered as outliers. **Figures 5** and **8** show the Q-Q plot of residuals by year (**Figure 5**) and by quarter series (**Figure 8**) demonstrate that a departure was found, indicating that there are some observed values out-lied.

Quarterly trend, as compared to its respective yearly trend, appeared a significant peak in the first quarter (**Figures 6** and **9**) per year implied a consistent recruitment pattern of this resource. Environmental effects as well as operation information of longline fisheries are expected to be included in the further analyses for stock assessment and fisheries management.

4. Acknowledgments

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Table 1. Analysis of variance of standardized yearly CPUE by GLM procedure comes from North Atlantic albacore data of Taiwanese longline fishery during 1967 to 2005 years.

The GLM Procedure
MODEL: $Log\ (U_{ijklm} + C) = \mu + Y_i + Q_j + A_k + BE_l + YF_m + \varepsilon_{ijklm}$
Dependent Variable: albacore *Log*(CPUE+1.48),(no./1000hs)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	49	6867.14678	140.14585	272.89	<.0001
Error	6689	3435.26099	0.51357		
Corrected Total	6738	10302.40777			

R-Square	C.V.	Root MSE	Mean
0.67	32.6	0.716637	2.197135

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	38	845.3952520	22.2472435	43.32	<.0001
season	3	132.1776445	44.0592148	85.79	<.0001
subarea	2	961.8301269	480.9150634	936.42	<.0001
bigeye tuna	3	331.2314168	110.4104723	214.99	<.0001
Yellowfin tuna	3	55.2888870	18.4296290	35.89	<.0001

Table 2. Analysis of variance of standardized quarterly CPUE by GLM procedure comes from North Atlantic albacore data of Taiwanese longline fishery during 1967 to 2005 years.

The GLM Procedure
MODEL: $Log\ (U_{ijklm} + C) = \mu + YQ_{ij} + A_k + BE_l + YF_m + \varepsilon_{ijklm}$
Dependent Variable: albacore *Log*(CPUE+1.48),(no./1000hs)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	161	7017.55059	43.58727	87.27	<.0001
Error	6577	3284.85718	0.49945		
Corrected Total	6738	10302.40777			

R-Square	C.V.	Root MSE	Mean
0.68	32.2	0.706715	2.197135

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year-season	153	1106.652049	7.233020	14.48	<.0001
subarea	2	861.251629	430.625815	862.21	<.0001
bigeye tuna	3	327.876490	109.292163	218.83	<.0001
yellowfin tuna	3	52.279175	17.426392	34.89	<.0001

Table 3. The standardized yearly CPUE and nominal yearly CPUE(Left), and the year-season standardized quarterly CPUE and nominal quarterly CPUE (Right) of North Atlantic albacore by GLM are from 1967 to 2005 years.

year	std. CPUE	nominal CPUE
1967	9.8	16.6
1968	12.5	18.6
1969	11.9	17.6
1970	9.7	16.8
1971	6.1	11.8
1972	6.8	19.1
1973	8.5	22.7
1974	8.3	20.3
1975	6.5	18.3
1976	8.7	27.1
1977	7.7	22.1
1978	8.1	22.2
1979	8.0	24.3
1980	8.9	24.0
1981	8.2	23.5
1982	8.8	26.1
1983	9.1	27.6
1984	7.9	23.3
1985	6.9	20.1
1986	5.5	16.7
1987	5.3	15.7
1988	11.6	26.4
1989	8.6	19.1
1990	5.4	4.8
1991	7.2	8.0
1992	5.6	3.8
1993	6.7	9.5
1994	4.6	12.1
1995	4.7	14.0
1996	3.1	8.9
1997	3.6	10.6
1998	4.1	11.5
1999	2.6	7.9
2000	2.5	6.1
2001	2.5	7.8
2002	2.6	6.0
2003	5.0	9.8
2004	4.1	6.9
2005	3.2	4.4

year - season	std. CPUE	year - season	std. CPUE	year - season	std. CPUE	year - season	std. CPUE
1967.3	6.2	1978.1	12.1	1988.3	12.1	1999.1	4.7
1967.4	11.1	1978.2	5.9	1988.4	11.3	1999.2	2.1
1968.1	13.4	1978.3	6.7	1989.1	12.9	1999.3	1.9
1968.2	11.8	1978.4	8.7	1989.2	7.4	1999.4	2.4
1968.3	11.7	1979.1	14.2	1989.3	9.1	2000.1	4.0
1968.4	11.9	1979.2	6.5	1989.4	7.8	2000.2	2.7
1969.1	13.4	1979.3	4.6	1990.1	8.9	2000.3	1.7
1969.2	7.2	1979.4	9.9	1990.2	5.9	2000.4	1.5
1969.3	11.8	1980.1	16.3	1990.3	3.6	2001.1	3.0
1969.4	15.9	1980.2	6.7	1990.4	5.1	2001.2	2.3
1970.1	12.6	1980.3	6.0	1991.1	7.8	2001.3	2.2
1970.2	9.3	1980.4	9.5	1991.2	8.1	2001.4	2.8
1970.3	9.5	1981.1	10.2	1991.3	5.9	2002.1	3.8
1970.4	7.6	1981.2	7.5	1991.4	7.2	2002.2	2.1
1971.1	9.3	1981.3	7.0	1992.1	5.9	2002.3	2.2
1971.2	6.1	1981.4	8.9	1992.2	6.6	2002.4	2.5
1971.3	4.1	1982.1	10.3	1992.3	4.1	2003.1	5.8
1971.4	5.2	1982.2	8.9	1992.4	5.2	2003.2	4.9
1972.1	10.3	1982.3	6.7	1993.1	3.9	2003.3	4.3
1972.2	4.6	1982.4	10.7	1993.2	6.8	2003.4	5.6
1972.3	4.8	1983.1	8.8	1993.3	7.8	2004.1	5.8
1972.4	9.7	1983.2	8.7	1993.4	5.5	2004.2	4.9
1973.1	12.3	1983.3	8.4	1994.1	4.4	2004.3	2.5
1973.2	6.3	1983.4	13.8	1994.2	3.4	2004.4	3.5
1973.3	7.5	1984.1	11.5	1994.3	5.7	2005.1	5.9
1973.4	9.3	1984.2	7.5	1994.4	4.9	2005.2	3.6
1974.1	10.8	1984.3	6.3	1995.1	4.8	2005.3	1.1
1974.2	7.6	1984.4	7.3	1995.2	4.0	2005.4	2.7
1974.3	6.1	1985.1	8.7	1995.3	7.1		
1974.4	10.2	1985.2	7.5	1995.4	3.8		
1975.1	8.9	1985.3	4.7	1996.1	4.3		
1975.2	4.6	1985.4	8.1	1996.2	2.9		
1975.3	5.4	1986.1	7.0	1996.3	2.9		
1975.4	10.0	1986.2	5.0	1996.4	2.3		
1976.1	14.2	1986.3	5.2	1997.1	4.9		
1976.2	7.9	1986.4	5.1	1997.2	3.7		
1976.3	4.3	1987.1	5.8	1997.3	2.6		
1976.4	10.6	1987.2	4.5	1997.4	3.3		
1977.1	9.2	1987.3	6.2	1998.1	3.9		
1977.2	9.5	1987.4	6.5	1998.2	3.8		
1977.3	6.6	1988.1	12.9	1998.3	4.3		
1977.4	7.0	1988.2	11.1	1998.4	4.2		

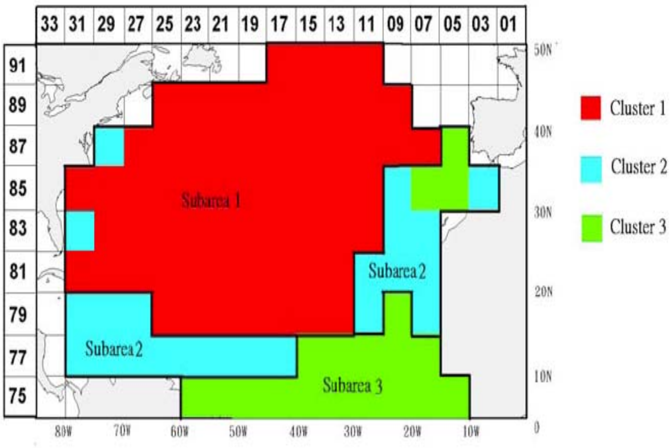

Figure 1. Map shows the definition of subarea in the North Atlantic used in the GLM analysis in this analysis.

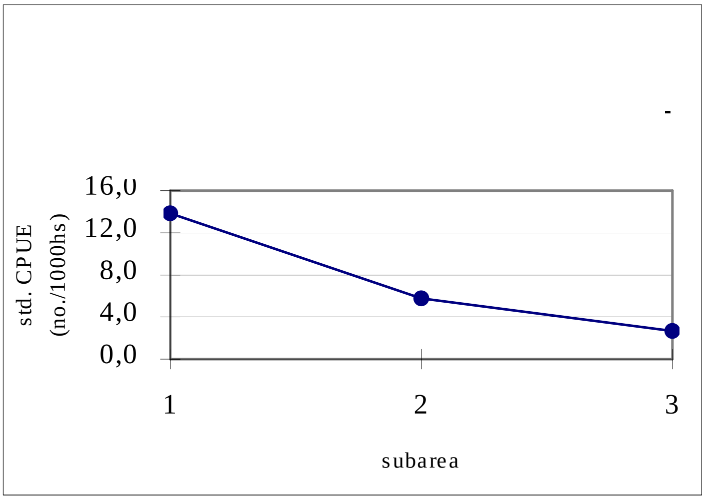

Figure 2. Standardized CPUE of North Atlantic albacore in subarea 1-3 by GLM, from 1967 to 2005.

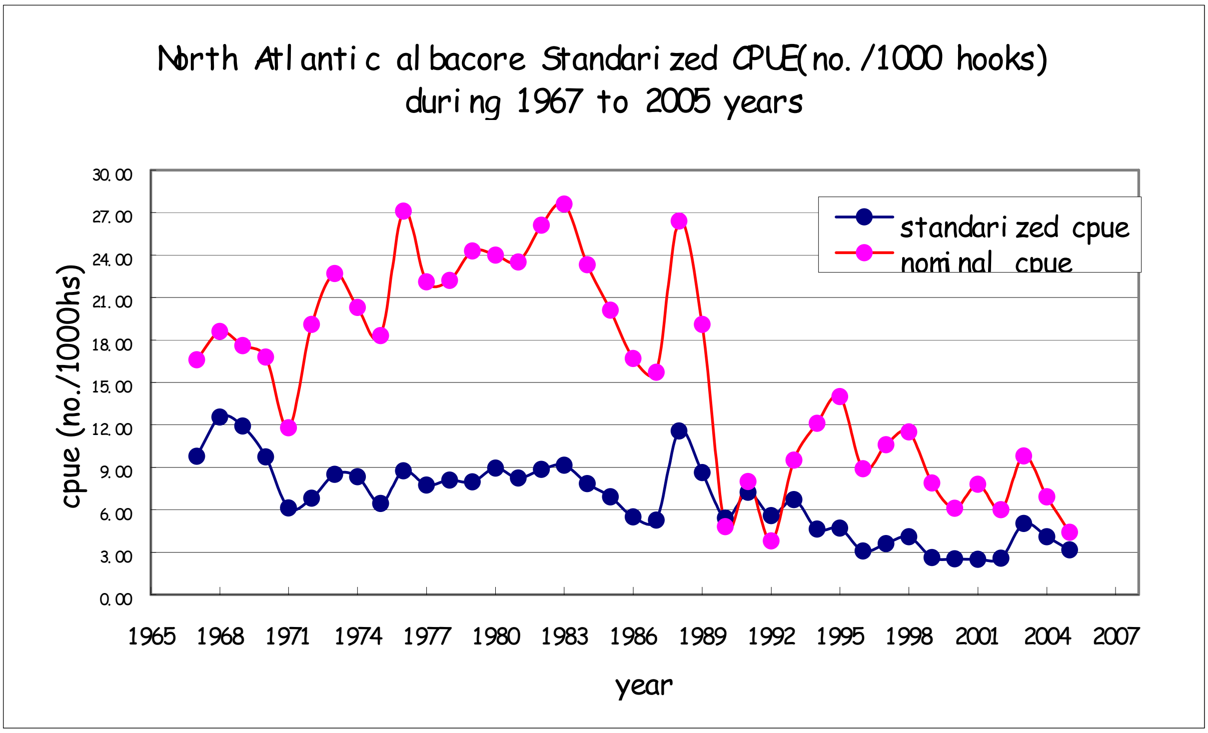

Figure 3. Comparison of annual nominal CPUE (no./1000hs) and standardized CPUE of North Atlantic albacore by GLM displays from 1967 to 2005.

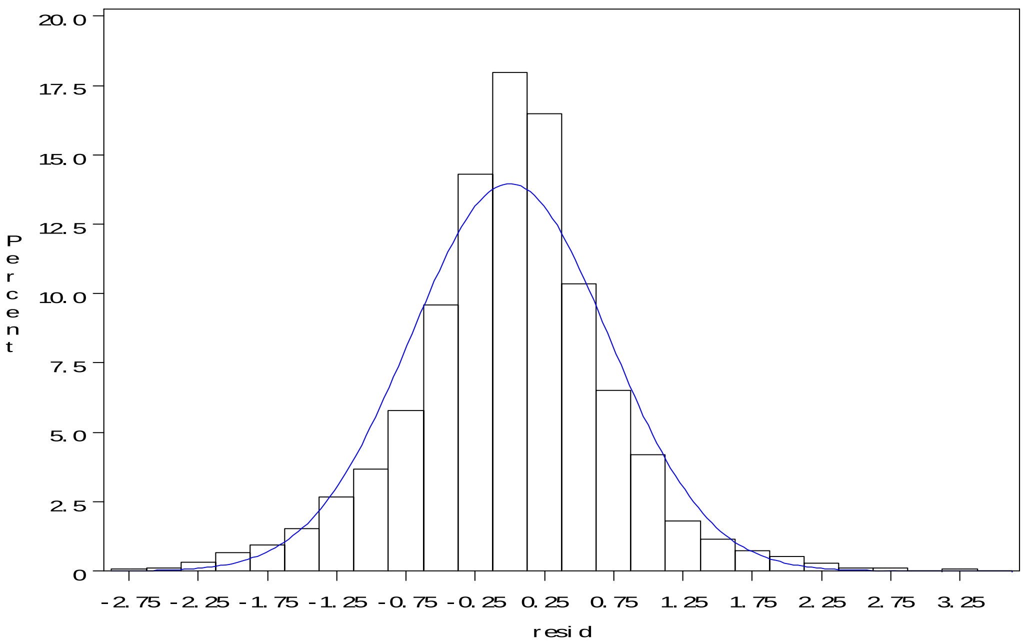

Figure 4. Residual frequency distribution of standardized residual is derived from GLM from 1967 to 2005. The standardized residual percent displays as a normal distribution pattern.

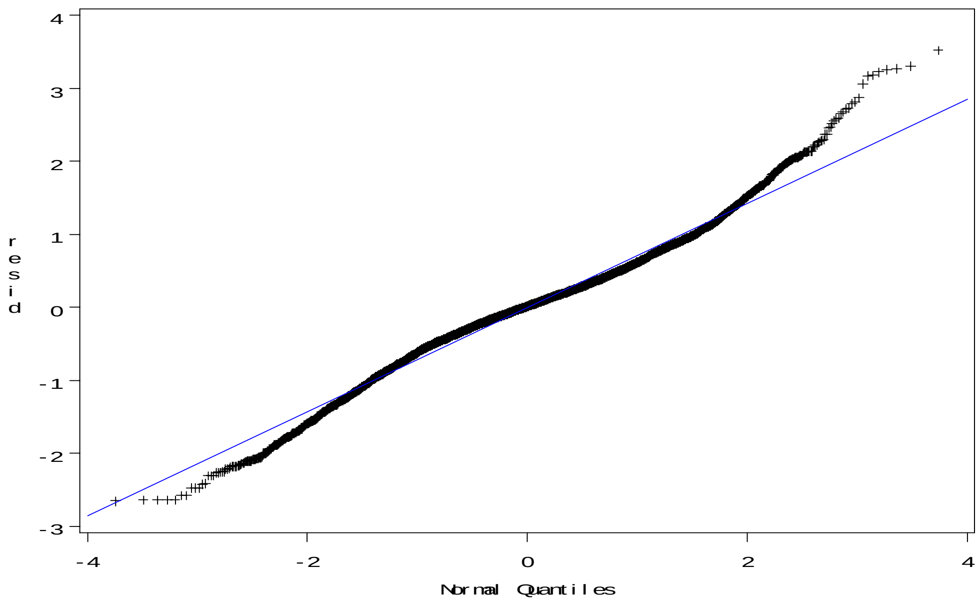

Figure 5. The Q-Q plot for the residuals by GLM to standardize yearly CPUE (no./1000hs) of North Atlantic albacore is from 1967 to 2005

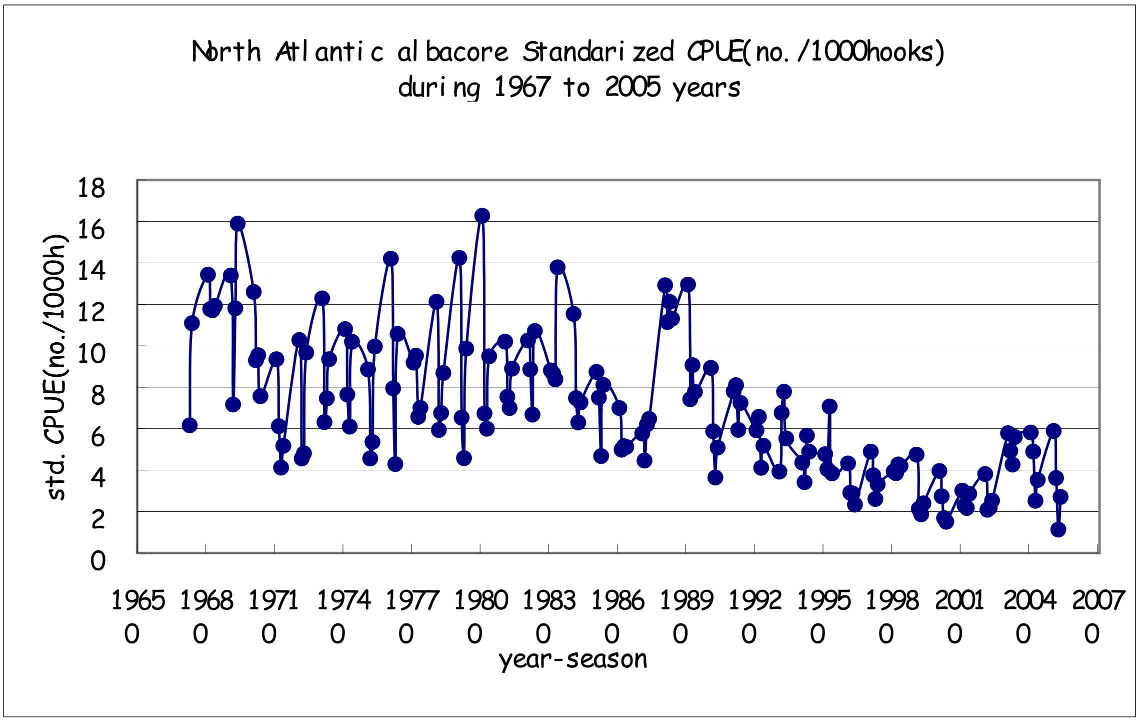

Figure 6. The quarterly standardized CPUE (no./1000hs) of North Atlantic albacore by GLM is from 1967 to 2005.

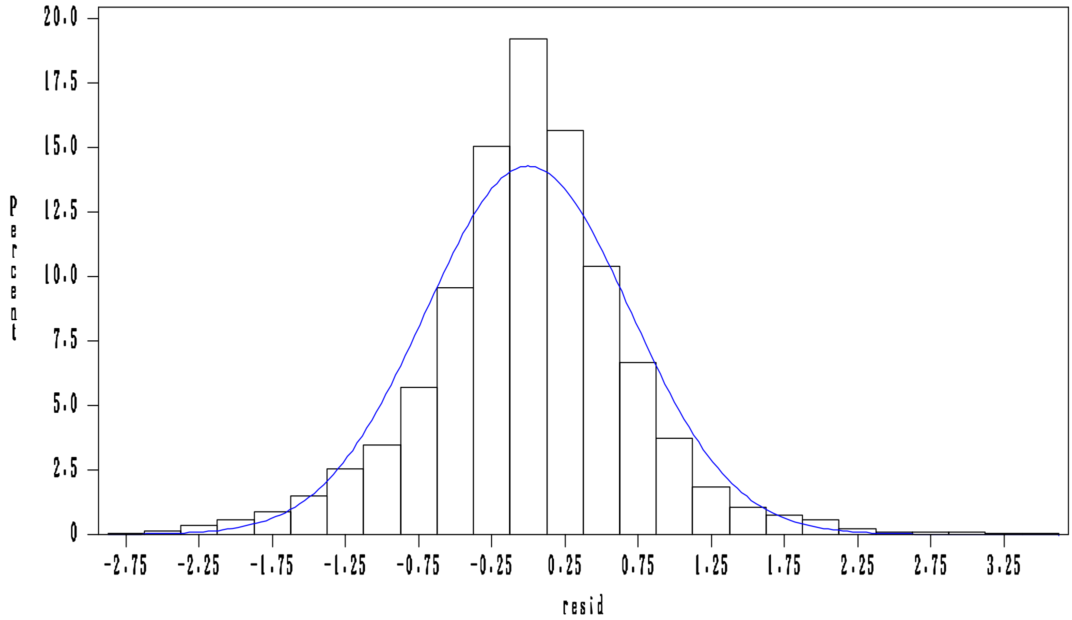

Figure 7. Residual frequency distribution of standardized residual is derived from GLM model from 1967 to 2005. The standardized residual percent displays as a normal distribution pattern.

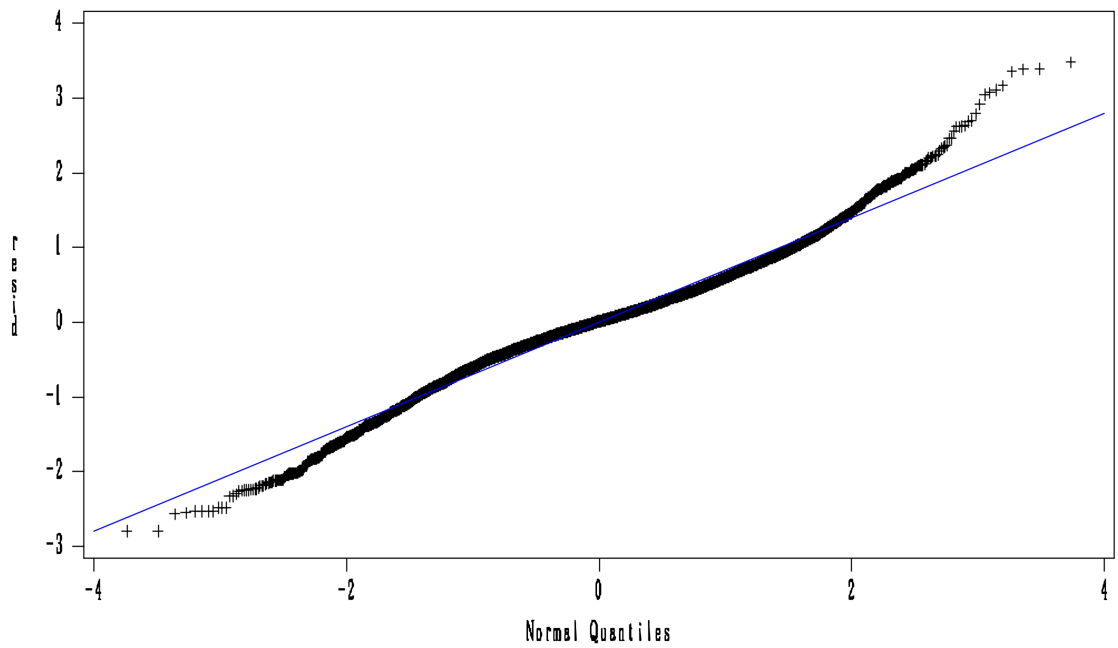

Figure 8. The Q-Q plot for the residuals by the GLM to standardize quarterly CPUE (no./1000hs) of North Atlantic albacore is from 1967 to 2005.

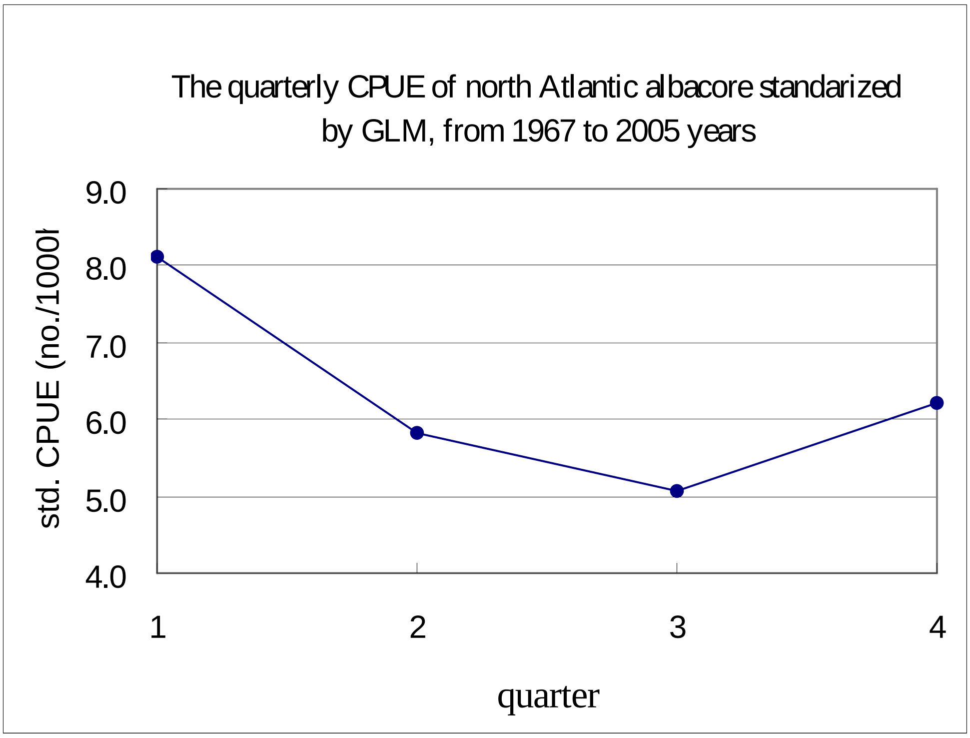

Figure 9. The quarterly CPUE of North Atlantic albacore standardized by GLM, from 1967 to 2005.