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TRIAL ESTIMATION OF STANDARDIZED CATCH PER UNIT EFFORT OF YELLOWFIN TUNA BY THE TAIWANESE LONGLINE FISHERY IN THE TROPICAL WATERS OF THE ATLANTIC OCEAN

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SUMMARY

The trial standardized catch per unit effort (CPUE) of Atlantic yellowfin tuna caught by Taiwanese longline fishery was estimated by general linear models (GLM). For the manipulation, several factors were used including year, quarter, subarea, vessel category and the two-way interactions. Before estimating CPUE, historical catch and effort data were selected and re-examined by spatial and temporal distribution in the tropical core fishing area; then the 1990-2011 catch and effort data within the tropical core area (15°N- 20°S) were selected and stratified into five subareas to make the nominal CPUE as homogeneous as possible among subareas by cluster analysis. The GLM and Delta-GLM were used to standardize yellowfin tuna CPUE for the Taiwanese longline fishery in the Atlantic tropical waters. The results obtained show a very similar trend except for the displacement of peaks in the series. Discrepancies occurred between the Japanese longline CPUE series and any one of the three Taiwanese series. Logically, the comparison suggests that the applicability of Standardized CPUE for yellowfin tuna by the Taiwanese longline fishery in the Atlantic Ocean warrants verification and refining before the stock assessment session.

RÉSUMÉ

La capture par unité d'effort (CPUE) standardisée expérimentale de l'albacore de l'Atlantique capturé par la pêcherie palangrière du Taipei chinois a été estimée par des modèles linéaires généralisés (GLM). Pour la manipulation, plusieurs facteurs ont été utilisés, y compris année, trimestre, sous-zone, catégorie de navires et interactions à double sens. Avant d'estimer la CPUE, les données historiques de prise et d'effort ont été sélectionnées et réexaminées par la distribution spatio-temporelle dans la zone de pêche centrale tropicale ; ensuite, les données de prise et d'effort de 1990-2011 à l'intérieur de la zone centrale tropicale (15°N- 20°S) ont été sélectionnées et stratifiées en cinq sous-zones pour rendre la CPUE nominale aussi homogène que possible parmi les sous-zones par analyse de groupement. Les GLM et Delta-GLM ont été utilisés pour standardiser la CPUE de l'albacore pour la pêcherie palangrière du Taipei chinois dans les eaux atlantiques tropicales. Les résultats obtenus montrent une tendance très similaire, sauf pour le déplacement des pics dans les séries. Des divergences sont apparues entre les séries de CPUE palangrière japonaise et n'importe laquelle des trois séries du Taipei chinois. Logiquement, la comparaison suggère que l'applicabilité de la CPUE standardisée pour l'albacore par la pêcherie palangrière du Taipei chinois opérant dans l'océan Atlantique doit être vérifiée et affinée avant la réunion d'évaluation du stock.

RESUMEN

Se estimó la captura por unidad de esfuerzo (CPUE) de prueba estandarizada del rabil del Atlántico capturado por la pesquería de palangre de Taipei chino mediante modelos lineales generalizados (GLM). Para la manipulación, se utilizaron varios factores, entre ellos, año, trimestre, subárea, categoría de buque y las interacciones en dos sentidos. Antes de estimar la CPUE, se seleccionaron los datos históricos de captura y esfuerzo y se volvieron a examinar mediante una distribución espacial y temporal en la zona de pesca central tropical, después se seleccionaron los datos de captura y esfuerzo de 1990-2011 dentro de la zona central tropical (15°N- 20°S) y se estratificaron en cinco subáreas para que la CPUE nominal fuera lo más homogénea posible en las diferentes zonas mediante un análisis de conglomeración. Se

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utilizaron GLM y Delta-GLM para estandarizar la CPUE de rabil para la pesquería de palangre de Taipei Chino en aguas tropicales del Atlántico. Los resultados obtenidos muestran una tendencia muy similar, con la excepción del desplazamiento de los picos de la serie. Las discrepancias se observaron entre las series de CPUE de la pesquería de palangre japonesa y cada una de las tres series de Taipei Chino. Lógicamente, la comparación sugiere que la aplicabilidad de la CPUE estandarizada para el rabil para la pesquería de palangre de Taipei Chino en el océano Atlántico requiere una verificación y mejora antes de la sesión de evaluación de stock.

KEYWORDS

Abundance indices, Fishery indicators, Yellowfin, Longline gear

1. Introduction

As usual, catch per unit effort (CPUE) is defined as catch divided by its effort used; and the dimension of catch and longline effort are in numbers (or in weight) and hooks, respectively. The standardized CPUE is frequently used as abundance index in the stock assessment, which is an important input value used when the population parameters are estimated in evaluating a population (Maunder and Punt 2004, Quinn and Deriso 1999).

Moreover, data used for standardizing CPUE are always obtained from catch and effort information of commercial fisheries, which are called fishery dependent data mostly provided by fishing stakeholders. Those data are recorded by fishing boat skippers and compiled by fishing authorities or its agents in charge. Thus, those data may have more or less variability in time and space due to the fishing targets, fish distributions and environmental factors. And consequently, estimates of fish abundance index may be influenced either by those factors; and also catchability may be varied. Subsequently, the nominal CPUE may not reflect the real abundance index as possible in efficacy. For reduce those effects on catchability, a procedure is to standardize the fishery dependent data to obtain standardized CPUE.

Several methods were used in standardizing CPUE (Hinton and Maunder 2004); and general linear models (GLMs) are the common ones frequently used (Maunder and Punt 2004). Those GLMs are extended to include, such as, general additive models (GAMs) (Hastie et al. 2001), general linear mixed models (GLMMs) (Pinheiro and Bates 2000), and others (Maunder and Punt 2004). Moreover, fishery dependent data were often encountered a number of zero catch, especially when the fishery is not to target the study species. The frequent way to prevent zero catch in logarithmic transformation of nominal CPUE in applying GLMs to standardize CPUE is to add a percentage of grand mean to nominal CPUE (Cao et al. 2011), or other error structures were applied, such as a Tweedie distribution (Shono 2008). Lo et al. (1992) claimed that a number of zero catch may result in uncertainty for standardized CPUE; thus in order to improve the declined effect of zero catch and to increase the accuracy of standardized CPUE, they suggested a delta lognormal error structure to be assumed in CPUE standardization models. And then, a delta GLM model was suggested to improve the flexibility of the delta lognormal model and the delta GLM was used to standardize the fishery dependent data into abundance index (Hill et al. 2007).

We are attempting to find a region where yellowfin tuna is targeted by Taiwanese longline fishery; to standardize yellowfin tuna abundance index within this selected region by delta GLM; and to compare the results estimated and reported previously (Hsu 2012; Satoh et al. 2012).

2. Materials and methods

2.1 Fishing region stratification

One of the important factors in standardizing CPUE is the stratification of larger fishing region into several smaller ones (Su et al. 2008), which is usually used in the Pacific Ocean. Yellowfin tuna distributes extensively in the Atlantic Ocean, and it is much abundant in the tropical waters. The fishing types used can be used to reflect the targets usually, hence, **Figure 1** points out that Taiwanese longline quarterly nominal CPUE distributions indicated that the major region of yellowfin tuna catch was within the tropical waters ((15oN – 20oS) (**Figure 1**) because the more hooks per basket (HPB) were used to target the tropical tunas. Therefore, the historical logbook data, obtained from the Overseas Fisheries Development Council (OFDC), may be extracted for the core part of yellowfin catches from the tropical waters.

2.2 Fishing effort and hooks per basket

According to the analysis of fishing effort used by Taiwanese longline fishery in logbooks submitted by fishing companies indicated that the reasonable hooks used to target tropical tunas (bigeye tuna and yellowfin tuna) per daily operation may be around 3,000 hooks (Hsu 2011), hence, a upper limit of hooks used per day would be set below 3,200 hooks; and further, hooks greater than 3,200 hooks, the daily fishing information in logbooks was deleted in the present analysis.

Moreover, the information of HPB may be an important factor in the standardization process, although several previous reports regarding to analyze hooks per basket may not be useful in CPUE analysis (Takeuchi 2001; Goodyear 2003; Bach et al. 2006). A trial including HPB as one of the factors was made in this analysis to analyze the effect between target species and HPB used by Taiwanese longline fishery.

2.3 Standardize catch per unit effort

2.3.1 Delta-GLM CPUE standardization methods

Standardized yellowfin tuna CPUE and other tunas and tuna-like species has been estimated previously by generalized linear model (GLM) approaches (e.g. Yokawa and Clark 2005; Bigelow 2006; Satoh et al. 2012). In the present study, an alternative delta-GLM (Lo et al. 1992) was applied in which the result is obtained by the multiplication between the separate estimates that the proportion of positive yellowfin tuna catches assuming a binomial error distribution, and the mean catch rate of positive catches by assuming a different error distribution such as lognormal distribution. The standardized CPUE index is the product of these models estimated components. The formulation of the delta GLM for both dataset 1 for proportion of positive catch (p) was

$$\log\left(\frac{p}{1-p}\right) = \mu + f_1 + f_2 + \ldots + error$$

and dataset 2 for the positive catch rate:

$$\log(CPUE_{ijkl}) = \mu + f_1 + f_2 + \ldots + error$$

where CPUEijkl is the catch in number per 1,000 hooks in year i, month j, gear k, area l and error represents the random error term under the effects of f_1, f_2, …, etc for year, month, gear, area, …, respectively. No interaction terms were considered without loss generality. Analyses were done using the R statistical computer software (R version 2.2.0), and a delta-GLM procedure obtained from E.J. Dick (NOAA Fisheries). Given the preferred error distribution without diagnosis of models, a step-wise regression procedure was used to determine the set of explanatory variables. The difference in deviance between two consecutive models was evaluated by Chi square and deviance analysis tables are presented for the data series, including the deviance for the proportion of positive observations and for positive catch rates.

2.3.2 GLM model used to standardize yellowfin tuna CPUE

Satoh et al. (2012) submitted a yellowfin tuna standardized CPUE by years and by quarterly series for representing Japanese longline fleet operating in the Atlantic Ocean. In their document, two standardization model were provided:

GLM model was used for the annual series with year, month, and sub-area as the fixed factor and year-month and year-subarea as two way interactions. The model was built and a lognormal error structure was used as:

$$\log(CPUE + c) = \mu + year + month + year * month + year * subarea + error$$

where c used 10% grand mean. And a GLM model was used for the standardized quarterly CPUE series with year (Y), quarter (q), latitude (Lat), and longitude (Lon) as the fixed factors and several interactions (Lat^p and Lon^p, where p for power with $p =$1, 2 and 3; and Q represents the sum of interactions

$Lat*Lon$, Lat^3*Lon, $Y*q$, $q*Lat$, $q*Lat^2$, $q*Lat^3$, $q*lon$ and $q*Lon^3$) with lognormal error structure (ε); and the formulas was:

$$\log(CPUE+c)=\mu+\mathrm{Y}+q+\sum\left(Lat^p+Lon^p\right)+Q+\varepsilon$$

For comparing the consistency of yellowfin tuna abundance indices between Japanese and Taiwanese longline fleets, both methods were used to estimate yellowfin tuna abundance index for Taiwanese longline fishery in the Atlantic Ocean.

3. Results

3.1 Data used

Logbook data were used in the present trial examination of standardized CPUE for yellowfin tuna caught by Taiwanese longline fleet in the Atlantic Ocean. The data were provided by the Oversea Fisheries Development Council (OFDC) who is taking in charge of catch statistics compilation of Taiwanese longline fishery. Those data released include daily fishing information vessel by vessel within a 5 degree squared block. Information included vessel tonnage category, fishing date, hooks per basket (since 1995), total hooks used, sea surface temperature, catch in number and in weight by species, bait used (in occasion).

3.2 Hooks per basket, target species and fishing pattern

Analyzing the distribution of accumulated fishing days by hooks per basket indicated that there were two apparent modes, revealing that the target species is different in corresponding with these two modes (**Figures 2** and **3**). One of the modes represents the fishing vessels using less hooks per basket (8-11 hooks per basket) to target albacore mainly; and the rest represents more hooks per basket (15-18 hooks per basket) to target tropical tunas, such as bigeye tuna and yellowfin tuna. There are apparently in different fishing regions for those two fisheries using different HPB due to the habitats of temperate tunas and tropical tunas in the waters, in which the fishing waters for tropical tunas mainly in the tropical waters; and for temperate tunas in the waters of high latitudes (**Figure 1**).

Further, Examining spatial and temporal distribution of catch for yellowfin tuna, fishing effort and nominal CPUE in quarterly 5-degree squared area for Taiwanese longline fishery in the Atlantic Ocean, indicating that the major region of yellowfin tuna for this fleet is in the tropical waters (15oN-20oS). And apparently, there were significantly fishing effort occurred in the tropical waters after 1990 onward. In the present trial estimation of abundance index of yellowfin tuna, the fishing activities and fishery dependent data within tropical waters were extracted to standardize CPUE after 1990.

3.3 Stratification of fishing regions

The fishing region of yellowfin tuna in the tropical waters of Atlantic Ocean was stratified into 5 sub-areas in according to the HPB composition (**Figure 1**), spawning ground of yellowfin tuna and fishing patterns of vessels. The 5 stratified regions were depicted in **Figure 4. Figure 4** indicated accordingly, that sub-area 1 located northwestern waters had less fishing efforts operation historically; sub-area 2 in the central north waters of tropical Atlantic Ocean was the major fishing ground of Taiwanese longline fleet and caught bigeye tuna and yellowfin tuna mainly; Sub-area 3 in the northeastern region of tropical waters was the spawning ground of yellowfin tuna, there are heavy fishing effort suffered in this sub-area; sub-area 4 in the central equatorial waters of the south latitude, the proportion of low HPB and albacore catch is high (**Figure 1**), and mainly the conventional longline fleet operated in this sub-area; and sub-area 5 in the southeast waters, whereas the albacore catch was also high, and this waters within 15oS-20oS is mainly conditional longline fleet operation (**Figure 4**).

3.4 Nominal catch per unit effort

1990-2011nomial CPUE of yellowfin tuna by Taiwanese longline fleet in the tropical Atlantic waters showed a decreasing tendency (**Figure 5**). The series decreased from 2.03 ind./1000 hooks in 1990 to 1.40 ind./1000 hooks in 1993, this decreasing during inception period may reflected the transferring of the traditional albacore target to tropical species target by Taiwanese longline fleet. The series then increased to 3.49 ind/1000 hooks in 1994, and decreasing from 3.01 ind./1000 hooks in 1995 to 0.54 ind./1000 hooks in 2001; and increased to 1.76 ind./1000 hooks in 2005; thereafter a fluctuated decreasing between 0.28 ind./1000 hooks and 0.68 ind./1000 hooks from 2005 onward to 2011.

3.5 Standardized catch per unit effort

The nominal CPUE series was standardized by delta GLM. A total of 191,430 1990-2011 data records was extracted for positive yellowfin tuna catch; and among those data extracted, a total of 93,575 data records (49%) were found with at least one yellowfin tuna caught. First of all, the positive yellowfin tuna CPUE was estimated with analyzing effect of factors selected for the standardization purpose. The results, in **Table 1**, indicate that all factors are significant at 5% level except season factor (quarter). However, the two-way interactions between season and other fixed factors are in statistical significance ($p<0.05$); subsequently, the season factor was used also in the standardization model. Under the assumption of log-normal error distribution, the GLM model was pursued. The ANOVA table for the standardization positive yellowfin tuna CPUE was tabulated in **Table 2**, indicating that all factors are significant at 5%. Then parameters of standardizing positive yellowfin tuna CPUE was shown in **Table 3**. Also the residuals distribution of model fitting and Q-Q plot was illustrated in **Figure 6**, revealing that the residuals distribution may be similar to a normal distribution and the Q-Q plot also looks approximately 1:1, although the diagnosis was not fully satisfied as normal distribution as logarithmic transformation. The error assumption in GLM model of standardizing the positive yellowfin tuna CPUE may not be much reasonable as expected.

Further the standardization was made to the proportion of yellowfin tuna positive catch. The factors that will be used to standardize positive catch was evaluated by stepwise regression again; and the results in **Table 4** indicated that the variability of only year and sub-area are significant ($p<0.05$). Thus, the two fixed factors were selected to standardize the proportion of positive yellowfin tuna catch in GLM. Under the assumption of binomial distribution error structure, The ANOVA table (**Table 5**) was indicated that this two factors are significant ($p<0.05$) to the GLM in standardizing proportion of positive yellowfin tuna catch. Then, parameters of standardizing proportion of yellowfin tuna catch were shown in **Table 6**. We are not expected the residuals distribution as a normal distribution but binomial distribution that was assumed for the standardized model for the proportion of positive catch. Thus the Q-Q plot and histogram for the residuals distribution, as in **Figure 7**, indicated that the residuals distributes randomly and dispersed symmetrically on the both sides of zero mean as it is in the assumption as the binomial distribution.

Therefore the standardized yellowfin CPUE was obtained by the product of the standardized positive yellowfin tuna catch and proportion of positive yellowfin tuna catch; and illustrated in **Figure 8**, indicating that the time series is increasing from 1990 – 1992 (under 1.0 ind./1000 hooks) to about 2.11 ind./1000 hooks in 1994, and then decreasing to about 0.62 ind./1000 hooks in 1998, and fluctuation around the low values below 0.62 ind./1000 hooks. To compare with result of Hsu (2012) as shown in **Figure 9**, the result in the present study is apparently different with the result estimated in Hsu (2012), which the overall catch data in entire Atlantic Ocean were used.

3.6 Standardization of yellowfin tuna by Taiwanese longline fleet using Japanese models

Without any factor examination, the models used in standardizing CPUE of yellowfin tuna by Japanese longline fleet (Satoh et al. 2012) were applied in the current study. The GLM used year, month, and two way interactions of year and month, year and subarea as factor to standardize yearly series in number and in weight; and factor and interactions were used in the standardization of quarterly series. The ANOVA tables were shown in the **Tables 7, 8,** and **9**, respectively. Factors used to standardize yearly series are all significant ($p<0.5$); and some of factors used to standardize quarterly were not ($p>0.5$) and were omitted in GLM.

Under the factors used in GLM, the standardized CPUE for yearly and quarterly series were estimated. And the models were evaluated for error structure assumed by Q-Q plots and residuals histogram distribution, illustrated in **Figures 10, 11**, and **12**, respectively. All those examinations indicated the distributions are approximately consistent to normal distribution but the left skewness and double peaks are performed. And then, the yearly standardized CPUE in number and weight and quarterly standardized CPUE in number were estimated as in **Figure 13**, although the diagnosis of error assumption in visual shows that the assumption may not fully suitable for the detection of the error of the used data set distributed randomly.

3.7 Comparison of standardized CPUE

Comparison was made visually as in **Figure 14** among the time series of standardized yellowfin tuna CPUEs by Taiwanese longline fleet, which were standardized by delta GLM, GLM with factors as Satoh et al. (2012); GLM (Hsu 2012); and the Japanese longline fleet (Satoh et al. 2012). Roughly, series with delta GLM standardization indicated one major peak and a minor peak, which are 1994-1996 and 2002-2005, respectively. Series standardized by GLM with factors similar to Japanese longline series (Satoh et al. 2012) shows a year displacement for the major peak; and 2003-2005 for the minor peak, which was a tendency similar to Hsu (2012). However, all those series reveal a very different tendency with Japanese longline series.

All of the standardized CPUEs of yellowfin tuna for Taiwanese longline fleet in the Atlantic Ocean are listed with 95% confidence intervals in **Appendix Tables I, II, III** and **IV** in different measurements and time frames.

4. Discussion

Taiwanese longline fleets are composed of deep sea longline fleet and offshore longline fleet, which are operated in the three oceans. The offshore longline fleet targets multispecies in season and in occasion, but mainly targets yellowfin tuna in the deep sea; and the deep sea longline fleet targets tunas and tuna-like species, which the deep sea longliners are composed of the conventional longline fleet to target mainly albacore, and the super-cold longline fleet to target the tropical species, mainly bigeye tuna, and yellowfin tuna as incidental catch.

The current study used almost the data submitted by deep longline fleet. And the standardized method used was the model used for a significant zero catch (Lo et al. 1992) within the dataset, although other methods were used, such as Shono (2008). And the comparison was made among the resultant longline CPUEs visually from the Atlantic Ocean.

Yellowfin tuna is the third high catch by Taiwanese longline fleet in the Atlantic Ocean right behind catches of bigeye tuna and albacore in order. Two periods can roughly stratified for the change of fishing patterns of Taiwanese longline fleet in the Atlantic Ocean. The fishery has been transferred to target tropical bigeye tuna since 1990. This is why the time frame was set to start from 1990 in the trial study. And only the tropical waters was selected because yellowfin tuna is one of the tropical species, although yellowfin tuna can be also caught by the conventional longline fleet incidentally that targets always albacore in the temperate waters. During the present analysis, we also found a significant operation of Taiwanese longline fleet in the tropical water (**Figure 1**) from all the way of time series of 1981-1984. Moreover, we also found in the fishing effort for the fleet, which was suffered in the eastern tropical waters in the Atlantic Ocean; and the catches of yellowfin tuna were less than 1,000 t (Hsu 2012). Therefore, we assumed that the data of yellowfin tuna in the tropical fishing region after 1990 may be an eligible representative CPUE for the entire Atlantic Ocean.

Delta GLM is one of the models used to standardize CPUE (Anon. 2011), especially for the data with significant zero catch (Lo et al. 1992), such as Taiwanese catch data of yellowfin tuna (about 51% are zero catch) in the Atlantic Ocean. The result seems not concordant with the series estimated before (Hsu 2012), however, the tendency is similar except those in 1994 and 1995. Comparison to the standardized CPUE series of Japanese longline fleet (Satoch et al. 2012) indicated that both series were in different trends. Thus, it is necessary to re-verify the original daily logbooks before standardizing catch per unit effort for using as abundance index in the stock assessment, and the species is not limited to yellowfin tuna, other species, such as bigeye tuna, albacore, swordfish etc. are also necessary to validate their logic in future.

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Table 1. Total deviance of positive CPUE for yellowfin tuna caught by Taiwanese longline fishery operating in the tropics of Atlantic Ocean.

	DF	SS	Change deviance	% total deviance
Intercept	93573	101596.07		
Year	93552	88698.27	12897.80	14.54*
Year+q	93549	88585.88	112.39	0.13
Year+q+subarea	93545	82366.95	6218.93	7.55*
Year+q+subarea+CT	93542	82217.10	6368.78	7.75*
Year+q+subarea+CT+Year*q	93479	80598.99	7986.90	9.91*
Year+q+subarea+CT+Year*q+Year*subarea	93397	77906.00	10679.88	13.71*
Year+q+subarea+CT+Year*q+Year*subarea+Year*CT	93361	76880.17	5486.78	7.14*
Year+q+subarea+CT+Year*q+Year*subarea+Year*CT+q*subarea	93349	76339.96	12245.92	16.04*
Year+q+subarea+CT+Year*q+Year*subarea+Year*CT+q*subarea+subarea*CT	93340	76249.19	12336.69	16.18*

Note. q: season. CT: CT number of longliner. Subarea: the divided area. Stars indicate proportion of total deviance is above 5%.

Table 2. Results of ANOVA table for positive CPUE standardization by general linear model

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	233	25346.9	108.785	133.17	<.0001
Error	93340	76249.2	0.8169		
Corrected Total	93573	101596			

R-Square	Coeff Var	Root MSE	logcpue Mean
0.249487	410.297	0.90382	0.22029

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	21	1908.12	90.863	111.23	<.0001
q	3	35.4473	11.8158	14.46	<.0001
subarea	4	38.9026	9.72565	11.91	<.0001
CT	3	46.9487	15.6496	19.16	<.0001
Year*q	63	1074.47	17.055	20.88	<.0001
Year*subarea	79	1921.77	24.3262	29.78	<.0001
Year*CT	36	930.351	25.8431	31.64	<.0001
q*subarea	12	524.48	43.7066	53.5	<.0001
subarea*CT	9	90.7674	10.0853	12.35	<.0001

Table 3. Parameters of positive CPUE for yellowfin tuna caught by Taiwanese longline fishery operating in the tropics of Atlantic Ocean standardized by GLM.

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits	Wald 95% Confidence Limits	Chi-Square	Pr > ChiSq
Intercept		1	-0.5297	0.0385	-0.6051	-0.4543	189.65	<.0001
Year	1990	1	0.7633	0.1988	0.3737	1.1529	14.74	0.0001
Year	1991	1	1.0077	0.1981	0.6195	1.396	25.88	<.0001
Year	1992	1	0.7791	0.2709	0.2483	1.31	8.27	0.004
Year	1993	1	1.0149	0.079	0.8601	1.1697	165.13	<.0001
Year	1994	1	1.8023	0.0697	1.6656	1.9389	668.41	<.0001
Year	1995	1	1.6766	0.0494	1.5798	1.7734	1152.37	<.0001
Year	1996	1	0.8193	0.049	0.7234	0.9153	280.1	<.0001
Year	1997	1	0.4711	0.0515	0.3701	0.5722	83.56	<.0001
Year	1998	1	0.8011	0.0553	0.6927	0.9095	209.86	<.0001
Year	1999	1	0.3	0.046	0.2099	0.3902	42.52	<.0001
Year	2000	1	0.434	0.0501	0.3357	0.5323	74.92	<.0001
Year	2001	1	0.0695	0.0663	-0.0604	0.1995	1.1	0.2943
Year	2002	1	0.7952	0.0556	0.6862	0.9042	204.45	<.0001
Year	2003	1	0.6806	0.0571	0.5686	0.7926	141.91	<.0001
Year	2004	1	0.8492	0.048	0.7552	0.9432	313.48	<.0001
Year	2005	1	0.6067	0.0459	0.5168	0.6967	174.64	<.0001
Year	2006	1	0.0177	0.0741	-0.1276	0.163	0.06	0.8118
Year	2007	1	-0.2847	0.0546	-0.3918	-0.1776	27.16	<.0001
Year	2008	1	-0.0875	0.0578	-0.2008	0.0258	2.29	0.1302
Year	2009	1	-0.0947	0.0544	-0.2014	0.012	3.03	0.0819
Year	2010	1	-0.1915	0.0525	-0.2943	-0.0886	13.31	0.0003
Year	2011	0	0	0	0	0	.	.

Table 4. Total deviance of proportion of positive catch sets for yellowfin tuna caught by Taiwanese longline fishery operating in the tropics of Atlantic Ocean, in which q is the season by calendar quarter, CT is the vessel categories, and subarea is the stratified areas as indicated in **Figure 5**.

	DF	SS	Change deviance	% total deviance
Intercept	9823	615.29		
Year	9802	555.95	59.33	10.67*
Year+q	9799	552.23	3.73	0.67
Year+q+subarea	9795	503.79	48.44	9.61*
Year+q+subarea+CT	9792	499.67	4.13	0.83
Year+q+subarea+CT+Year*q	9729	487.09	12.58	2.58
Year+q+subarea+CT+Year*q+Year*subarea	9646	465.24	21.85	4.70
Year+q+subarea+CT+Year*q+Year*subarea+Year*CT	9609	460.18	5.05	1.10
Year+q+subarea+CT+Year*q+Year*subarea+Year*CT+q*subarea	9597	452.45	7.73	1.71
Year+q+subarea+CT+Year*q+Year*subarea+Year*CT+q*subarea+subarea*CT	9588	451.54	0.91	0.20

*indicate proportion of total deviance is significant at 5%.

Table 5. Results of ANOVA table for positive catch sets standardization by general linear model

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	25	107.89	4.31559	83.34	<.0001
Error	9798	507.399	0.05179		
Corrected Total	9823	615.289			
R-Square	**Coeff Var**	**Root MSE**	**Logppp Mean**		
0.18	57.67	0.23	0.39		
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Year	21	53.915	2.56738	49.58	<.0001
subarea	4	48.5559	12.139	234.41	<.0001

Table 6. Parameters of proportion of positive catch sets for yellowfin tuna caught by Taiwanese longline fishery operating in the tropics of Atlantic Ocean standardized by GLM.

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits	Wald 95% Confidence Limits	Chi-Square	Pr > ChiSq
Intercept		1	-0.9479	0.0174	-0.982	-0.9138	2965.8	<.0001
Year	1990	1	1.4302	0.0695	1.294	1.5665	423.15	<.0001
Year	1991	1	1.189	0.0828	1.0266	1.3513	206.1	<.0001
Year	1992	1	1.2519	0.0938	1.068	1.4359	177.95	<.0001
Year	1993	1	1.0145	0.0562	0.9042	1.1247	325.35	<.0001
Year	1994	1	1.3214	0.0475	1.2283	1.4145	774.3	<.0001
Year	1995	1	1.6247	0.0354	1.5553	1.6941	2105.4	<.0001
Year	1996	1	1.3604	0.0278	1.3059	1.4149	2395.4	<.0001
Year	1997	1	0.3171	0.0249	0.2682	0.366	161.58	<.0001
Year	1998	1	-0.0189	0.0264	-0.0705	0.0328	0.51	0.4742
Year	1999	1	0.4828	0.0233	0.4372	0.5285	429.39	<.0001
Year	2000	1	0.7696	0.0253	0.72	0.8192	926.23	<.0001
Year	2001	1	0.2653	0.0296	0.2074	0.3233	80.53	<.0001
Year	2002	1	0.5724	0.0272	0.5191	0.6258	442.47	<.0001
Year	2003	1	1.0558	0.0311	0.9949	1.1168	1153.9	<.0001
Year	2004	1	0.6392	0.0243	0.5916	0.6868	692.82	<.0001
Year	2005	1	1.0071	0.024	0.9601	1.0541	1764	<.0001
Year	2006	1	0.8238	0.0407	0.744	0.9036	409.6	<.0001
Year	2007	1	0.3759	0.0256	0.3258	0.4261	215.96	<.0001
Year	2008	1	0.0077	0.0267	-0.0446	0.06	0.08	0.7735
Year	2009	1	0.0699	0.0238	0.0232	0.1166	8.61	0.0033
Year	2010	1	-0.4078	0.0242	-0.4553	-0.3602	282.8	<.0001
Year	2011	0	0	0	0	0	.	.

Table 7. Results of ANOVA table for CPUE (number) standardization by general linear model

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	350	88089.3	251.684	158.62	<.0001
Error	191078	303189	1.5867		
Corrected Total	191428	391278			
R-Square	**Coeff Var**	**Root MSE**	**LogMean**		
0.225132	-133.03	1.25965	-0.9469		
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Year	21	12184.9	580.235	365.68	<.0001
Month	11	751.079	68.2799	43.03	<.0001
Year*subarea	87	28593.4	328.66	207.13	<.0001
Year*Month	231	10301.1	44.5935	28.1	<.0001

Table 8. Results of ANOVA table for CPUE (weight) standardization by general linear model

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	350	81312.9	232.323	140.61	<.0001
Error	191078	315701	1.6522		
Corrected Total	191428	397014			
R-Square	**Coeff Var**	**Root MSE**	**Logppp Mean**		
0.20481	47.3797	1.28538	2.71295		
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Year	21	11180.9	532.424	322.25	<.0001
Year*subarea	11	719.335	65.3941	39.58	<.0001
Year*Month	87	26258.9	301.827	182.68	<.0001
Month*subarea	231	10856.2	46.9965	28.44	<.0001

Table 9. Results of ANOVA table for CPUE (quarter) standardization by general linear model

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	110	78593.3	714.485	437.16	<.0001
Error	191318	312685	1.6344		
Corrected Total	191428	391278			
R-Square	**Coeff Var**	**Root MSE**	**Logppp Mean**		
0.20086	-135.01	1.27843	-0.9469		
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Year	21	28665.1	1365	835.18	<.0001
q	3	1020.99	340.33	208.23	<.0001
Lat	1	45.9052	45.9052	28.09	<.0001
Lon	1	3.72195	3.72195	2.28	0.1313
Lat_2	1	42.9979	42.9979	26.31	<.0001
Lon_2	1	4.13954	4.13954	2.53	0.1115
Lat_3	1	233.209	233.209	142.69	<.0001
Lon_3	1	29.1143	29.1143	17.81	<.0001
Lat*Lon	1	970.05	970.05	593.53	<.0001
Lon*Lat_2	1	1136.16	1136.16	695.17	<.0001
Year*q	63	5621.95	89.2374	54.6	<.0001
Lat*q	3	413.978	137.993	84.43	<.0001
Lat_2*q	3	296.999	98.9998	60.57	<.0001
Lat_3*q	3	285.413	95.1378	58.21	<.0001
Lon*q	3	234.3	78.1001	47.79	<.0001
Lon_3*q	3	778.881	259.627	158.85	<.0001

Appendix Table I. Yearly series standardized catch per unit effort (in No/1000 hooks) of yellowfin tuna caught by Taiwanese longline fleet in the Atlantic Ocean.

Year	cpue_p	cpue_95%lower	cpue_95%upper
1990	0.7810	0.4581	1.3224
1991	0.9032	0.5186	1.5583
1992	0.7384	0.3650	1.4768
1993	0.8393	0.6201	1.1299
1994	2.1146	1.6208	2.7478
1995	2.0875	1.6950	2.5647
1996	0.8038	0.6531	0.9874
1997	0.3276	0.2599	0.4122
1998	0.3614	0.2824	0.4619
1999	0.3066	0.2472	0.3797
2000	0.4140	0.3322	0.5150
2001	0.2119	0.1622	0.2763
2002	0.5310	0.4189	0.6719
2003	0.6128	0.4852	0.7722
2004	0.5828	0.4690	0.7231
2005	0.5560	0.4527	0.6818
2006	0.2811	0.2118	0.3717
2007	0.1598	0.1261	0.2022
2008	0.1515	0.1178	0.1946
2009	0.1572	0.1237	0.1996
2010	0.0996	0.0781	0.1270
2011	0.1645	0.1488	0.1817

Appendix Table II. *Yearly series standardized catch per unit effort (in kg/1000 hooks) of yellowfin tuna caught by Taiwanese longline fleet in the Atlantic Ocean.

Year	cpue_p	cpue_95%lower	cpue_95%upper
1990	32.36	18.98	54.79
1991	31.27	17.95	53.95
1992	26.61	13.15	53.22
1993	27.21	20.10	36.63
1994	58.00	44.46	75.37
1995	65.70	53.34	80.71
1996	27.40	22.27	33.66
1997	12.47	9.90	15.70
1998	13.17	10.29	16.83
1999	10.92	8.80	13.52
2000	14.10	11.32	17.54
2001	8.27	6.33	10.79
2002	19.51	15.39	24.68
2003	25.18	19.94	31.74
2004	21.88	17.60	27.14
2005	22.54	18.35	27.64
2006	14.21	10.71	18.79
2007	8.50	6.70	10.76
2008	7.58	5.89	9.73
2009	8.05	6.33	10.21
2010	4.53	3.55	5.77
2011	7.31	6.61	8.08

Appendix Table III. Annual yellowfin CPUE in number (left) and in weight (right) standardized for all Atlantic from 1990 to 2011 by expressing in real scale and relative scale in which the average from 1990 to 2011 is 1.0.

	CPUE in number			CPUE in weight		
Year	real scale	relative scale	CV	real scale	relative scale	CV
1990	0.54654	1.23	0.131848	20.6581	1.26	0.003559
1991	0.32319	0.73	1.029271	12.7418	0.78	0.026641
1992	0.47049	1.06	0.301175	19.3454	1.18	0.007474
1993	0.68664	1.55	0.140001	24.6652	1.50	0.003977
1994	0.93011	2.10	0.04693	30.1824	1.84	0.001476
1995	1.12566	2.54	0.021383	34.9091	2.13	0.000704
1996	0.87637	1.98	0.020311	32.3083	1.97	0.000562
1997	0.4341	0.98	0.039069	15.5178	0.95	0.001115
1998	0.3446	0.78	0.051364	11.5949	0.71	0.001558
1999	0.29478	0.67	0.042608	10.9509	0.67	0.001171
2000	0.38257	0.86	0.035366	13.3517	0.81	0.001034
2001	0.20249	0.46	0.101635	7.62	0.46	0.002757
2002	0.31188	0.70	0.0766	11.1856	0.68	0.00218
2003	0.45323	1.02	0.075458	17.3976	1.06	0.002006
2004	0.4175	0.94	0.040335	15.9554	0.97	0.001077
2005	0.79067	1.78	0.018946	31.285	1.91	0.000489
2006	0.33231	0.75	0.137582	14.7323	0.90	0.003167
2007	0.28296	0.64	0.141716	12.9455	0.79	0.003161
2008	0.14444	0.33	0.21933	6.493	0.40	0.004979
2009	0.14764	0.33	0.254606	6.5559	0.40	0.005851
2010	0.11595	0.26	0.223286	4.591	0.28	0.005755
2011	0.1363	0.31	0.266838	5.5728	0.34	0.006659

Appendix Table IV Annual yellowfin CPUE in number (quarter) standardized for all Atlantic from 1990 to 2011 by expressing in real scale and relative scale in which the average from 1990 to 2011 is 1.0.

		CPUE in number		
Year	quarter	Real scale	relative scale	CV
1990	1	0.70664	1.620511	0.103985
1990	2	0.55092	1.263404	0.164924
1990	3	0.73571	1.687176	0.112123
1990	4	0.56474	1.295097	0.102383
1991	1	0.76802	1.761271	0.083318
1991	2	0.46574	1.068064	0.340834
1991	3	0.31853	0.730473	0.711173
1991	4	0.63088	1.446773	0.136698
1992	1	0.43446	0.996331	0.158956
1992	2	0.36727	0.842246	0.297901
1992	3	0.57449	1.317456	0.243886
1992	4	2.53589	5.815461	0.054829
1993	1	0.83199	1.907971	0.109629
1993	2	0.53616	1.229556	0.21529
1993	3	0.33113	0.759368	0.214991
1993	4	0.47606	1.09173	0.092467
1994	1	0.75201	1.724556	0.065132
1994	2	0.52637	1.207105	0.132378
1994	3	0.52828	1.211485	0.107235
1994	4	1.3445	3.083291	0.030093
1995	1	1.45697	3.341215	0.030042
1995	2	0.58	1.330092	0.101448

1995	3	0.65458	1.501124	0.053424
1995	4	1.07325	2.461244	0.022036
1996	1	1.11583	2.558891	0.021455
1996	2	0.36835	0.844723	0.083589
1996	3	0.42707	0.979384	0.059733
1996	4	0.80076	1.836353	0.02871
1997	1	0.44252	1.014814	0.047139
1997	2	0.16915	0.387905	0.158439
1997	3	0.2125	0.487318	0.117976
1997	4	0.24704	0.566528	0.096907
1998	1	0.27515	0.630991	0.080429
1998	2	0.15161	0.347682	0.188246
1998	3	0.17486	0.401	0.163845
1998	4	0.18077	0.414553	0.134591
1999	1	0.28582	0.65546	0.070149
1999	2	0.18935	0.434229	0.121468
1999	3	0.24898	0.570976	0.090971
1999	4	0.22411	0.513943	0.087323
2000	1	0.43352	0.994175	0.04475
2000	2	0.27574	0.632344	0.09237
2000	3	0.33015	0.757121	0.088414
2000	4	0.23088	0.529468	0.112353
2001	1	0.1983	0.454754	0.118154
2001	2	0.21817	0.500321	0.145987
2001	3	0.15084	0.345916	0.270949
2001	4	0.15206	0.348713	0.236288
2002	1	0.27392	0.62817	0.077577
2002	2	0.24148	0.553777	0.108166
2002	3	0.33994	0.779572	0.101812
2002	4	0.5696	1.306242	0.065327
2003	1	0.73806	1.692565	0.037057
2003	2	0.66872	1.53355	0.047823
2003	3	0.37825	0.867427	0.098453
2003	4	0.52466	1.203183	0.071589
2004	1	0.39244	0.899968	0.053817
2004	2	0.45726	1.048617	0.053777
2004	3	0.4348	0.99711	0.056808
2004	4	0.40467	0.928014	0.054439
2005	1	0.48159	1.104412	0.040574
2005	2	0.86094	1.974361	0.026564
2005	3	0.61995	1.421708	0.038987
2005	4	0.59037	1.353873	0.038264
2006	1	0.52936	1.213961	0.075846
2006	2	0.3349	0.768014	0.150015
2006	3	0.36982	0.848094	0.135444
2006	4	0.39353	0.902468	0.125098
2007	1	0.35331	0.810233	0.085279
2007	2	0.40358	0.925515	0.063977
2007	3	0.20616	0.472779	0.11753
2007	4	0.13611	0.312136	0.167291
2008	1	0.22937	0.526006	0.094781
2008	2	0.15301	0.350892	0.161166
2008	3	0.17702	0.405953	0.208225
2008	4	0.12518	0.287071	0.212254
2009	1	0.22361	0.512796	0.093824
2009	2	0.21321	0.488946	0.101121
2009	3	0.09387	0.215269	0.249707

2009	4	0.13629	0.312549	0.156725
2010	1	0.1369	0.313948	0.141344
2010	2	0.11673	0.267693	0.182815
2010	3	0.11583	0.265629	0.210999
2010	4	0.0947	0.217172	0.204541
2011	1	0.17741	0.406848	0.105293
2011	2	0.16797	0.385199	0.118354
2011	3	0.15371	0.352497	0.139223
2011	4	0.10693	0.245219	0.182736

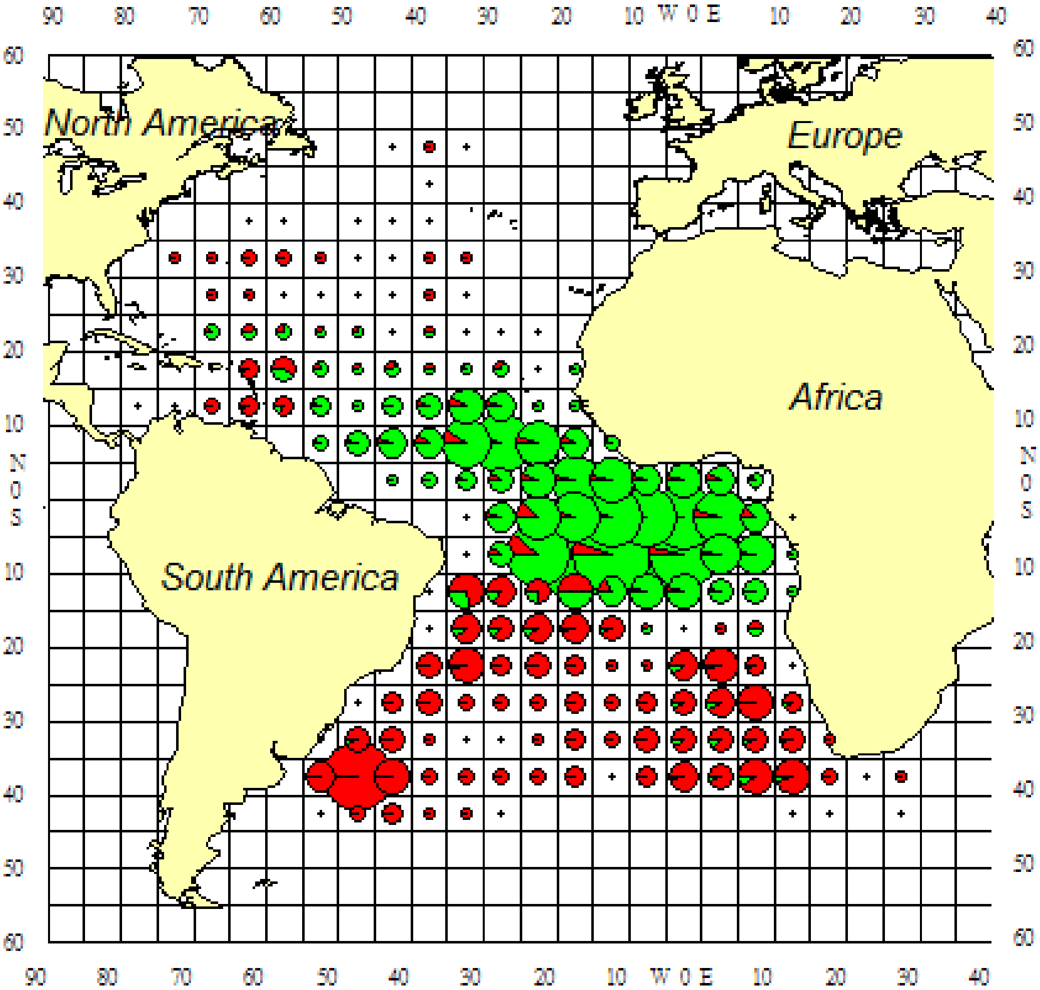


Figure. 1. Distributions of fishing type of Taiwanese longline fishery in the Atlantic Ocean from 1995-2011. (Green indicates targeting on bigeye tuna and red indicates targeting on albacore).

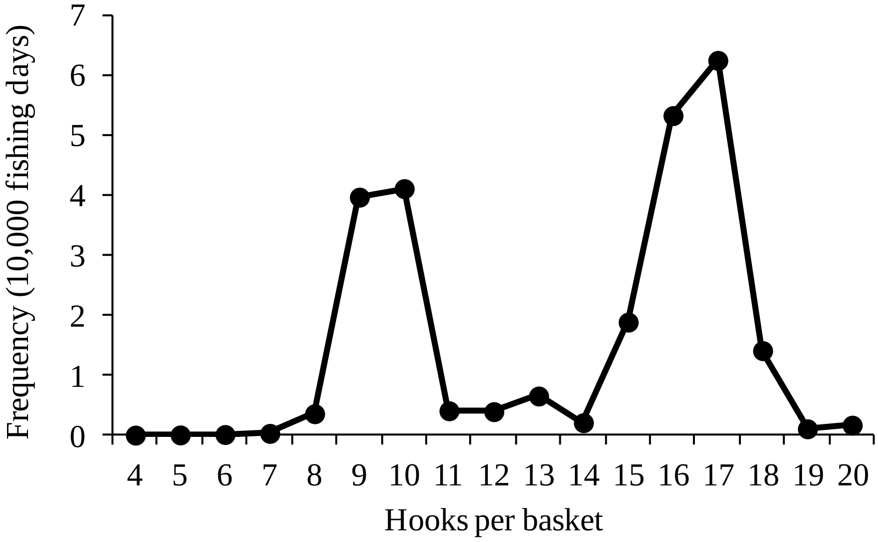


Figure 2. Distributions of cumulative fishing days by hooks per basket for Taiwanese longline fishery in the Atlantic Ocean during 1995-2011.

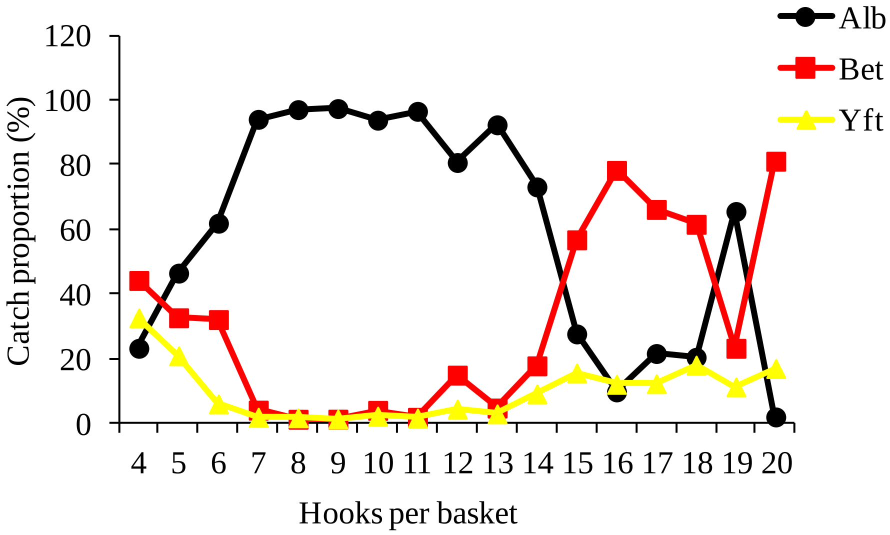


Figure 3. Distributions of catch species composition byhooks per basket for Taiwanese longline fishery in the Atlantic Ocean during 1995-2011.

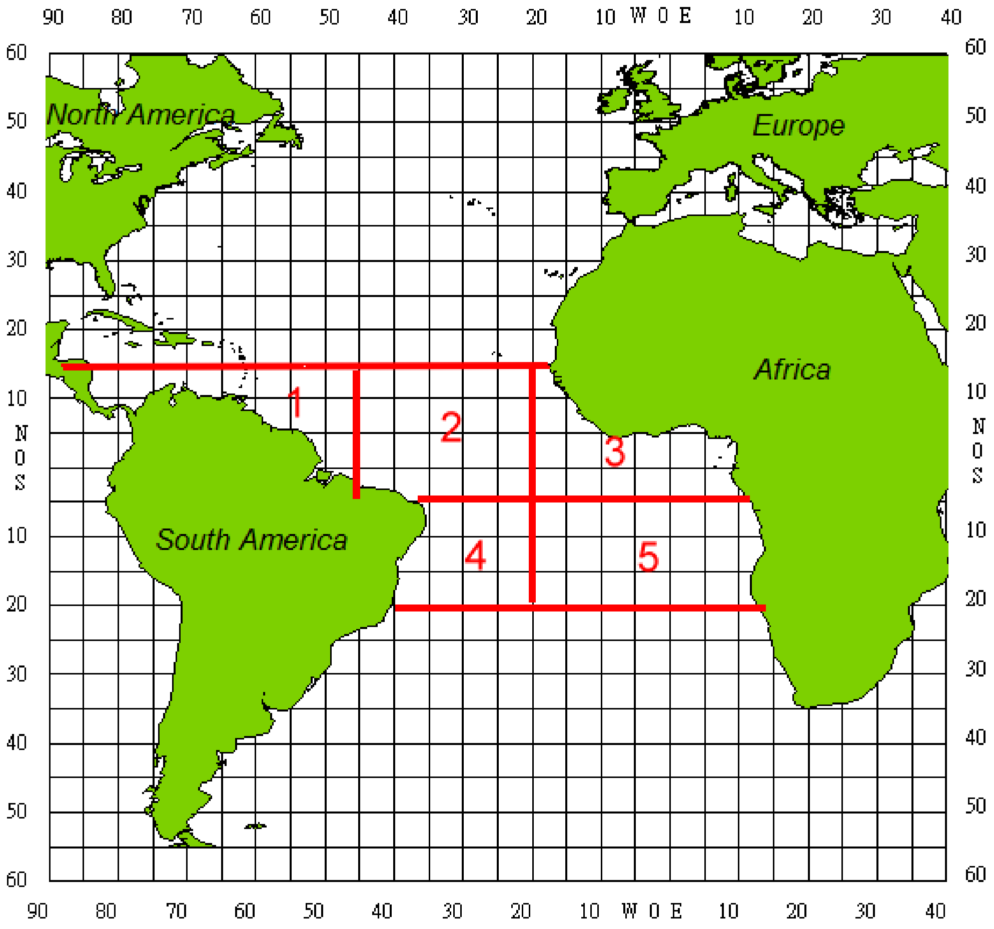


Figure 4. Five divided subareas based on Taiwanese longline fishery data operating in the tropics of the Atlantic Ocean.

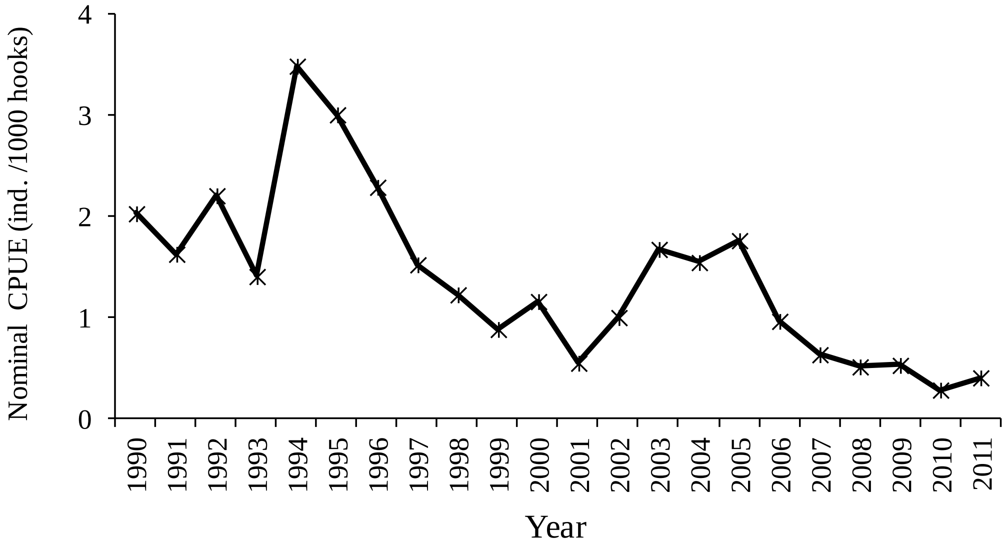


Figure 5. The nominal CPUE trend of yellowfin tuna caught by Taiwanese longline fishery in the tropics of Atlantic Ocean.

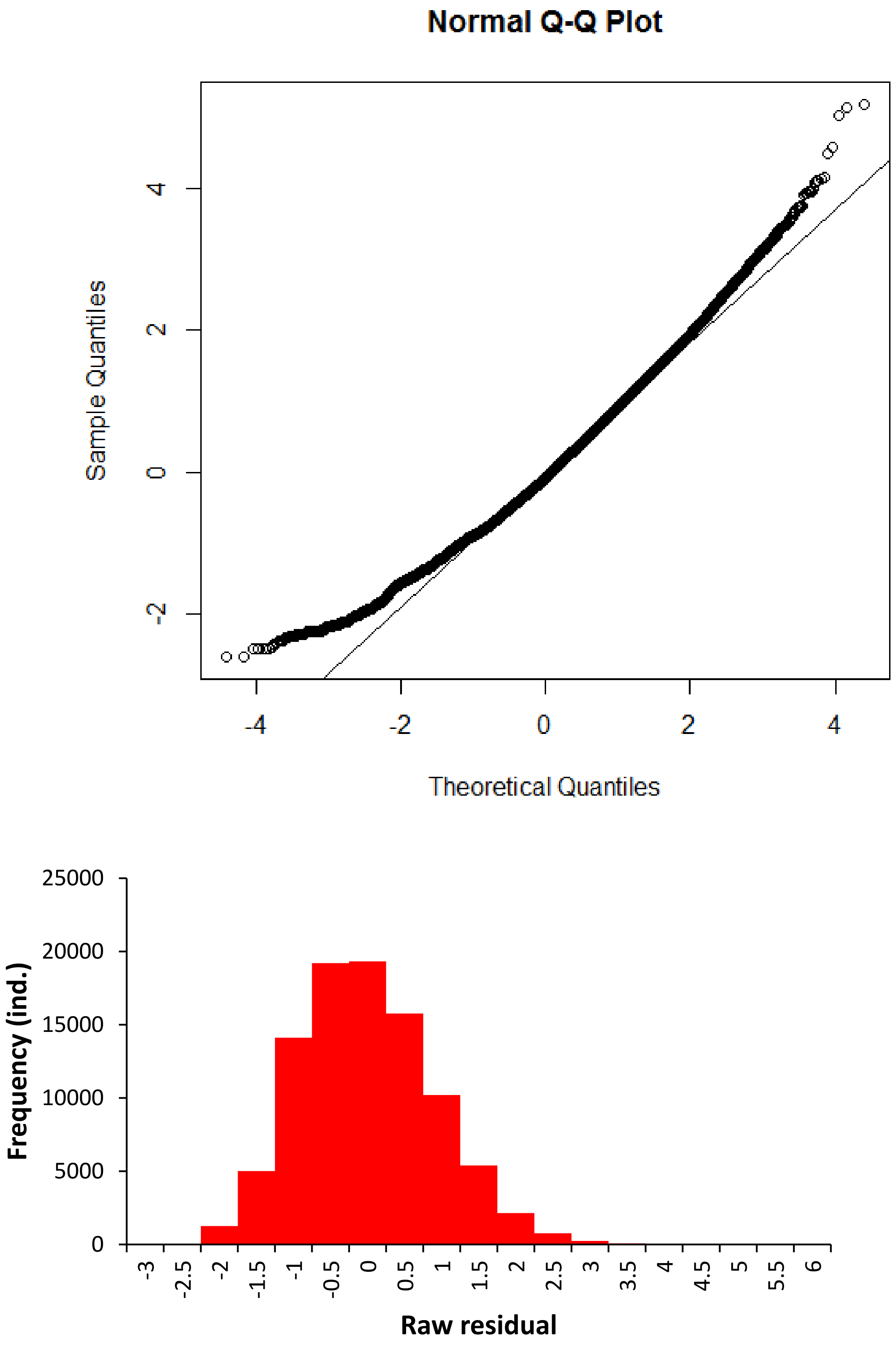
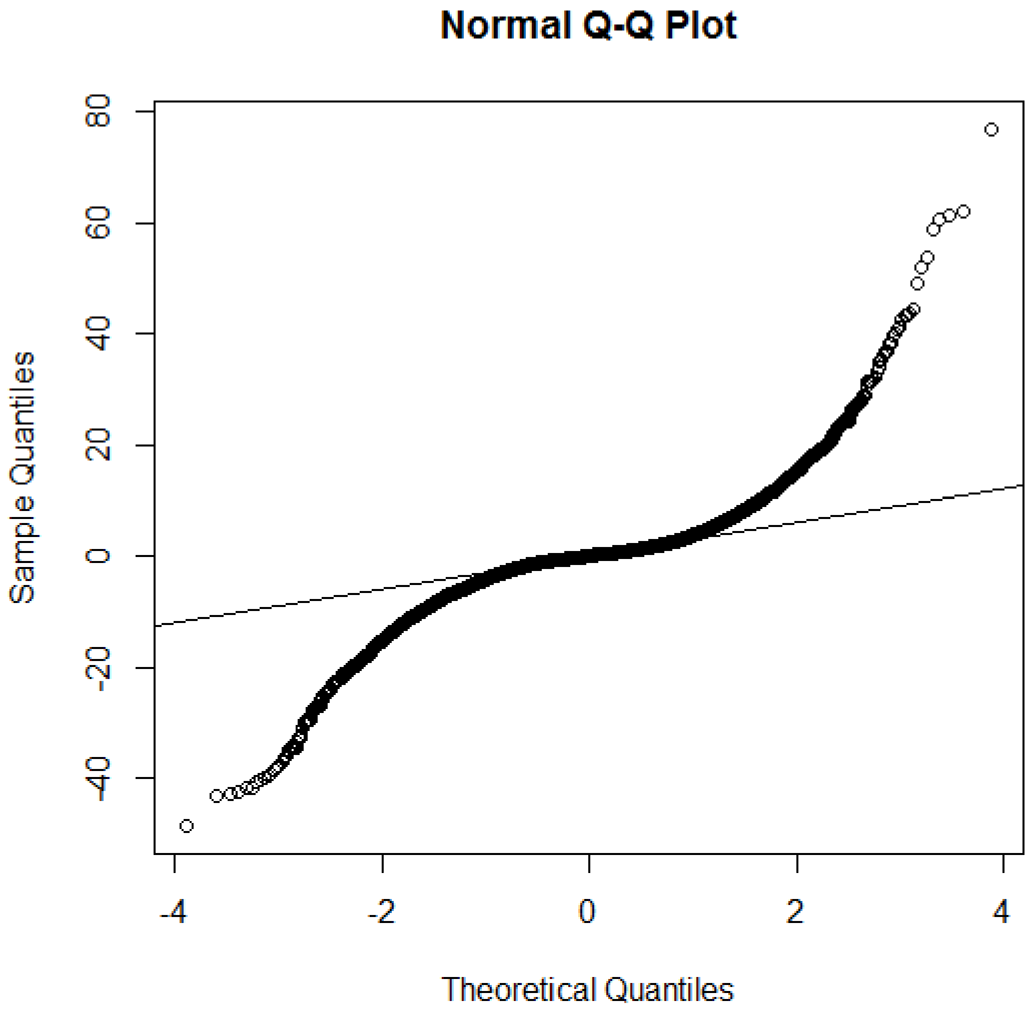


Figure 6. The Q-Q plots (up) and histogram (down) of residuals with lognormal error structure in GLM of positive CPUE for yellowfin tuna caught by Taiwanese longline fishery in the tropics of Atlantic Ocean.



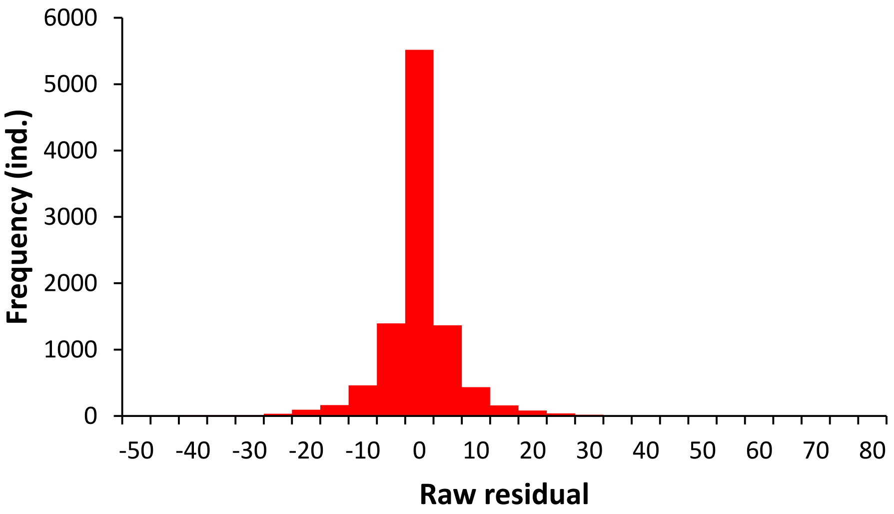


Figure 7. The Q-Q plots (up) and histogram (down) of residuals with binomial error structure in GLM of proportion of positive catch sets for yellowfin tuna caught by Taiwanese longline fishery in the tropics of Atlantic Ocean.

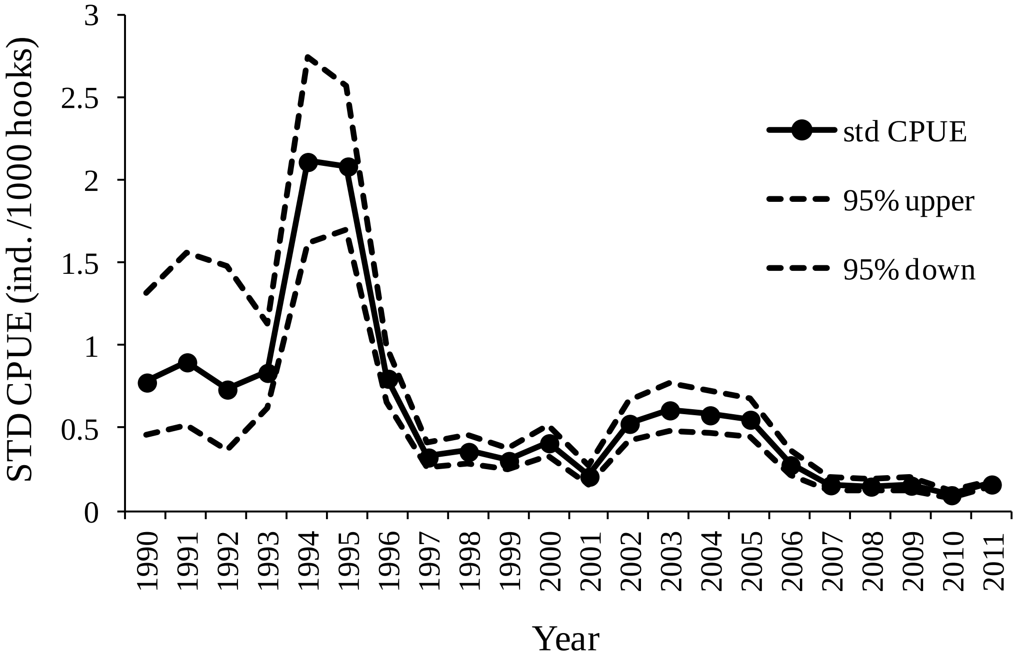


Figure 8. Standardized CPUE of yellowfin tuna caught by Taiwanese longline fishery in the tropics of the Atlantic Ocean.

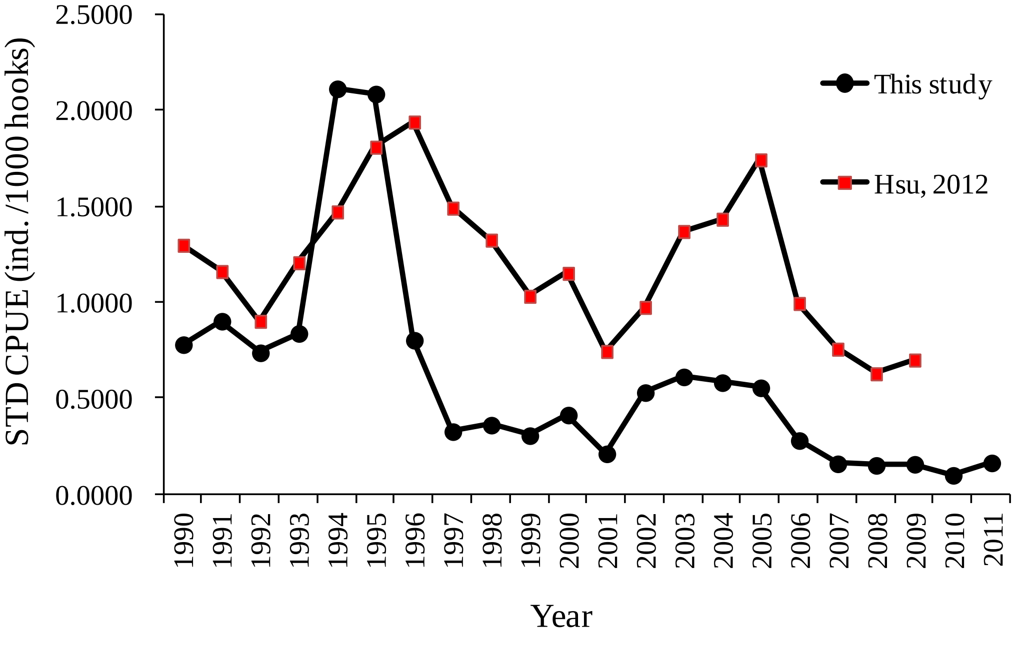


Figure 9. Comparisons of standardized CPUE trends between Hsu (2012) and this study.

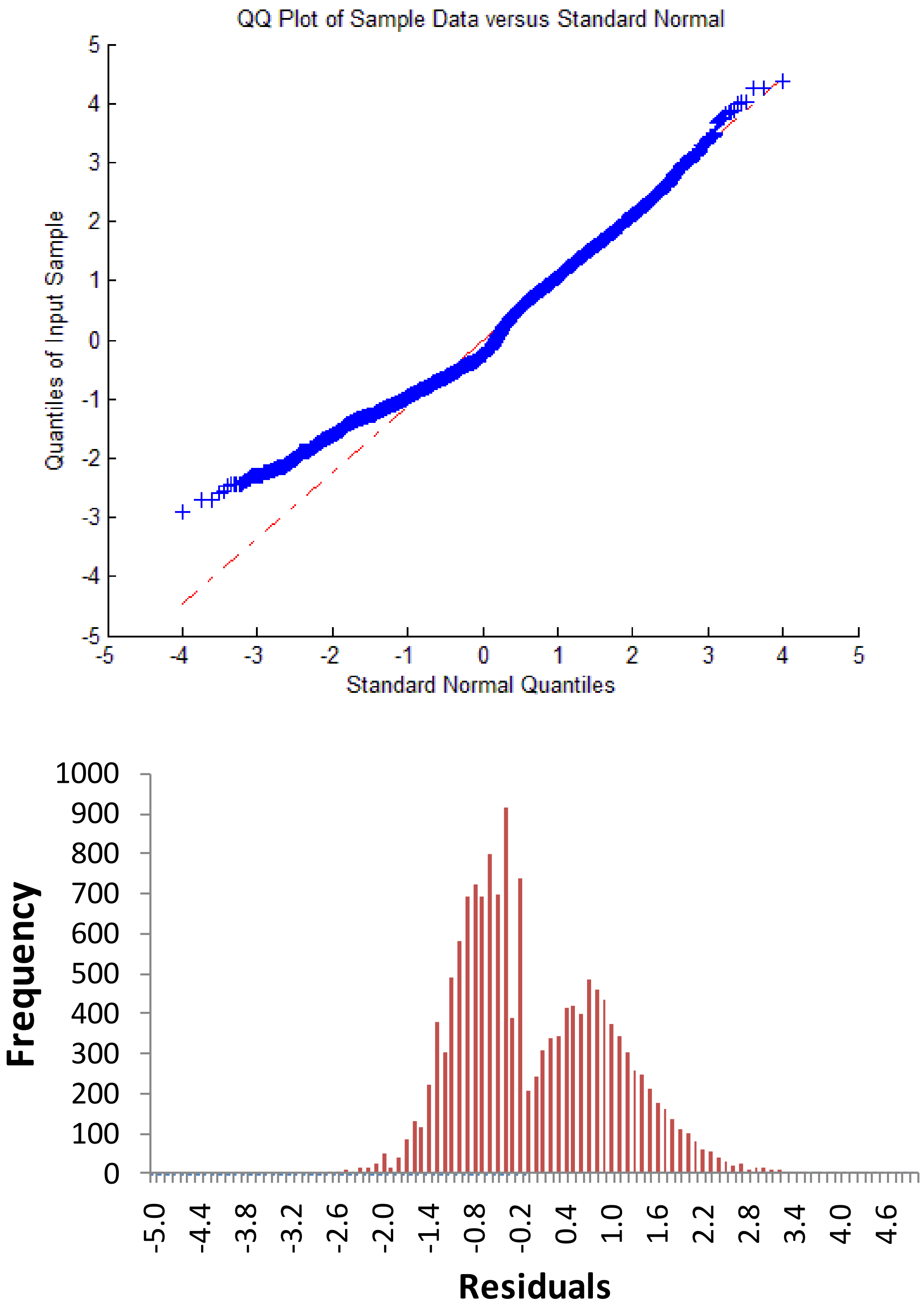


Figure 10. Overall histogram and QQ-plot of standard residuals from the GLM analyses for annual CPUE in number base applying the final model in this study.

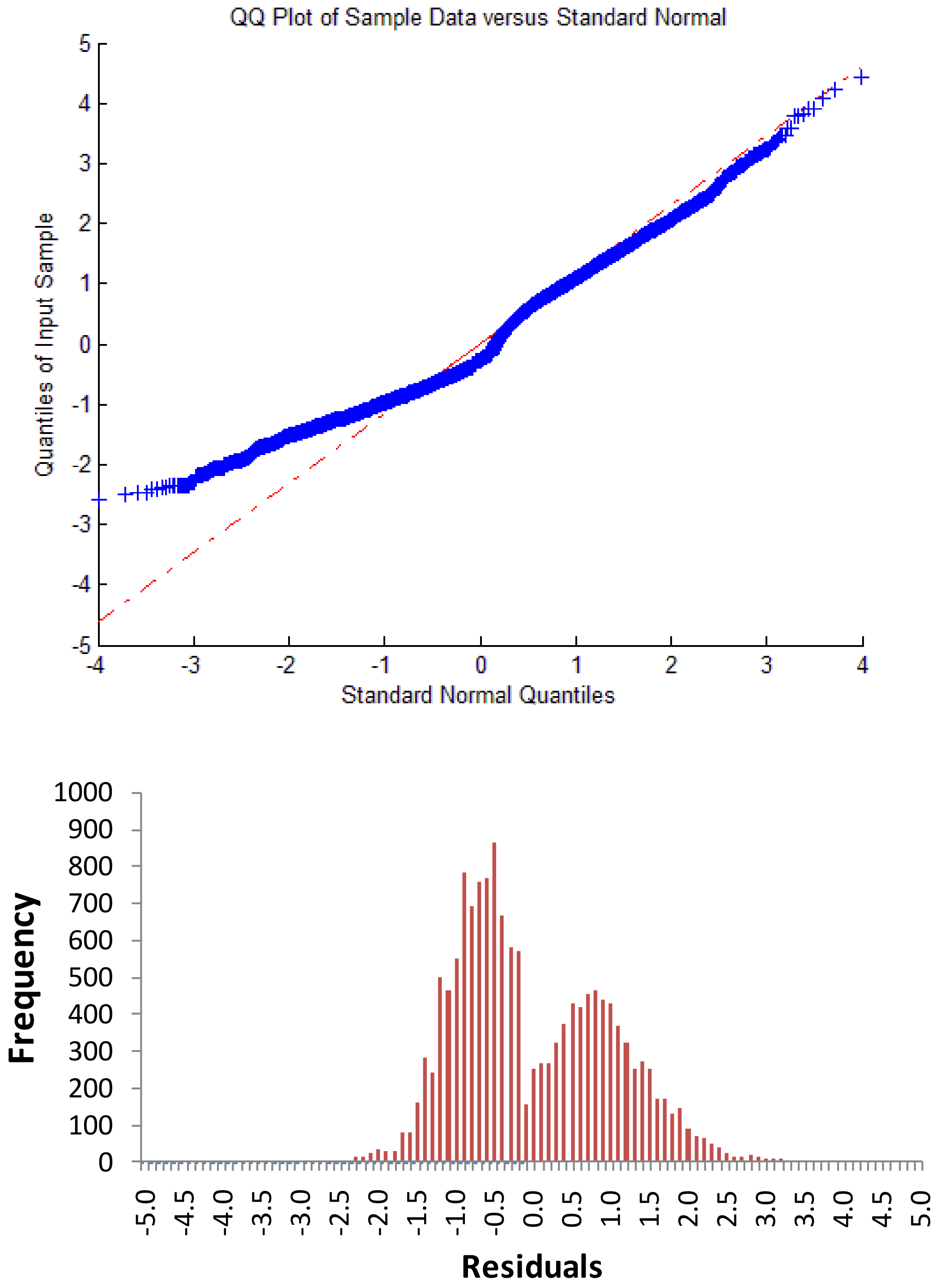


Figure 11. Overall histogram and QQ-plot of standard residuals from the GLM analyses for annual CPUE in weight base applying the final model in this study.

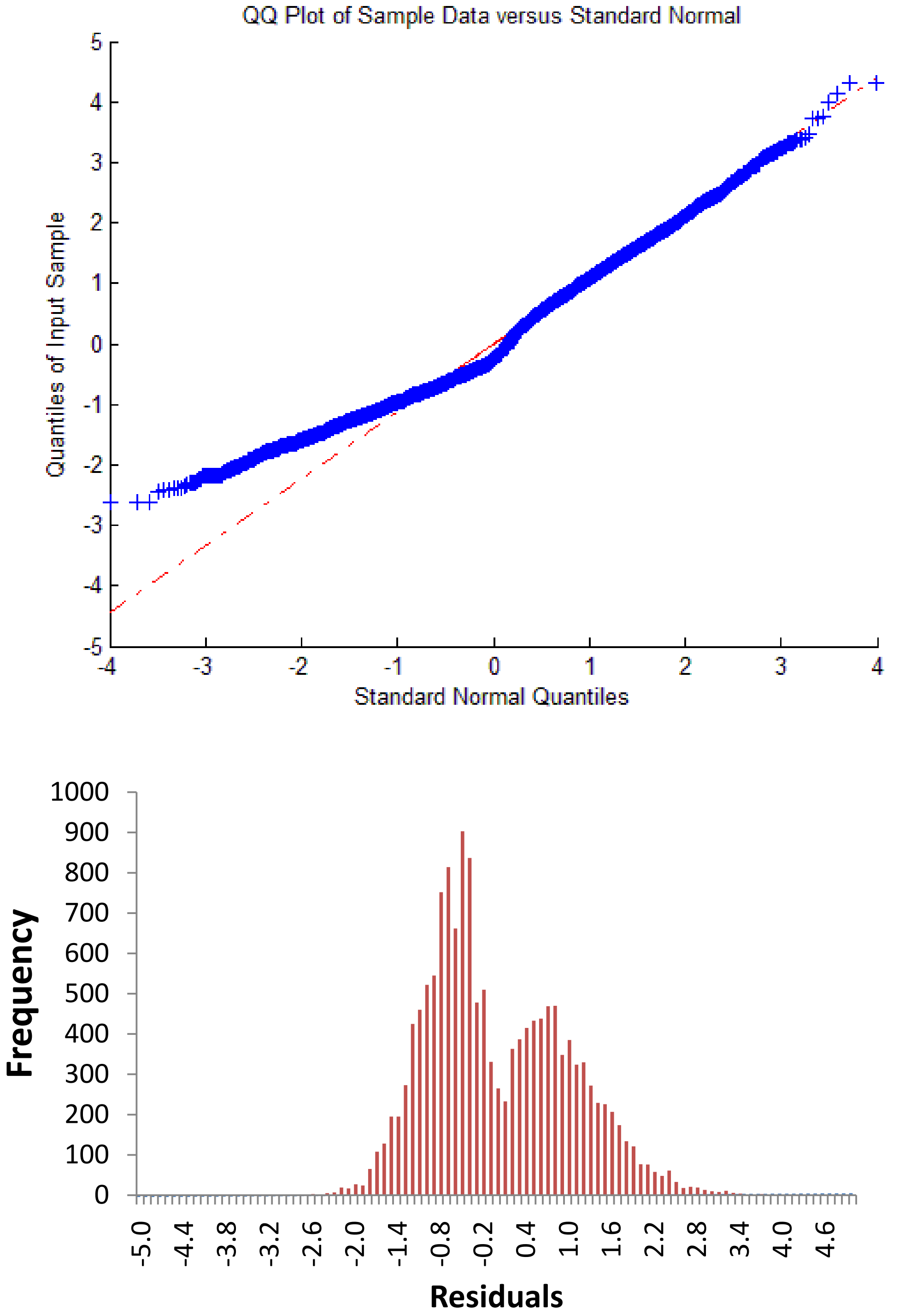
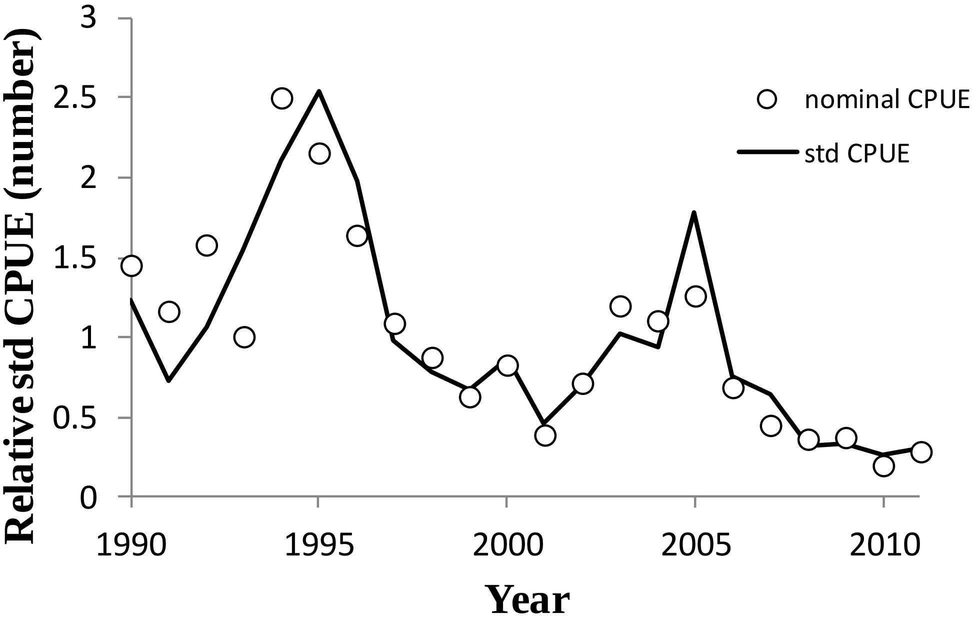
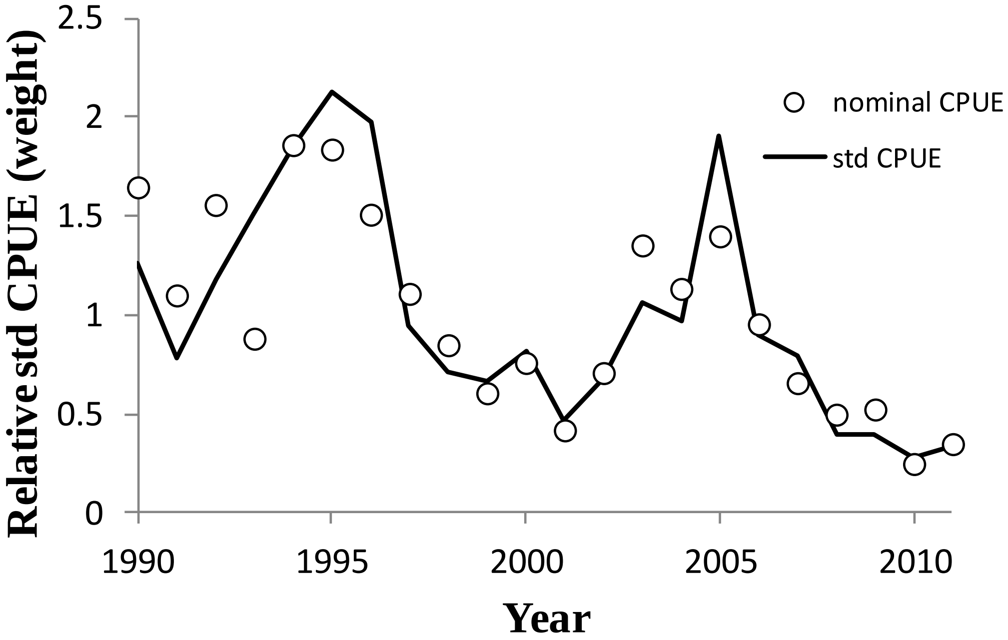


Figure 12. Overall histogram and QQ-plot of standard residuals from the GLM analyses for annual quarter CPUE in number base applying the final model in this study.


3
2.5
2
1.5
1
0.5
0
1990
1995
2000
2005
2010
Year
Relative std CPUE (number)
nominal CPUE
std CPUE


2.5
2
1.5
1
0.5
0
1990
1995
2000
2005
2010
Year
Relative std CPUE (weight)
nominal CPUE
std CPUE

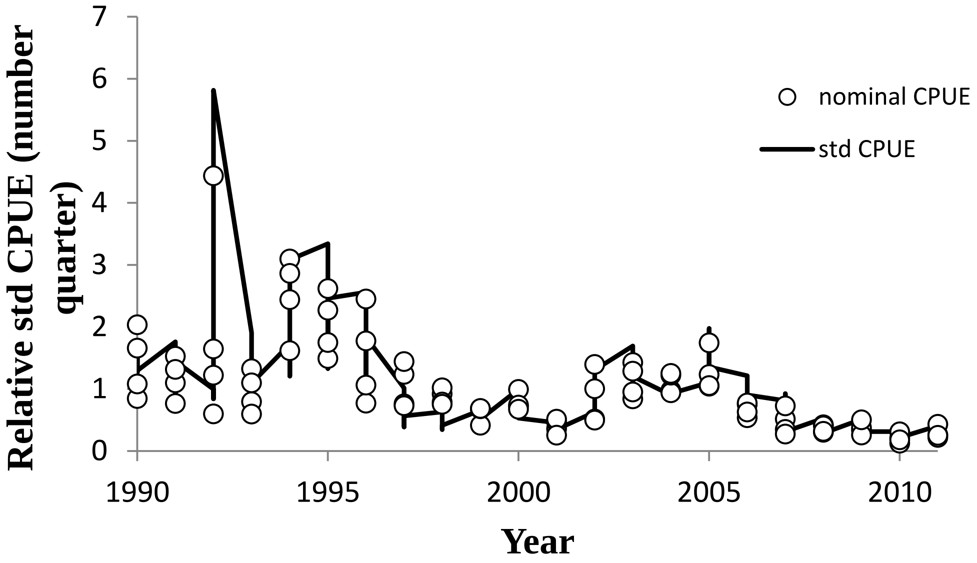


Figure 13. Standardized (solid line) and nominal (open circle) annual CPUE in number (top) , weight (median) and quarter (bottom) base expressed in relative scale in which the average from 1990 to 2011 is 1.0.

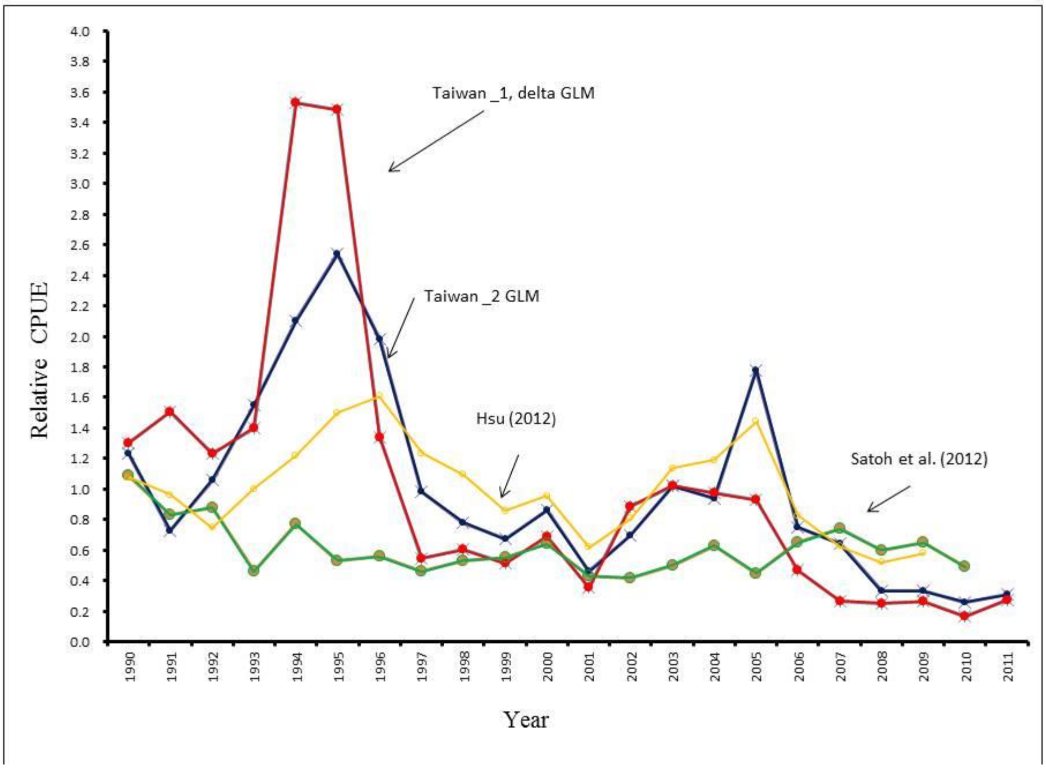


Figure 14. The comparison among different standardized CPUE series of yellowfin tuna by Japanese and Taiwanese longline fleets, in which the values are normalized by average of each series.