Abundance index of Pacific Bluefin tuna (*Thunnus orientalis*) by Taiwanese small-scale longline fleet in the southwestern North Pacific Ocean

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ABSTRACT

Taiwanese small scale longline fleet is the main gear to harvest Pacific bluefin tuna (PBF) in the southeastern, eastern and north eastern waters off Taiwan, The fishery targets giant PBF spawners which almost all PBF in catch are larger than 165 cm in fork length, and seasonally from April to June each year when the spawner aggregated to spawn within the indicated waters. The standardized catch per unit effort of PBF for this fleet is important to be applied to stock assessment as an abundance index of spawners. Taiwanese PBF fishery is composed of only small scale longliners (<100 GRT) with a long history, first as by-catch status and later since1993, as the target species. Other fisheries such as set net, may catch a few PBF incidentally. This longline fleet can change their target species easily toward yellowfin or or bigeye tunas, billfish and swordfish depending on the fishing seasons and market price. Catches are mainly unloaded at ports of Tungkang, Suao and Hsinkang. A trip lasts for about 1 week on an average, the duration depending upon the fishing condition; and whether they deployed either 1 or 2 set(s) per day according to hooks used per set. Salted or fresh squid bait is used. The fishing season of PBF is extended from March to September recently, and most of PBF catches are usually taken in May and June when giant PBF migrate and aggregate for spawning in the waters off Taiwan. Currently almost 60% of PBF landed are domestically consumed and the rest are exported. Collections of catch and effort data of PBF for this fleet was initiated in 1999 and extended to 2008 from auction records at fish markets for catch information; and Port Security Inspection Station for fleet dynamics that is used to estimate fishing effort.; Since 2008 logbook system has been established instead of collecting fishery data for this fleet. Accordingly, a time series of standardized catch per unit effort was estimated by applying general linear model with year, month and vessel’s pattern as fixed factors with and assuming of a Gaussian error structure. The standardized catch per unit effort showed a significant steep declining trend, i.e. a sharp decline from 1999 to 2002, restored and stayed steady in 2003 and 2004; dropped to a low level in 2005 and remained there until 2008, then decreased again 2009 to the historical lowest level of this series in 2010 and 2011.

PREFACE

This paper is updated based on the report (ISC PBF-WG-06-14 and ISC PBF WG-07-25) presented in the ISC Pacific bluefin tuna Working Group Meeting (Shimizu, Japan 2006; 2007) and Lee and Hsu (2008) about the newly updated index of abundance for the Pacific bluefin tuna targeted by Taiwanese small-scale longline fishery. The primary objective of the present study is to generate representative abundance indices included in assessments of the Pacific bluefin tuna updated to 2011.

INTRODUCTION

Pacific bluefin tuna *Thunnus orientalis* is a large highly migratory pelagic species over most of the eastern and western Pacific Ocean, which have been exposed to multi-fisheries since industrial fishing launched in the 1950s. This species represents one of the economically important predatory fish resources. Knowledge about this species has been greatly improved by the long historical fisheries and long-term studies from different fishing nations. Yet, spawning stock was little known before the longliners were intensively commenced in the 1990s for the high-priced sashimi market. Taiwanese small-scale longline fleet (vessels less than 100 GRT) seasonally targeted the spawning stock in the waters off southeastern Taiwan from late April through June. Catches taken by Taiwanese fleet after 1997 were increased to around 10%; particularly the individuals caught are all giant spawners (Chen *et al.* 2006). Therefore, any assessment for this stock should include data compiled from Taiwanese fleet.

A common assumption underlying fish stock assessment is that catch per unit effort (CPUE) is proportional to abundance and therefore can be used as a representative of relative index of abundance. CPUE could be derived from any source of fishery-dependent data and it also might be different from any compiled data. Hence reliable data source is critical in order to reflect the fishery and the examinations on data are necessary to be verified before any statistical analysis and model. Furthermore, the process of reducing influences of any factor on CPUE is substantial, which can be done by applying generalized linear models. Thus, catch and effort data collection and compilation as well as developing a reliable abundance index to represent the spawning stock are very important and urged for Taiwanese fishery.

The primary objective of this study is to model a time series CPUE that can be used as an abundance index for the Taiwanese fishery and for use in assessments of the Pacific bluefin spawning stock. The information should improve data information and further future age-based and length-based stock assessments of the North Pacific bluefin tuna.

MATERIALS AND METHODS

Data collection and compilation

Before 2009, logbooks for this fishery were not available due to highly mobile fishing activities, which fleets can change their target species easily toward other tunas, such as yellowfin tuna, bigeye tuna, and tuna-like species, for example, billfish and swordfish depending on the fishing seasons and market price. To develop relative abundance index, catch and effort data were collected for bluefin tuna from southwestern North Pacific (Fig. 1) when the small-scale longline vessels (mostly 20 to 50 GRT) returned to domestic fishing ports from late-April to early-July. Starting 2009, Overseas Fishery Development Council (OFDC) is in charge of responsibility to distribute and compile logbooks submitted from Taiwanese small scale longline fleet. However, the catch/effort information provided from these logbooks for Pacific bluefin tuna may not be satisfied due to the reasons above mentioned and very low coverage rate (6-17% by Pacific Bluefin tuna catch) for vessels targeting Pacific Bluefin tuna. Thereby, the 2009-2011 fishery data compiled as similar as those before 2008 were used, and the logbooks data for 2009-2011 were used for comparison.

Daily catch data from auction records and time records of vessels in-and-out which can trace the fishing effort of each vessel were collected and compiled at Tungkang port in which most of bluefin tuna were landed. The available information for each data is as tabled below.

	(1) Catch data	(2) Effort data
Source	Tungkang Fishermen's Association	Security Inspect Station at Tungkang port
Kinds	A. date of landing,	A. name of vessel,
	B. name of vessel,	B. size of vessel (in GRT),
	C. number of fish caught,	C. embarkation time,
	D. eviscerated weight for each fish.	D. disembarkation time.

Fishing efforts were estimated as hooks lifted daily, which were estimated from vessels' fishing days. According to interviews with longline vessel captains, daily number of hooks deployed were about 1,200-1,600 hooks. Fishing effort was then converted from fishing days to number of hooks operated with assumption of average 1,400 hooks lifted daily. The estimated fishing days were subtracted two days because the vessel took about one day from Tungkang port to the fishing ground (Fig. 1) and vice versa.

To verify catch and effort data, auction records and estimated fishing efforts for a vessel were merged together when the following criteria were met.

1. The differences between auction date and arrival date of arriving port were less than two days that the time is in need of quality of fish meat for the sashimi market for vessels without freezers. The catches without matching efforts information for a particular vessel were excluded to be processed.

2. Only the vessels operated at and nearby fishing ground in May and June were included in the analysis because longline vessels were not targeting bluefin

tuna and vessels targeted bluefin tuna stayed longer at sea to search fish in the beginning and the end of Pacific Bluefin tuna fishing season. Therefore, we found too many zero catches with an extremely large fishing efforts to be judged as target for vessel operated in April and July.

3. Vessels never caught bluefin tuna throughout the fishing season were excluded to be processed because they targeted other species.

Model used for standardization

To develop a time series of relative abundance index of bluefin tuna caught by Taiwanese small-scale longline fleet, generalized linear model (GLM; Nelder and Wedderburn 1972) was applied to remove the impact of factors which changes fishing effort among vessels such as size, engine power, fishing technology, and catch composition, or cause differences between trips for the same vessel such as fishing time and fishing location (Gulland 1983). The available information for each trip recorded in the catch and effort data includes:

1. Year (1999-2011);
2. Month (May and June);
3. Size of vessel (3 levels, 10-20 GRT, 20-50 GRT and 50-100 GRT);
4. Effort (number of hooks);
5. Catch in number.

Therefore, A step-wise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed CPUE variability. Then the Chi-square (χ^2) distribution was used to test significance of an additional factor in the model and the number of additional parameters associated with the added factor minus one corresponds to the number of degree of freedom in the χ^2 test (McCullagh and Nelder 1989). Deviance analysis tables are presented the difference of deviance between two consecutive models. Because factor combinations had unequal numbers of observations, final selection of explanatory factors was conditional on significance of the χ^2 test and the type III test of significance within the final specified model.

Consequently, as Table 1 indicates that all two-way interaction combinations are not statistically significant, thus factors considered for GLM were fishing year, month, and size of vessel. All two-way interaction among year, month and size of vessel were excluded in the relative CPUE estimation. The fixed factors are the linear combination with expected logarithmic catch per unit effort (lnCPUE) assuming a Gaussian error distribution (Figure 9). To avoid zero CPUE making trouble with logarithmic transformation, a constant was added to all CPUEs. The full model used for GLM analyses as follows.

$$\ln(CPUE_{ijk}+constant) = \mu + Y_i + M_j + S_k + Y_i*M_j+Y_i*S_k+M_j*S_k + \varepsilon_{ijk}, \qquad (1)$$

where μ is overall mean, *constant* is 10% of overall mean of nominal CPUEs, Y_i is effect of year i, M_j is effect of month j, S_k is effect of size of vessel k, and ε_{ijk} is error term with $N(0, \sigma^2)$.

Relative index was calculated as the year effect least square means (LSMeans) for GLM because the primary objective is to detect trends over year in abundance. The analyses were run with the SAS GENMOD and GLM procedures (SAS Inst. Inc.) for model selection and GLM model, and MIX procedure was run for the general linear mixed model (Lee et al. 2006) for terms with "Year" two way interactions (Year*Mon and Year*level); and the error structure was assumed as a delta lognormal distribution.

RESULTS AND DISCUSSION

Catch, effort, and catch per unit effort

Catches of Pacific Bluefin tuna by Taiwanese fleets were reported by Tungkang and Suao Fisherman Associations mainly when auction had been progressed and very minor catches were reported from other fish markets, such as Hsinkang, etc. Those catches were mostly made by small scale longline vessels resided at those fishing harbors. Those catches were composited of about 99% of total annual Pacific Bluefin catch. The annual nominal catch of Pacific Bluefin tuna by Taiwanese small scale longline fishery is illustrated in Figure 2 from 1965 to 2011.

Taiwanese small scale longline vessels operate for Pacific Bluefin tuna at the waters off southeastern, eastern and northeastern Taiwan from April to June before 2009 and to July in 2011, when Pacific Bluefin tuna make their spawning migration and aggregate at the mentioned waters. The monthly composition of Pacific Bluefin catch is illustrated in Figure 3, indicating that May and June are the main fishing season.

Fishing effort was estimated in number of fishing days and then was converted to number of hooks, assuming 1,400 hooks operated in one day. Time series of mean effort per trip was illustrated in Figure 4 and it indicates that the mean effort was around 12,500-14,000 hooks from 1999 to 2001, reached to about 16,000 hooks in 2002, then declined to 11,800 hooks in 2004, and increased to the same level with 2002 in 2006 and to 19,000 hooks in 2007, dropped to about 10,000 hooks in 2008, then increased again to about 16,000 hooks in 2009, 19,000 hooks in 2010, and declined to 16,000 hooks in 2011. Also, the number of fishing vessels anticipated in fishing Pacific Bluefin tuna and landed Pacific bluefin tuna at those mentioned fishing ports, as indicated in Figure 5, rapidly increased from 468 vessels in 1999 to 684 vessels in 2002, decreased to 657-617 vessels between 2003 and 2005, and dropped down to 518 vessels in 2006, to 480-490 vessels from 2007 to 2009, and abruptly to 351 vessels in 2010 and 290 vessels in 2011.

Figure 6 expressed the sampling ratio from 2004 to 2011 by counting the numbers of Pacific bluefin tuna in catch/effort estimation divided by the total catch of pacific Bluefin tuna in the corresponding year. The sampling ratio was lowest level about 29.61% in 2005, and the highest about 83.79% in 2009. In comparison with the coverage of Pacific Bluefin tuna catch in logbooks from 2009 to 2011, the lowest sampling ratio about 6.54% in 2011 to the highest about 17.49% in 2010. The comparison may imply that the aution data may be much more appropriate to represent the stock and further to apply in standardizing catch per unit effort than those from the logbooks.

Nominal catch per unit effort series of Pacific bluefin tuna caught by the Taiwanese small-scale longline fleet was estimated by an average of number of fish per 1,000 hooks for each trip and is illustrated in Figure 7, and by an average of mass of fish per 1,000 hooks in Figure 8. The nominal catch per unit effort (in number per 1,000 hooks) depicted a sharp declining trend from 1999 to 2002, slightly increased in

2003 and 2004, and then fell down to value in 2005; a very slight increase to 2008, then sharply declined again to the historical lowest level in 2010; and increased to the 2009 level in 2011.. The nominal catch in mass per unit effort, in kg per 1,000 hooks (Figure 8), increased from about 170 kg/1,000 hooks in 1999 to about 210 kg/1,000 hooks; dropped abruptly to about 80 kg/1,000 hooks in 2001 and 60 kg/1,000 hooks in 2002; increased to the 2001 level in 2003 and about 120 kg/1,000 hooks in 2004; fell down to about 70 kg/1,000 hooks in 2005 and slightly decreased continuously to about 60 kg/1,000 hooks in 2007; restored to around 100 kg/1,000 hooks in 2008; and dropped abruptly to the historical lowest level (below 20 kg/1,000 hooks) in 2010 and slightly increased to about 40 kg/1,000 hooks in 2011.

The frequency distribution of arithmetic and logarithmic nominal catch per unit effort are illustrated in Figure 9, indicating that a log-normal distribution is found for the former, and a normal distribution for the later.

Abundance index

The abundance index of spawning bluefin tuna from Taiwanese longline fleet was developed using the collected catch and effort data by general linear model. Considering all bluefin fisheries from western North Pacific, Taiwanese fishery is a seasonally local fishery with apparent fishing season even though the detailed fishing position is bounded within the waters off eastern Taiwan. On the other hand, spawning bluefin density appears to be spatially homogeneous regarding this fishing ground.

The analysis of deviance from step-wise regression (Table 1) indicates that factors of year, month, and the size of the vessel type and two way interaction of Year*Month and Year*vessel type are significant for Chi-square test (p <0.0001) (Table 1) and therefore two approaches were proceeded: as is the base case, the three fixed factors, excluding two way interactions, were selected into GLM fitting to standardize CPUE of Pacific bluefin tuna caught by Taiwanese small-scale longline fishery from 1999 to 2011. Further, for the sensitivity analysis, addressing the two way interactions including “Year” factor, the general linear mixed model (GLMM) was applied to treat two-way interaction as random effects to standardize CPUE of Pacific Bluefin tuna by the fleet.

To validate the error assumption, the ANOVA to diagnosis the linear fitting of three fixed factors is tabulated in Tables 2-a, b, indicating that the linear effect of three factors under normal error distribution is statistically highly significant (p <0.0001); and the frequency distribution of residuals and the quantile-quantile (Q-Q) plot of residuals were examined (Figure 10). The distribution of residuals illustrates a normal distribution with zero mean and one standard deviation, and Q-Q plot demonstrates that most of residuals rely on 45° line. Also, normality of residuals were tested by the Kolmogorov-Smirnov (Sokal and Rohlf 1995), indicating that distribution of residuals follow normal distribution (D=0.037, p <0.01 for GLM procedure and D=0.029, p <0.01 for GLMM procedure).

The two-way interaction of Year*Month and Year*Vessel type were included in the GLM analysis with delta lognormal error assumption to estimate abundance index; and the results of different procedures and reported previously were compared visually with their medians. The ANOVA to diagnosis the assumption is tabulated in Tables 2-c, d, indicating that 3 fix factors and 2 two-way interaction are highly significant (p <0.0001) and the distribution of residuals is illustrated in Figure 11.

Standardized CPUE by GLM is illustrated in Figure 12. Annual abundance index sharply declined from the highest in 1999 to the lowest in 2002, restored and stayed steady in 2003 and 2004, and dropped down to the low level in 2005 and 2006, following a slight increase in 2008, further continuing a two-year decline in 2009 and 2010, and restored to 2009 level in 2011. Also, temporal changes and changes of size of vessel of standardized CPUE showed that bluefin tuna was more abundant in May than in June by operating lager vessels. Less abundant bluefin tuna in 2002, 2005 and 2006 may be due to declined catches from the longline fisheries. The consistent trend of abundance index with that of total catch provide evidence that the catch and effort data collected and compiled in this study could be used to develop representative abundance index of spawning bluefin tuna targeted by Taiwanese small-scale longline fishery.

Moreover, the abundance indices of Pacific Bluefin tuna, estimated by general linear model and general linear mixed model, for the representative of the fishing fleet of the current study show little difference in median, however, a great discrepancy was found in standard deviation (Figures 13 and 14).

Comparison among medians of estimated standardized catch per unit effort in previous workshops (ISC/PBFWG/2006; ISC/PBFWG/2007; ISC/PBFWG/2010; ISC/PBFWG/2012-1) and the current version indicated that those series are coincident within the overlapping years (Figure 15). Therefore, both of standardized catch per unit effort estimated by general linear model and general linear mixed model are valid to represent the abundance of spawner of Pacific Bluefin tuna by Taiwanese longline fishery. The abundance of large spawner of Pacific Bluefin tuna have been gradually declining since 2003 from year to year.

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Table 1 Results of stepwise linear regression statistics for type 3 analysis for model selection .

Source	DF	Chi-Sq	$P_r > ChiSq$
1.Intercept	1	17174.3	<0.001
2. Intercept+Year			
Year	12	1164.72	<0.001
3. Intercept+Year+Month			
Year	12	1169.66	<0.001
Month	1	507.30	<0.001
4. Intercept+Year+Month+Level			
Year	12	1137.58	<0.001
Month	1	510.07	<0.001
Level	2	86.55	<0.001
5. Intercept+Year+Month+Level+Year*Month			
Year	12	964.07	<0.001
Month	1	342.86	<0.001
Level	2	86.88	<0.001
Year*Month	12	262.77	<0.001
6. Intercept+Year+Month+Level+Year*Month+Year*Level			
Year	12	537.57	<0.001
Month	1	340.50	<0.001
Level	2	82.55	<0.001
Year*Month	12	261.53	<0.001
Year*Level	24	47.16	0.0032
7. Intercept+Year+Month+Level+Year*Month+Year*Level+Month*Level			
Year	12	536.72	<0.001
Month	1	257.56	<0.001
Level	2	82.15	<0.001
Year*Month	12	259.87	<0.001
Year*Level	24	47.62	0.0028
Month*Level	2	0.68	0.7113

Table 2. ANOVA table of explanatory variables in generalized linear model for bluefin tuna CPUE (in number per 1,000 hooks) from Taiwanese longline fleet for 1999-2011.

(a) For GLM procedure standardized CPUE (no./1000 hooks)

Source	DF	Sum of square	Mean square	F	$P_r > F$
Model	15	1956.697	130.446	131.74	<0.0001
Error	7534	7460.231	0.990		
Corrected total	7549	9416.928			

R-square	Coefficient of variation	Root MSE	logCPUE mean
0.2088	-59.0767	0.9951	-1.6844

Source	DF	Type III SS	Mean square	F value	$P_r > F$
Year	12	1213.155	101.096	102.10	<0.0001
Month	1	521.420	521.420	526.58	<0.0001
Vessel type	2	86.009	43.005	43.43	<0.0001

(b) For GLMM procedure standardized CPUE (no./1,000 hooks)

Source	DF	Sum of square	Mean square	F	$P_r > F$
Model	51	2256.742	44.2498	46.34	<0.0001
Error	7498	7160.186	0.9549		
Corrected total	7549	9416.928			

R-square	Coefficient of variation	Root MSE	logCPUE mean
0.2396	-58.0153	0.9972	-1.6844

Source	DF	Type III SS	Mean square	F value	$P_r > F$
Year	12	528.399	44.033	46.11	<0.0001
Month	1	330.309	330.309	345.89	<0.0001
Vessel type	2	78.721	39.360	41.22	<0.0001
Year*Month	12	252.371	21.031	22.02	<0.0001
Year*Vessel type	24	44.866	1.869	1.96	0.0034

(c) For GLM procedure standardized CPUE (no./1000 hooks) (kg/1000 hooks)

Source	DF	Sum of square	Mean square	F	$P_r > F$
Model	15	1584.872	105.658	104.82	<0.0001
Error	7469	7528.931	1.008		
Corrected total	7484	9113.803			

R-square	Coefficient of variation	Root MSE	logCPUE mean
0.1738	27.3515	1.0040	3.6707

Source	DF	Type III SS	Mean square	F value	$P_r > F$
Year	12	870.962	72.580	72.00	<0.0001
Month	1	534.611	534.611	530.36	<0.0001
Vessel type	2	79.045	39.523	39.21	<0.0001

d) For GLMM procedure standardized CPUE (kg/1,000 hooks)

Source	DF	Sum of square	Mean square	F	$P_r > F$
Model	51	1872.912	36.724	37.70	<0.0001
Error	7433	7240.891	0.974		
Corrected total	7484	9113.803			

R-square	Coefficient of variation	Root MSE	logCPUE mean
0.2055	26.8881	0.9870	3.6707

Source	DF	Type III SS	Mean square	F value	$P_r > F$
Year	12	370.212	30.851	31.67	<0.0001
Month	1	336.501	336.501	345.43	<0.0001
Vessel type	2	76.792	38.396	39.41	<0.0001
Year*Month	12	227.833	18.986	19.49	<0.0001
Year*Vessel type	24	57.421	2.393	2.46	<0.0001

Table 3. Values of standardized CPUE of Pacific Bluefin tuna by Taiwanese longline fleet from 1999-2011.

(a) Standardized by general linear model (unit: no./1000 hooks)

Year	CPUE	Lower_CPUE	Upperr CPUE	Nominal CPUE
1999	0.413056	0.368806	0.462159	0.921996
2000	0.342403	0.310456	0.377308	0.836641
2001	0.201139	0.181769	0.222243	0.378224
2002	0.127427	0.11257	0.143783	0.247032
2003	0.179934	0.159812	0.202137	0.392716
2004	0.173522	0.159493	0.188564	0.408846
2005	0.092097	0.082681	0.102267	0.214318
2006	0.109167	0.098066	0.121196	0.235489
2007	0.092075	0.074380	0.112642	0.230923
2008	0.121337	0.111219	0.132156	0.284235
2009	0.093483	0.085581	0.101904	0.148129
2010	0.058802	0.052022	0.066112	0.066642
2011	0.107214	0.092485	0.123648	0.144345

(b) Standardized by general linear mixed model (unit:no./1000 hooks)

Year	CPUE	Lower_CPUE	Upperr CPUE	Nominal CPUE	CV
1999	0.443933	0.260386	0.741653	0.921996	0.224757
2000	0.337595	0.195894	0.566376	0.836641	0.222550
2001	0.235964	0.133051	0.402016	0.378224	0.222253
2002	0.145970	0.076923	0.257732	0.247032	0.223759
2003	0.170438	0.091719	0.298180	0.392716	0.224965
2004	0.192825	0.106856	0.331008	0.408846	0.220432
2005	0.107257	0.053493	0.193803	0.214318	0.221125
2006	0.125462	0.064682	0.223416	0.235489	0.221696
2007	0.129884	0.061677	0.246368	0.230923	0.249392
2008	0.141344	0.074999	0.247819	0.284235	0.219690
2009	0.117074	0.059944	0.208692	0.148129	0.219346
2010	0.071421	0.031356	0.135792	0.066642	0.220219
2011	0.127487	0.065417	0.228042	0.144345	0.224171

(c) Standardized by general linear model (unit: kg/1000 hooks)

Year	CPUE	Lower_CPUE	Upperr CPUE	Nominal CPUE
1999	81.31731	73.20637	90.32649	164.6076
2000	72.03595	65.87524	78.77251	159.6866
2001	47.11336	43.20576	51.37409	75.63069
2002	32.83833	29.79871	36.18764	50.70929
2003	40.91510	37.04149	45.19341	73.17150
2004	42.59250	39.69327	45.70332	84.59848
2005	26.27625	24.30443	28.40782	45.97296
2006	30.09166	27.74547	32.63600	50.77753
2007	26.85207	23.06699	31.25731	50.54849
2008	33.15509	30.98348	35.47875	63.26107
2009	31.12111	29.12355	33.25552	34.31623
2010	21.50835	19.92740	23.21451	16.74411
2011	34.08886	30.51691	38.07842	37.50050

(d) Standardized by general linear mixed model (kg/1000 hooks)

Year	CPUE	Lower_CPUE	Upperr CPUE	Nominal CPUE	CV
1999	86.69965	54.19806	138.6794	164.6076	0.218041
2000	70.07110	44.04405	111.4663	159.6866	0.215411
2001	54.36364	34.18609	86.43846	75.63069	0.21516
2002	36.74038	23.01091	58.64920	50.70929	0.216986
2003	39.33955	24.56831	62.97922	73.17150	0.218364
2004	46.51648	29.37375	73.65203	84.59848	0.213153
2005	29.39562	18.53049	46.61949	45.97296	0.213849
2006	33.09202	20.82961	52.56132	50.77753	0.214591
2007	34.10732	20.21626	57.52690	50.54849	0.243216
2008	37.38404	23.65684	59.06498	63.26107	0.212101
2009	37.37683	23.65921	59.03631	34.31623	0.211962
2010	24.40695	15.42242	38.61380	16.74411	0.212654
2011	38.57305	24.16476	61.55998	37.50050	0.216881

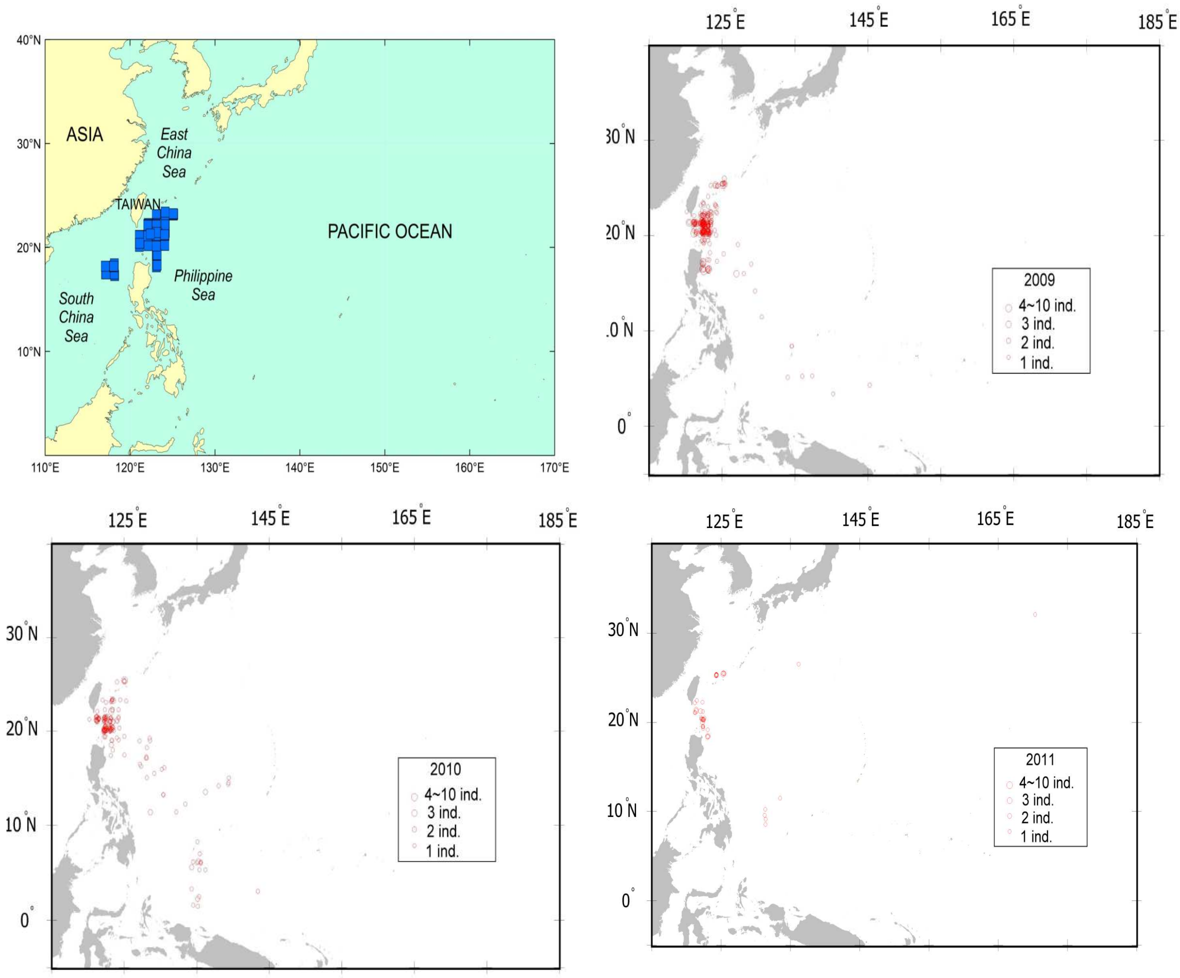


Figure 1. Location of the fishing area for Taiwanese small-scale longline fleet targeting Pacific bluefin tuna in the waters off southeastern Taiwan.

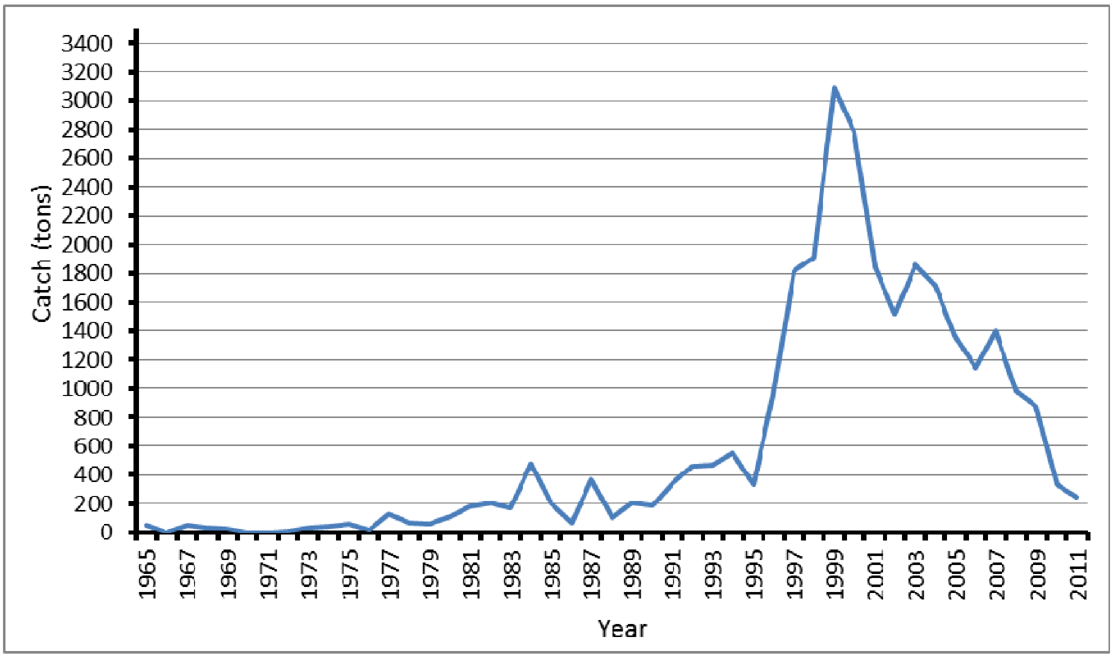


Figure 2. Annual catch of Pacific bluefin tuna by Taiwanese small scale longline fleet from 1965 to 2011.

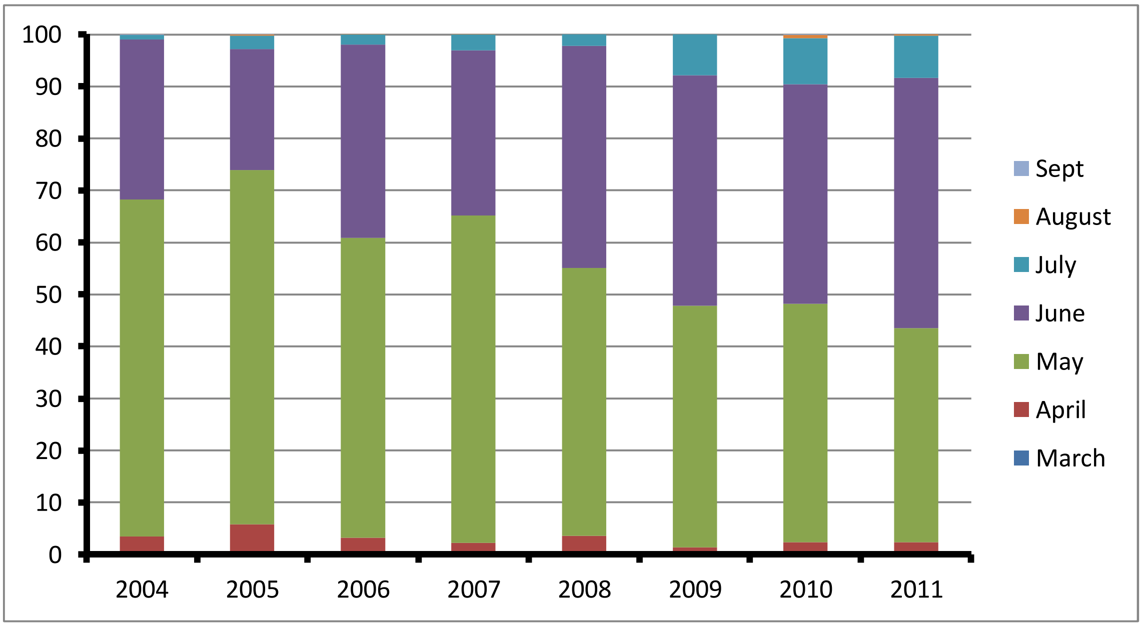


Figure 3. Monthly proportion of Pacific Bluefin tuna caught by Taiwanese longline fleet from 2004 to 2011.

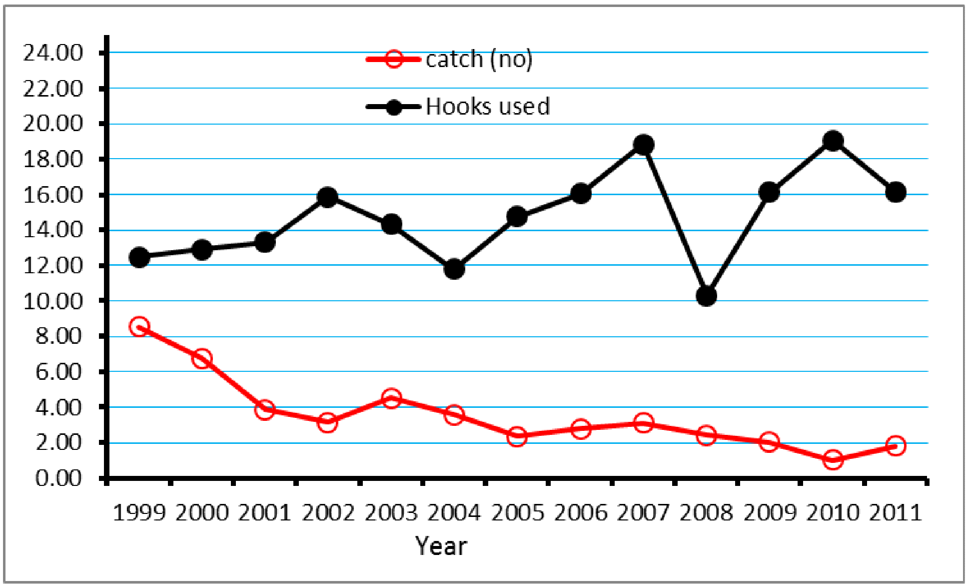


Figure 4. Mean catch in number and mean hooks used in 1000 hooks per trip of Pacific bluefin tuna caught by Taiwan small longline fleet in May and June each calendar year.

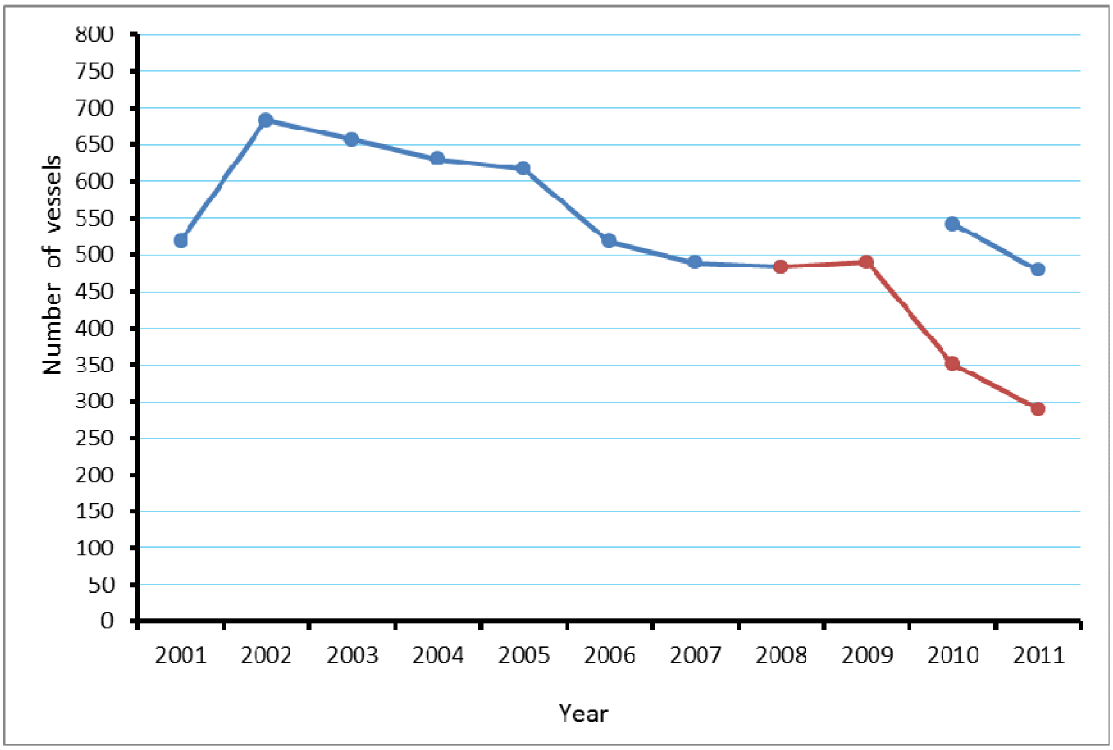
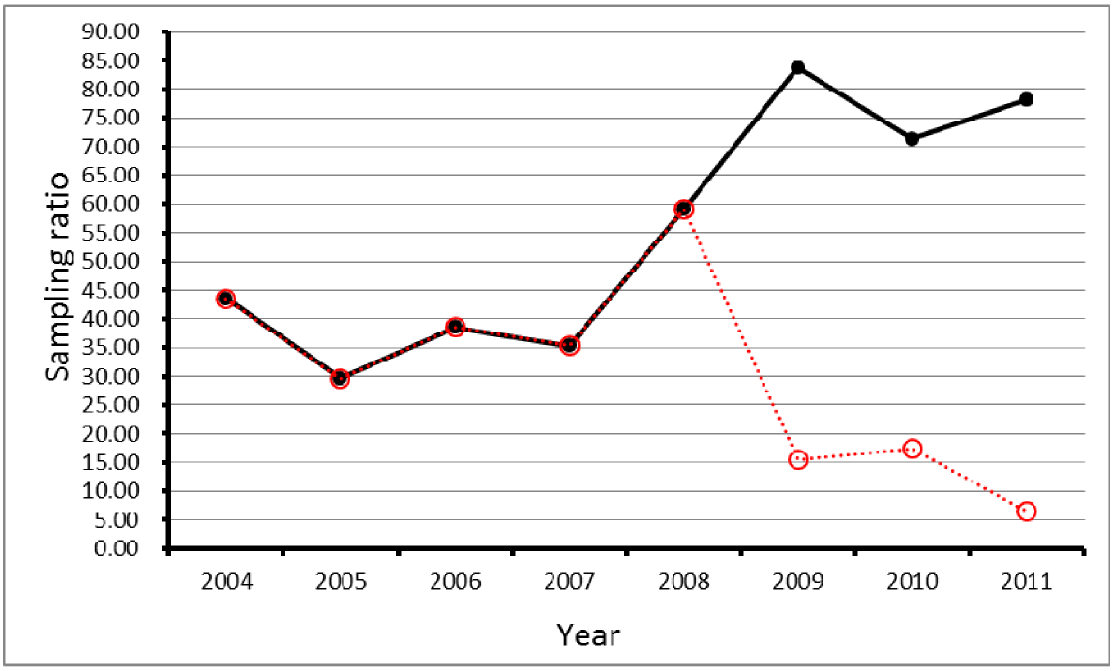
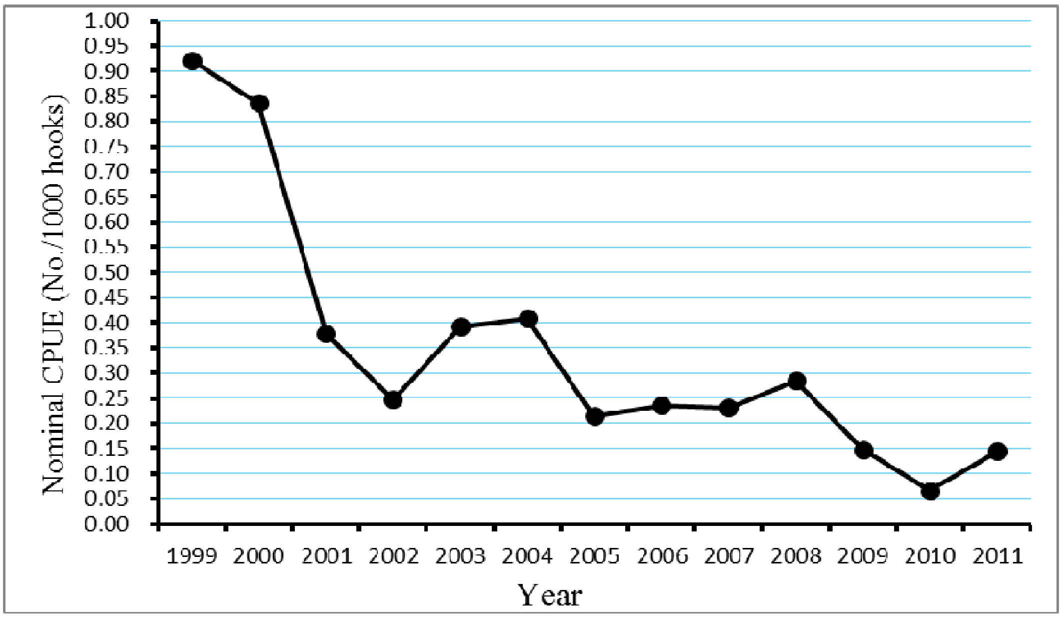


Figure 5. The number of fishing vessels anticipated in fishing Pacific Bluefin tuna and landed Pacific bluefin tuna at those domestic fishing ports. Reported active (red line) and total registered vessels were indicated.

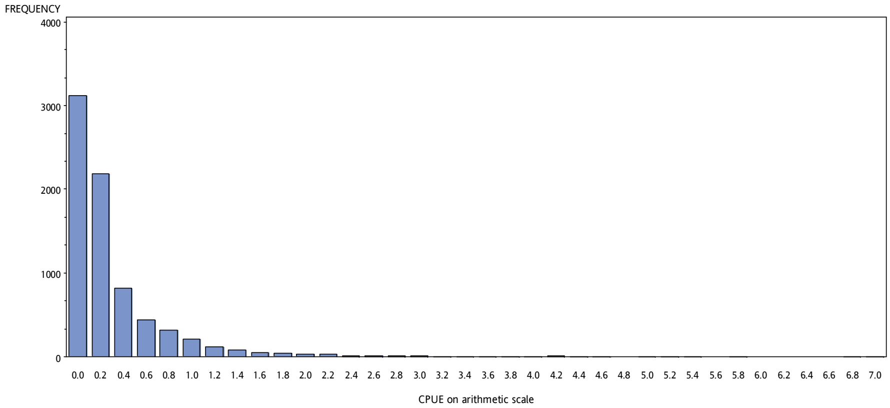


Figue 6. Sampling ratio of catch-effort for estimating abundance index (# of sampled fish/total # of fish caught), where the open circles with dot line from 2009 to 2011 indicated the logbook data used provided by Oversea Fisheries Development Council and applied in the previous estimation (ISC/PBFWG/2012-1).



Figur 7. Time series nominal CPUE (individual/1000 hooks) of bluefin tuna caught by Taiwanese small-scale longline fishery in the southwestern North Pacific Ocean for 1999-2011.

Figure 8. The time series nominal catch per unit effort in kg/1000 hooks of. bluefin tuna caught by Taiwanese small-scale longline fishery in the southwestern North Pacific Ocean for 1999-2011.



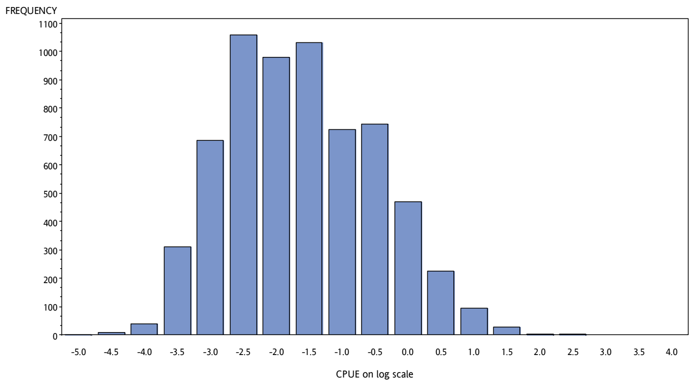


Figure 9. Frequency distribution of nominal catch per unit effort of Pacific Bluefin tuna caught by Taiwanese small scale longline fleet during May and June each year from 1999 to 2011 (upper panel: arithmetic scale; lower panel: logarithmic scale).

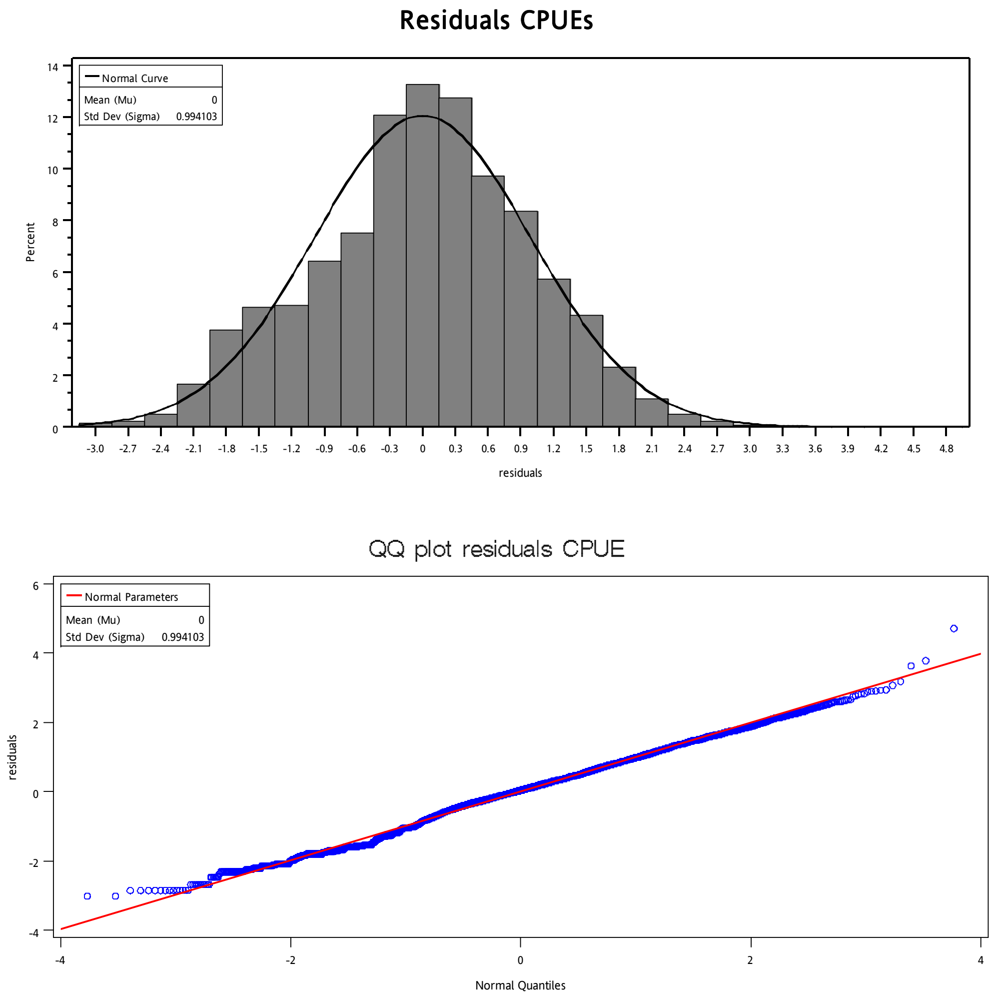


Figure 10. The frequency distribution of residuals derived from generalized linear model expressed in histograms (upper panel) and quantile-quantile plots (lower panel) with log-normal error structure to standardize CPUE of bluefin tuna caught by Taiwanese small-scale longline fishery for 1999-2011.

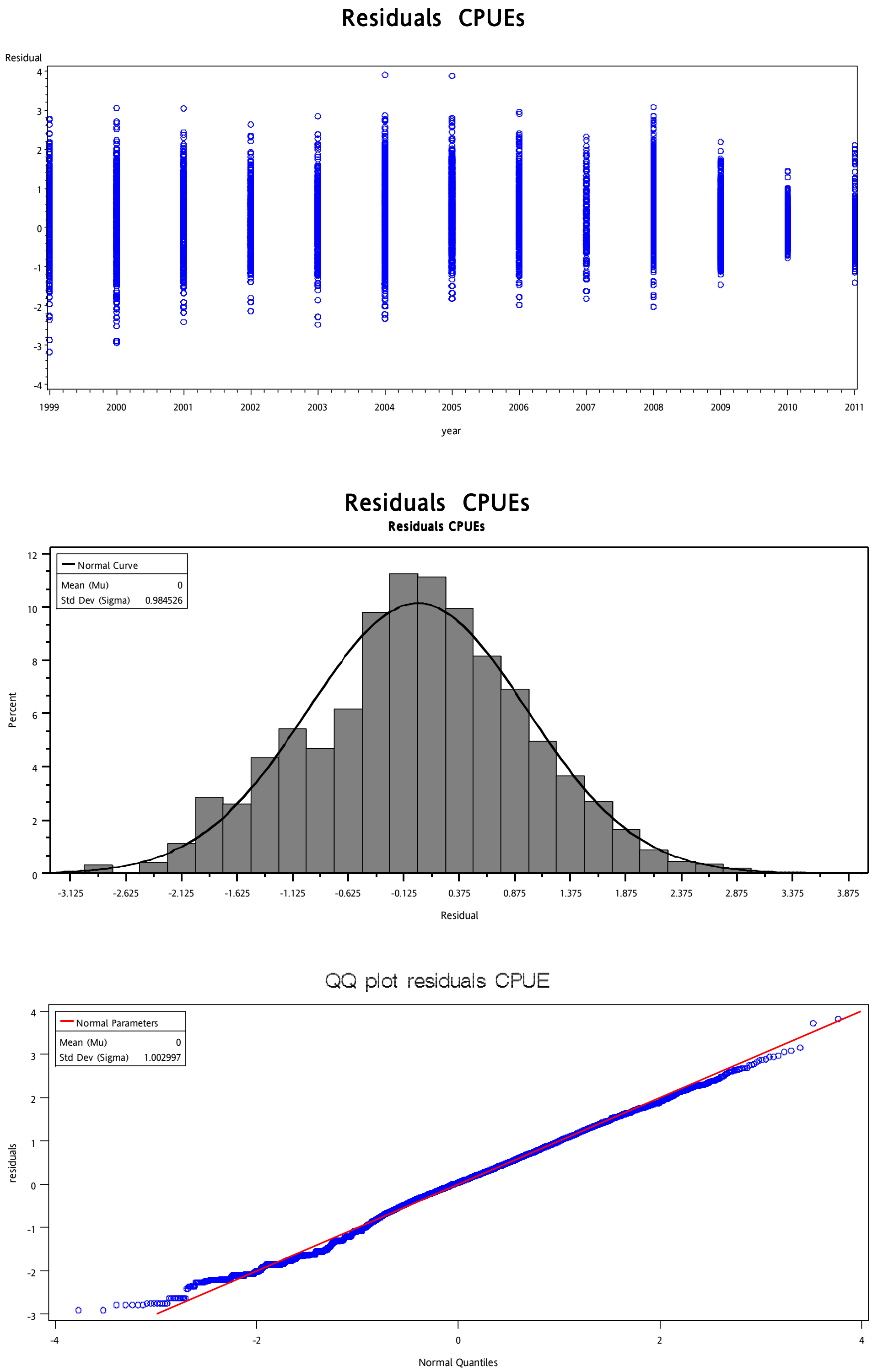


Figure 11. Distribution of residuals for generalized linear model with random effects to estimate abundance index of Pacific Bluefin tuna by Taiwanese longline fleet.

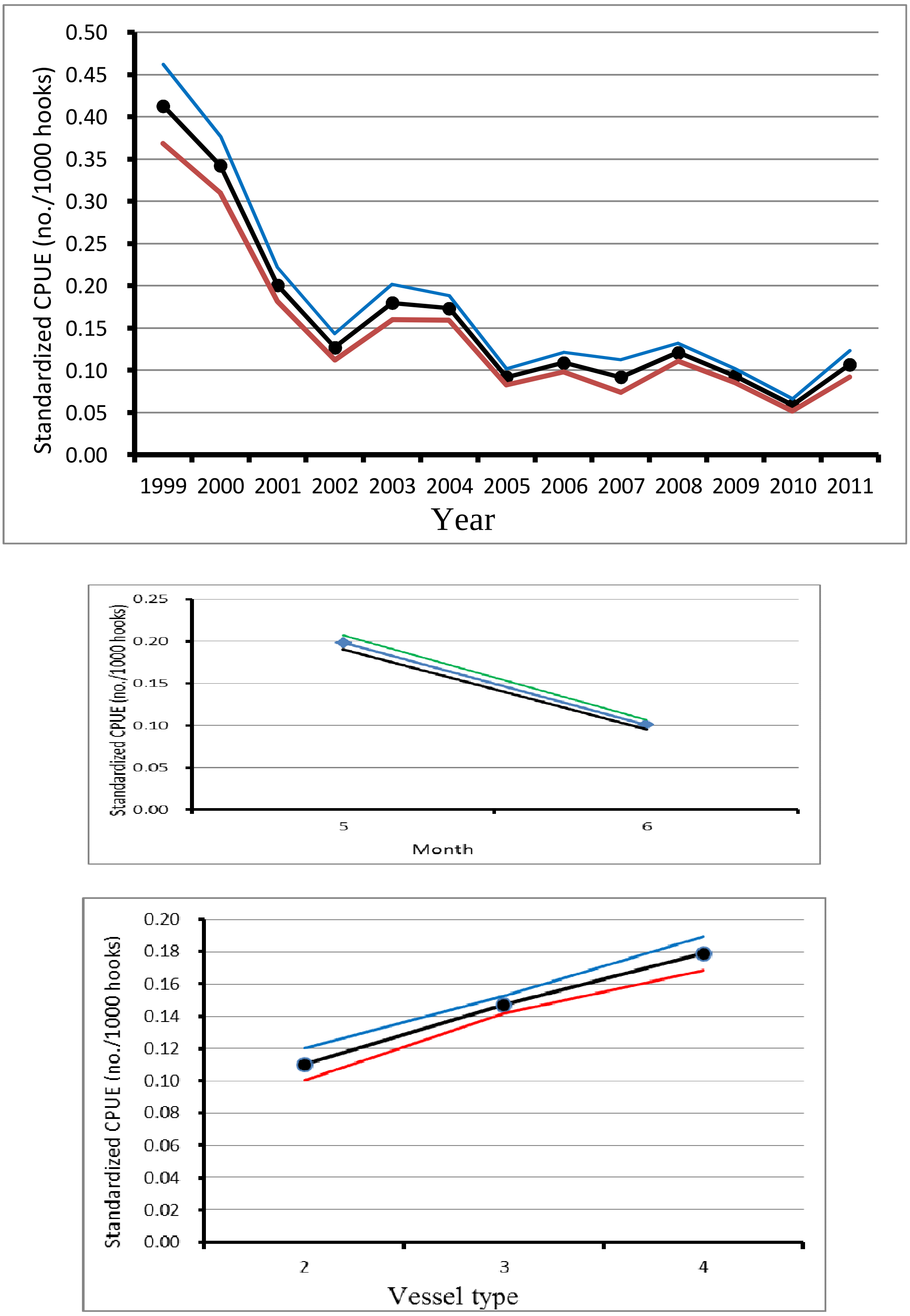


Figure 12. Time series of abundance index (upper panel), monthly variation of standardized catch per unit effort (middle panel) and standardized series by size of vessel (lower panel) of northern Pacific bluefin tuna estimated by general linear model from Taiwanese small-scale longline fishery. Lines without symbols represent the 95% confidence intervals for standardized catch per unit effort.

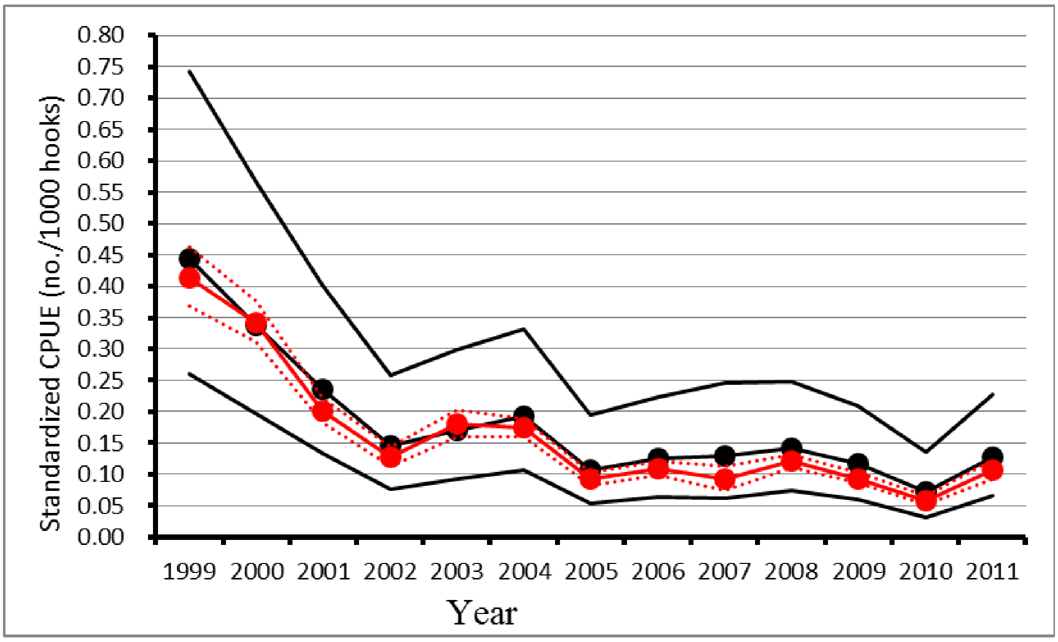


Figure 13. Comparisons between time series of abundance index expressed by standardized catch per unit effort (no./1000 hooks) of Pacific bluefin tuna estimated by general linear model and general linear mixed model from Taiwanese small-scale longline fishery. Lines without symbols and dot lines represent the 95% confidence intervals for standardized catch per unit effort.

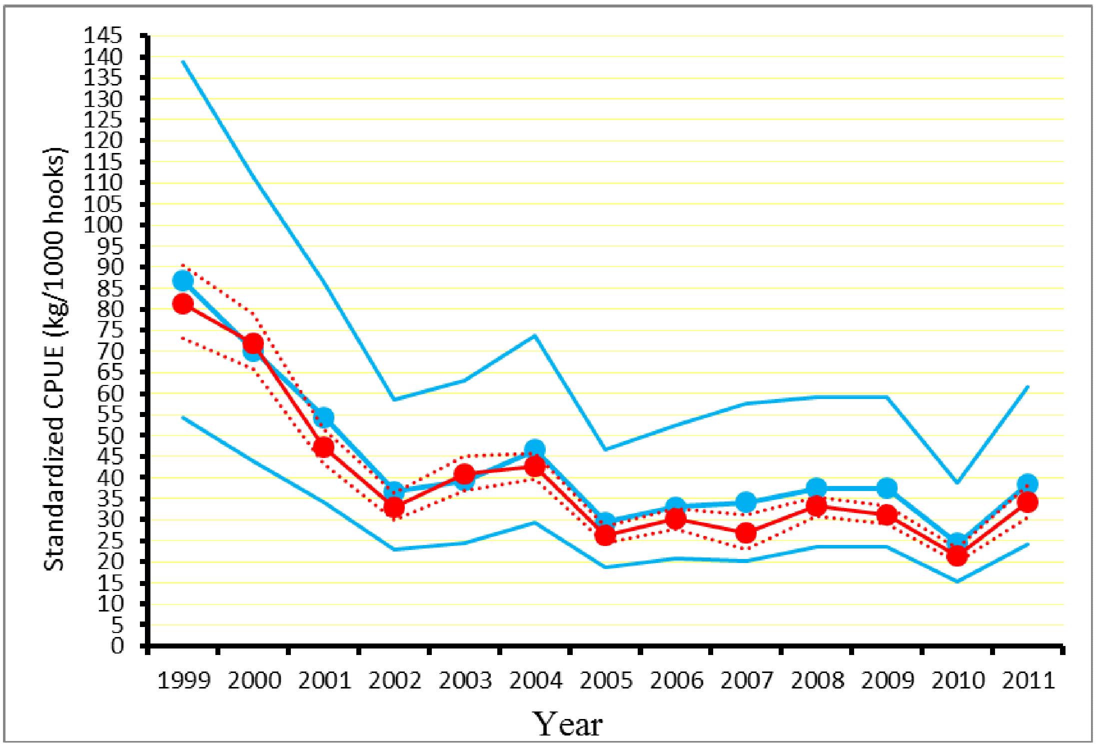


Figure 14. Comparisons between time series of abundance index expressed by standardized catch per unit effort (kg/1000 hooks) of Pacific bluefin tuna estimated by general linear model and general linear mixed model from Taiwanese small-scale longline fishery. Dot lines and lines without symbols represent the 95% confidence intervals for standardized catch per unit effort

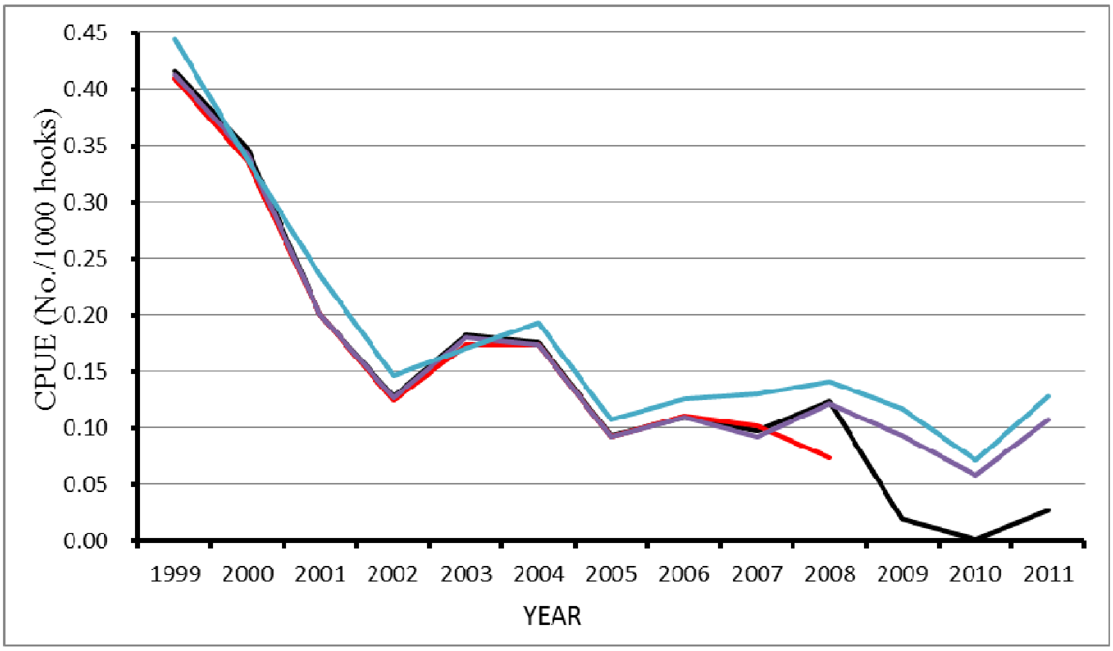


Figure 15. Comparisons among abundance indices of Pacific Bluefin tuna, estimated during different periods (ISC/PBFWG/2006/14; ISC/PBFWG/2007/25; Lee and Hsu 2008; ISC/PBFWG/2010, 2012-1 oral presentations), caught by Taiwanese longline fleet by eneral linear models under normal errot structure and general linear mixed model under Delta lognormal error structure.