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Standardized catch per unit effort of Pacific bluefin tuna (*Thunnus orientalis*) by general linear model for Taiwanese small-scale longline fishery in the southwestern North Pacific Ocean

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Standardized catch per unit effort of Pacific Bluefin tuna (*Thunnus orientalis*) by general linear model for Taiwanese small-scale longline fishery in the southwestern North Pacific Ocean [1]

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ABSTRACT

Longline is the main gear to harvest Pacific bluefin tuna (PBF) in the southeastern, eastern and northeastern waters off Taiwan. The fishery targets giant PBF spawners larger than 165 cm in fork length, and seasonally from April to June each year when the spawner aggregated to spawn within the waters above mentioned. The standardized catch per unit effort of PBF for this fleet is important to stock assessment as an abundance index of spawners. Taiwanese PBF fishery is composed of 3 categories using lonelines. 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 landed at ports of Tungkang, Suao and Hsinkang. A trip lasts from few days to longer than a week on an average, 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 more than 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 from auction records at fish markets for landing information; and Port Security Inspection Station to estimate fishing effort. 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 an assumption of a lognormal error structure. The standardized catch per unit effort showed a significant declining trend from 1999 to 2002, restored and stayed steadily in 2003 and 2004; dropped again in 2005 and remained with a slight fluctuation until 2008, then decreased to the historical lowest level of this series in 2010, then increased.

PREFACE

This paper is updated based on the reports (ISC PBF-WG-06-14 and ISC PBF WG-07-25 and ISC/12-2/PBFWG/14) presented in the ISC Pacific bluefin tuna Working Group Meeting (Shimizu, Japan 2006; 2007; 2012) 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 2013.

INTRODUCTION

Pacific bluefin tuna *Thunnus orientalis* is a large highly migratory pelagic species over most of the eastern and western North Pacific Ocean, which have been surffered to multi-fisheries since industrial fishing launched dated back 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, eastern and northeastern Taiwan from March through September. Catches taken by Taiwanese fleet after 1997 were increased to around 10% of the total landings over fisheries; particularly the individuals caught are all giant spawners (Chen *et al.* 2006), and decreased abruptly from 2000 till 2010 (Hsu and Wang 2012), and then slightly increased to the recent. 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.

Before computation for standardization, two kinds of data were merged together, which were catch data and fishing effort estimation. Those data were obtained from Regional Fisherman Association and Security Inspect Station at Tungkang Port before 2011; and Suao and Hsinkang Ports were then included after 2012 because of significantly increasing disembarkation of Pacific Bluefin tuna fishing vessels at these two Ports. Information for both catch and effort data was composed of:

	(1) Catch data	(2) Effort data
Kinds	A. date of landing, B. name of vessel, C. number of fish caught, D. eviscerated weight for each fish, E. Fork length was measured.	A. name of vessel, B. categories of vessel (in GRT), C. embarkation time, 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 per day. The estimated fishing days were subtracted two days if the fishing grounds located in the southeastern Taiwan because the vessel took about one day from Tungkang port to the fishing ground (Fig. 1) and vice versa. However, one day were subtracted if fishing ground was in the northeastern Taiwan. It is easy to identify where the vessels operated in according to whichever the Pacific bluefin tuna landed. The annual catch for longline fishery is recorded and shown in Fig. 2. Moreover, a vessel with total estimated hooks used less than 2,400 hooks were omitted because it was suspected a carrier.

Moreover, 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 either two days or one day from different fishing grounds defined above for 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 in processing.

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 as indicated in Fig. 3, vessels targeted bluefin tuna stayed longer at sea to search fish in the beginning and the end of Pacific bluefin tuna fishing season than the main season in May and June. Therefore, we found too many zero catches with an extremely large fishing efforts to be judged as target for vessel operated in before April and after July.

3. Vessels without caught any Pacific 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 Pacific 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 (1999-2013);
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 their two-way 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 statistically significant but month and level interaction; thus factors considered for GLM have two options, only the fixed factors and the fixed factors and the significant interactions. To consider the model parsimonious and explanatory power, only the fixed factors that were fishing year, month, and size of vessel was considered in the analysis. 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 lognormal error distribution. To avoid zero catch making logarithmic transformation undefined, a constant was added to all CPUEs. The full model used for GLM analyses as follows.

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

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 $\log N(0, \sigma^2)$.

Relative index was calculated as the year effect least square means (LSMeans) for GLM because the primary objective is to detect trends over yearly abundance. The analyses were run with the SAS GLM procedures (SAS Inst. Inc., v.9.2) for model selection.

RESULTS AND DISCUSSION

Fishing ground

Fig.1 indicates the main fishing grounds of Pacific bluefin tuna from 2010 to 2013, in which the marked areas are somewhere with more than one Pacific bluefin tuna was caught, It obviously suggested that the Pacific bluefin tuna were caught around southeastern and northeastern waters off Taiwan. As the result, to standardized catch per unit effort of the species for Taiwanese longline fishery can ignore the effect made by fishing grounds. Taiwanese small scale longline vessels are targeting Pacific Bluefin tuna that make their spawning migration and aggregate at the mentioned waters.

Catch

Catches of Pacific Bluefin tuna by Taiwanese longline 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 before 2012; and recently, a new regulation is in effect that the Pacific bluefin tuna catch have to tag the fish and report the position immediately on board after then. Those catches were mostly made by small scale longline vessels resided at those fishing harbors. The annual nominal catch of Pacific Bluefin tuna by Taiwanese small scale longline fishery is illustrated in Figure 2 from 1965 to 2013.

The annual catch of Pacific bluefin tuna by Taiwanese longline fleet from 1965 to 2013 was depicted in Fig. 2. The apparent catch was found by 1993 and increasing to peak at 1999, then an abrupt declining to the lowest in 2012, and a sight increasing in 2013.

Taiwanese longline fishery for Pacific bluefin tuna was mainly starting from March and elapsing to either August or September. To examine the major timing for this fishery, Fig. 3 shows the monthly catch proportion in number from 2004 to 2013; and obviously indicates that catches within May and June occupy over 90%. A very rare catches was found before April and After July.

The mean weights of annual catch in Fig. 4 indicated that from 238 kg in 2004 increased to 268 kg in 2009, then decreased to 240 kg in 2010, and increased abruptly to 401 kg in 2013.The size composition were sliced into age composition by an age length key proposed in 2011 Pacific Bluefin Tuna Working Group, based on the otoloth reading (Shimose et al. 2009). The modes of Pacific bluefin catch by Taiwaese fleet were varying from about 11 years old in 1998 and 1999 to 14 years old in 2012 (Fig. 5).

Fishing effort

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. As Fig. 6 indicated, numbers of registered vessel for Pacific bluefin tuna fishery varied year by year from 684 in 2002 to 484 in 2008, and to 590 in 2012. A slightly decreasing occurred in 2013 to 530 vessels. Sizes of those vessels ranged from about 10 tons (CT2) to about 100 tons (CT4).

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.

Nominal catch per unit effort

Nominal catch per unit effort is estimated by the quotient between the catch in number and hooks estimated during a cruise for each vessel. Annual nominal catch per unit effort was then averaged over cruises and vessels during the year. As Fig. 7, 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 a new low value in 2005; then a very slight increase to 2008 and sharply declined again to the historical lowest level in 2010; and increased to the recent.

The frequency distribution of arithmetic and logarithmic nominal catch per unit effort are illustrated in Fig. 8, indicating that a log-normal distribution is found for the former, and approximately a normal distribution for the later.

Standardized abundance index

The abundance index of spawning bluefin tuna, estimated for 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 (vessel category) 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 possible 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 2013. Further, 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. Moreover, results of two approaches shows not apparently significant in average but standard error (Hsu and Wang 2012: ISC/12-2/PBFWG/14); and only 2% explanatory increases from GLM to GLMM. Therefore, the GLM only was used to estimate the standardized catch per unit effort of Pacific bluefin tuna for Taiwanese longline fleet to represent the spawner abundance index.

To validate the error assumption, the ANOVA was used to diagnosis the linear fitting of three fixed factors (Tables 2), indicating that the linear effect of three factors under lognormal 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 (Fig. 9). 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). The result is validated the lognormal error distribution.

Standardized CPUE by GLM is illustrated in Fig. 10; and the values with 95% confidence intervals are tabulated in Table 3. The annual abundance index time series reveals that 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 and over 2009 level from 2011 after. 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 larger 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.

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 indicates that those series are coincident within the overlapping years (Figure 11). The comparison was also made for standardized catch per unit effort between Japanese and Taiwanese longline fleets, indicating that there are somewhat different. The discrepancies might be coming from targeting different size groups, which could be investigated from size compositions of both fisheries. Therefore, the standardized catch per unit effort estimated by general linear model is valid to represent the abundance of spawner of Pacific Bluefin tuna for Taiwanese longline fishery. The abundance of large spawner of Pacific Bluefin tuna have been gradually declining since 2003 from year to year; and slight increasing .from 2011. Consequently, Table 3 tabulates the standardized catch per unit effort in number per 1,000 hooks, 95% confidence intervals, estimated coefficient of variation and nominal catch per unit effort for references from 1999 to 2013.

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Table 1 Results of stepwise linear regression statistics for type 3 analysis for model selection, in which “ns” denotes the estimated parameter is not significant statistically.

Source	DF	Chi-Sq	$P_r > ChiSq$
1.Intercept	1	20383.3	<0.001
2. Intercept+Year			
Year	14	1275.21	<0.001
3. Intercept+Year+Month			
Year	14	1276.62	<0.001
Month	1	443.14	<0.001
4. Intercept+Year+Month+Level			
Year	14	1247.82	<0.001
Month	1	446.19	<0.001
Level	2	71.83	<0.001
5. Intercept+Year+Month+Level+Year*Month			
Year	14	1075.11	<0.001
Month	1	292.03	<0.001
Level	2	69.54	<0.001
Year*Month	14	355.31	<0.001
6. Intercept+Year+Month+Level+Year*Month+Year*Level			
Year	14	592.47	<0.001
Month	1	291.37	<0.001
Level	2	58.54	<0.001
Year*Month	14	355.68	<0.001
Year*Level	28	69.80	0.0032
7. Intercept+Year+Month+Level+Year*Month+Year*Level+Month*Level			
Year	14	592.02	<0.001
Month	1	213.67	<0.001
Level	2	57.22	<0.001
Year*Month	14	350.11	<0.001
Year*Level	28	69.93	0.0028
Month*Level	2	0.14	0.9341 (ns)

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.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1820.63	107.096	117.48	<.0001
Error	8150	7429.84	0.91164		
Corrected Total	8167	9250.47			

R-Square	Coeff Var	Root MSE	logcpue Mean
0.19682	-56.795	0.9548	-1.6811

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	14	1226.34	87.5957	96.09	<.0001
mon	1	417.156	417.156	457.59	<.0001
level	2	65.6287	32.8144	35.99	<.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	Upper CPUE	CV	Nominal CPUE
1999	0.42583	0.38159	0.47477	0.121006	0.921996
2000	0.34748	0.31611	0.38166	0.125783	0.836640
2001	0.20591	0.1868	0.22668	0.205119	0.378224
2002	0.1308	0.11626	0.14674	0.358723	0.247032
2003	0.19007	0.16973	0.21243	0.254606	0.392716
2004	0.17938	0.16523	0.19453	0.194514	0.408845
2005	0.09496	0.08569	0.10494	0.398631	0.214318
2006	0.11244	0.10152	0.12424	0.350125	0.235489
2007	0.0973	0.07959	0.11775	0.755344	0.230923
2008	0.12142	0.1117	0.1318	0.270318	0.284235
2009	0.09481	0.08717	0.10294	0.327476	0.148129
2010	0.05933	0.05278	0.06636	0.620243	0.066642
2011	0.10802	0.09378	0.12384	0.496445	0.144345
2012	0.14632	0.13022	0.164	0.324904	0.210348
2013	0.16304	0.1428	0.18559	0.337954	0.219576

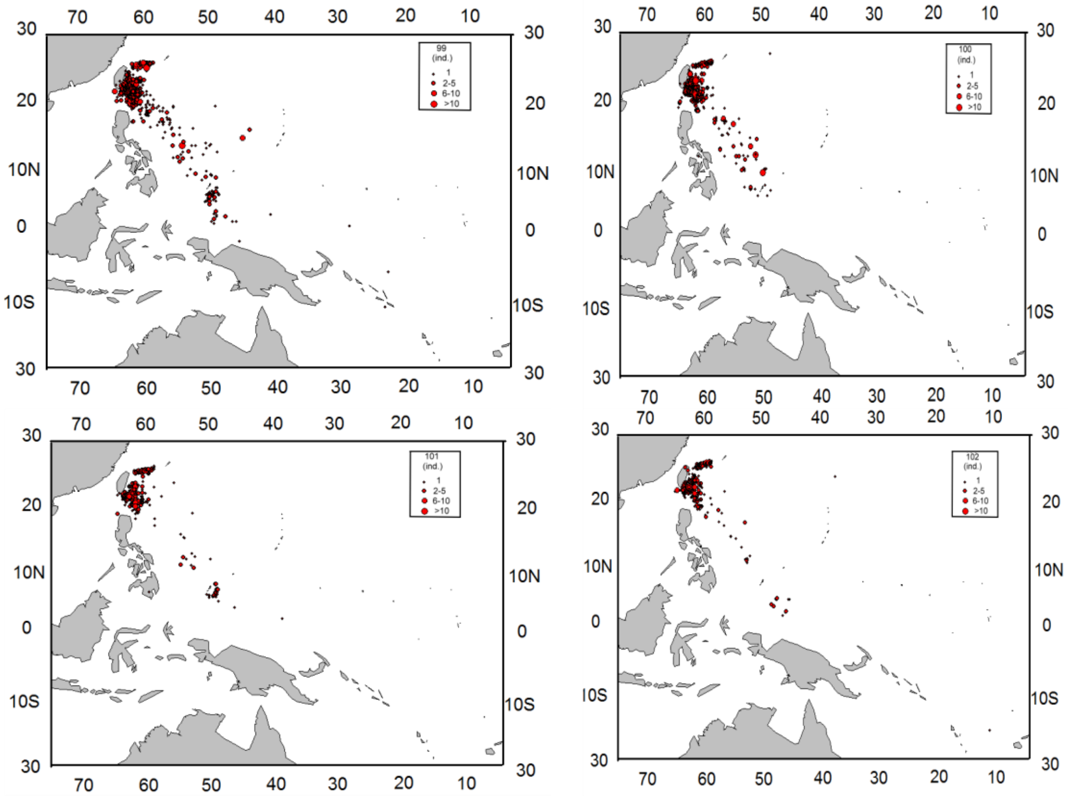


Figure 1. Location of the fishing operations with the positive catch for Taiwanese small-scale longline fleet targeting Pacific bluefin tuna in the waters off southeastern Taiwan from 2010 to 2013.

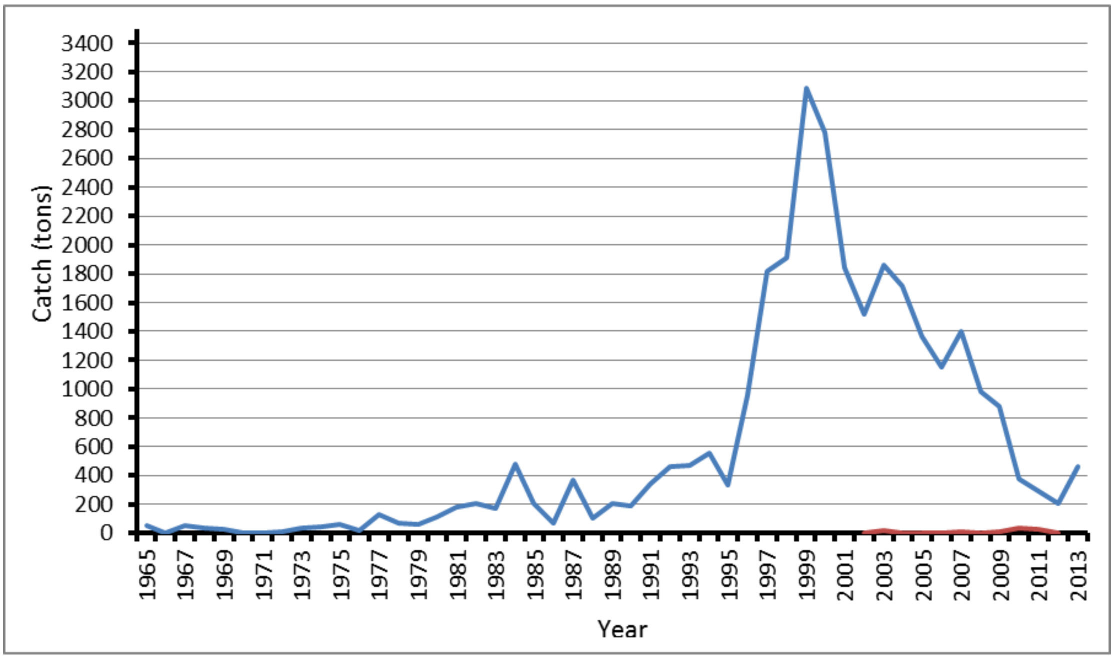


Figure 2. Annual catch of Pacific bluefin tuna by Taiwanese small scale longline fleet from 1965 to 2013.

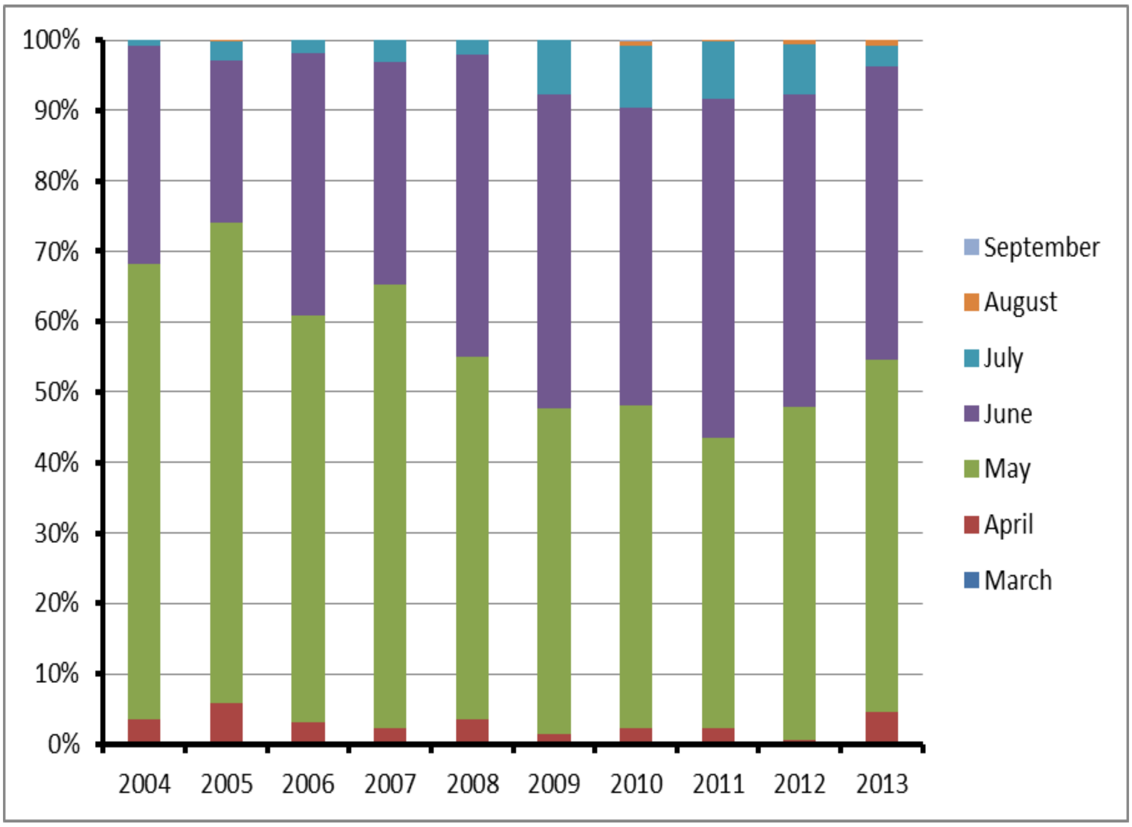


Figure 3. Monthly proportion of Pacific Bluefin tuna caught by Taiwanese longline fleet from 2004 to 2013.

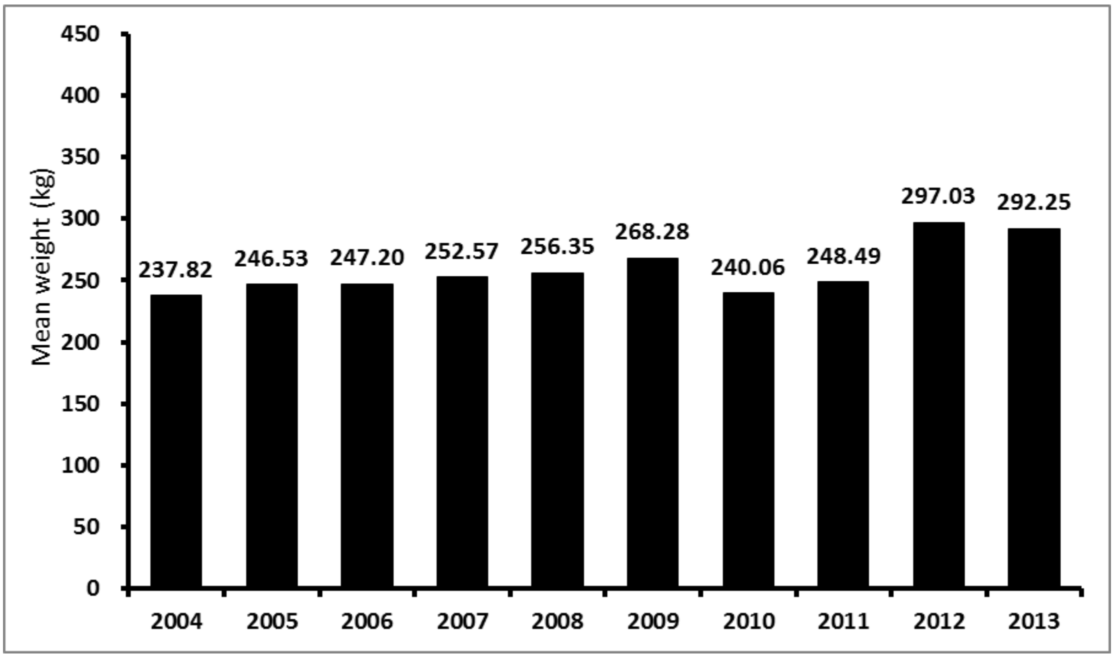


Figure 4. Changes of mean weight (kg) of the Pacific Bluefin tuna caught by Taiwanese small scale longline fishery from 2004-2013, the numerals over bar each year denote the mean weight for that year.

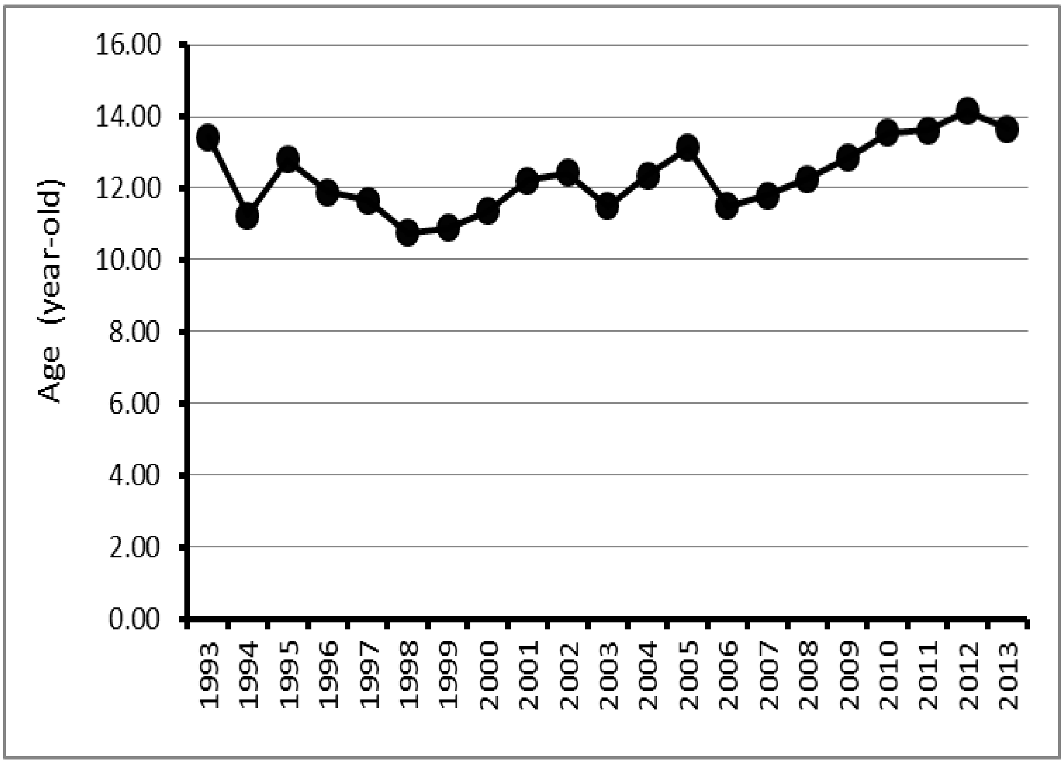


Figure 5. Changes of mean age in annual catches of Pacific bluefin tuna caught by Taiwanese longline fleet.

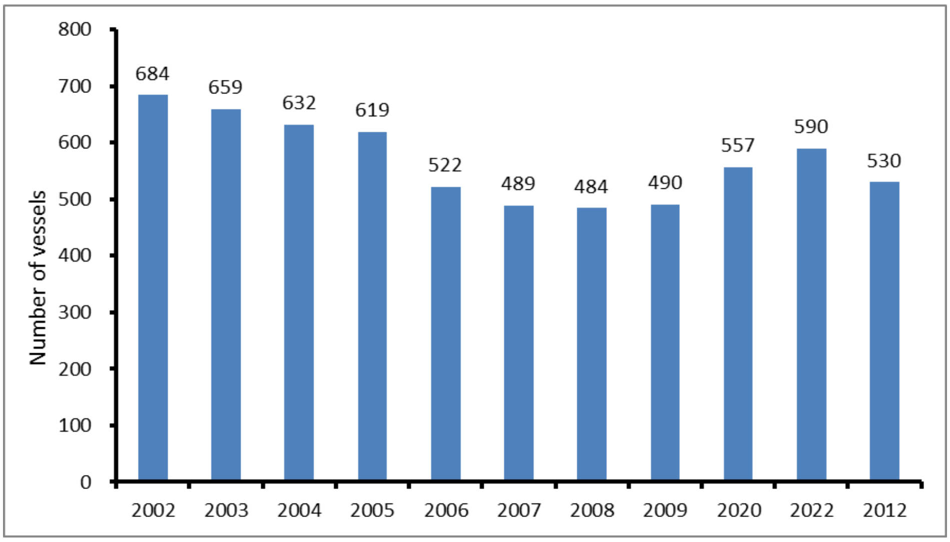


Figure 6. Number of vessels of Taiwanese small scale longline fleet registered to fishing Pacific Bluefin tuna from 2002 to 2012, in which the numbers above each histogram denote the exact number of vessels each corresponding year.

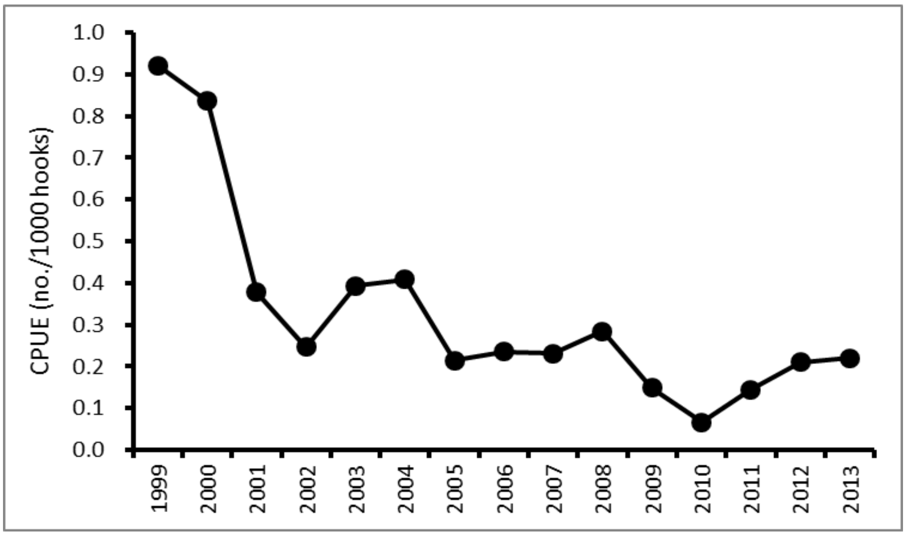


Figure 7. Time series nominal CPUE (individual/1000 hooks) of bluefin tuna caught by Taiwanese small-scale longline fishery in the southwestern North Pacific Ocean for 1999-2013.

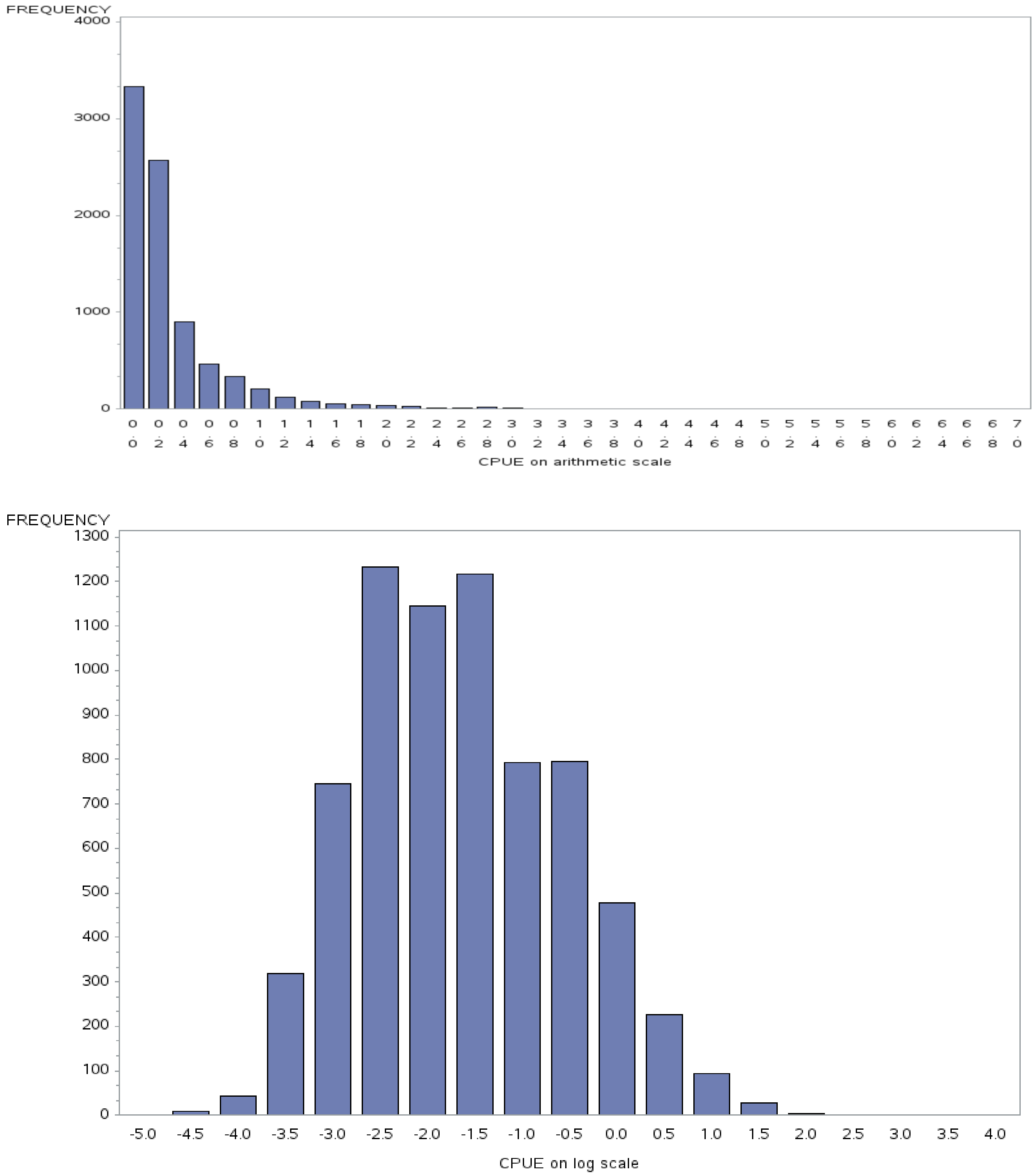
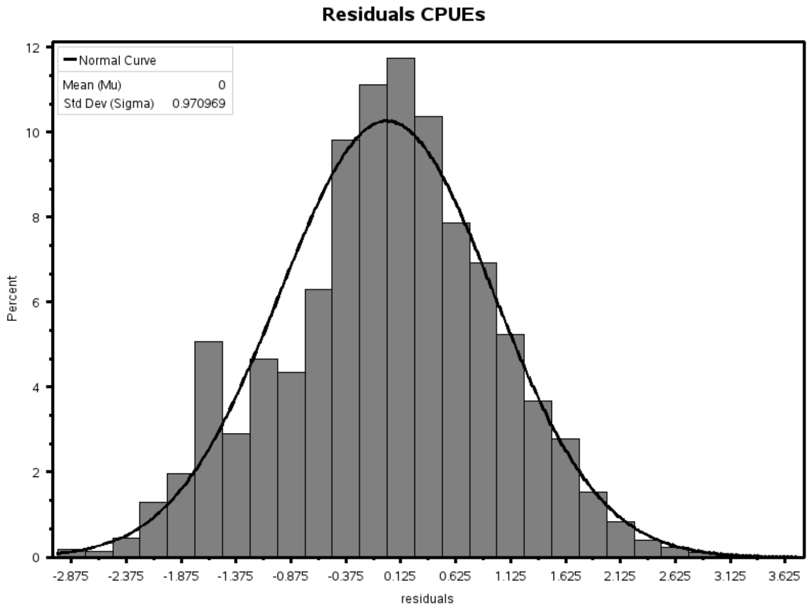
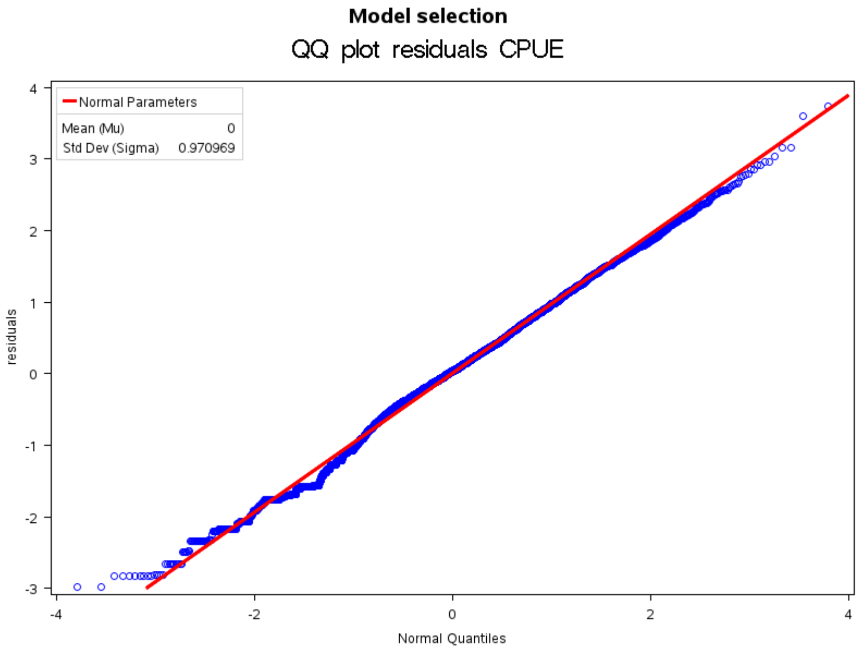


Figure 8. Frequency distribution of nominal catch per unit effort of Pacific Bluefin tuna caught by Taiwanese small scale longline fleet during May and June each year from 1999 to 2013 (upper panel: arithmetic scale; lower panel: logarithmic scale).





Tests for Normality

Test	Statistic		p Value	
Kolmogorov-Smirnov	D	0.03633	Pr > D	<0.0100
Cramer-von Mises	W-Sq	2.06335	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	13.7415	Pr > A-Sq	<0.0050

Figure 9. The frequency distribution of residuals derived from generalized linear model expressed in histograms (upper panel) and Q-Q plot (lower panel) with lognormal error structure to standardize CPUE of bluefin tuna caught by Taiwanese small-scale longline fishery for 1999-2013; and the results of test of normality were included.

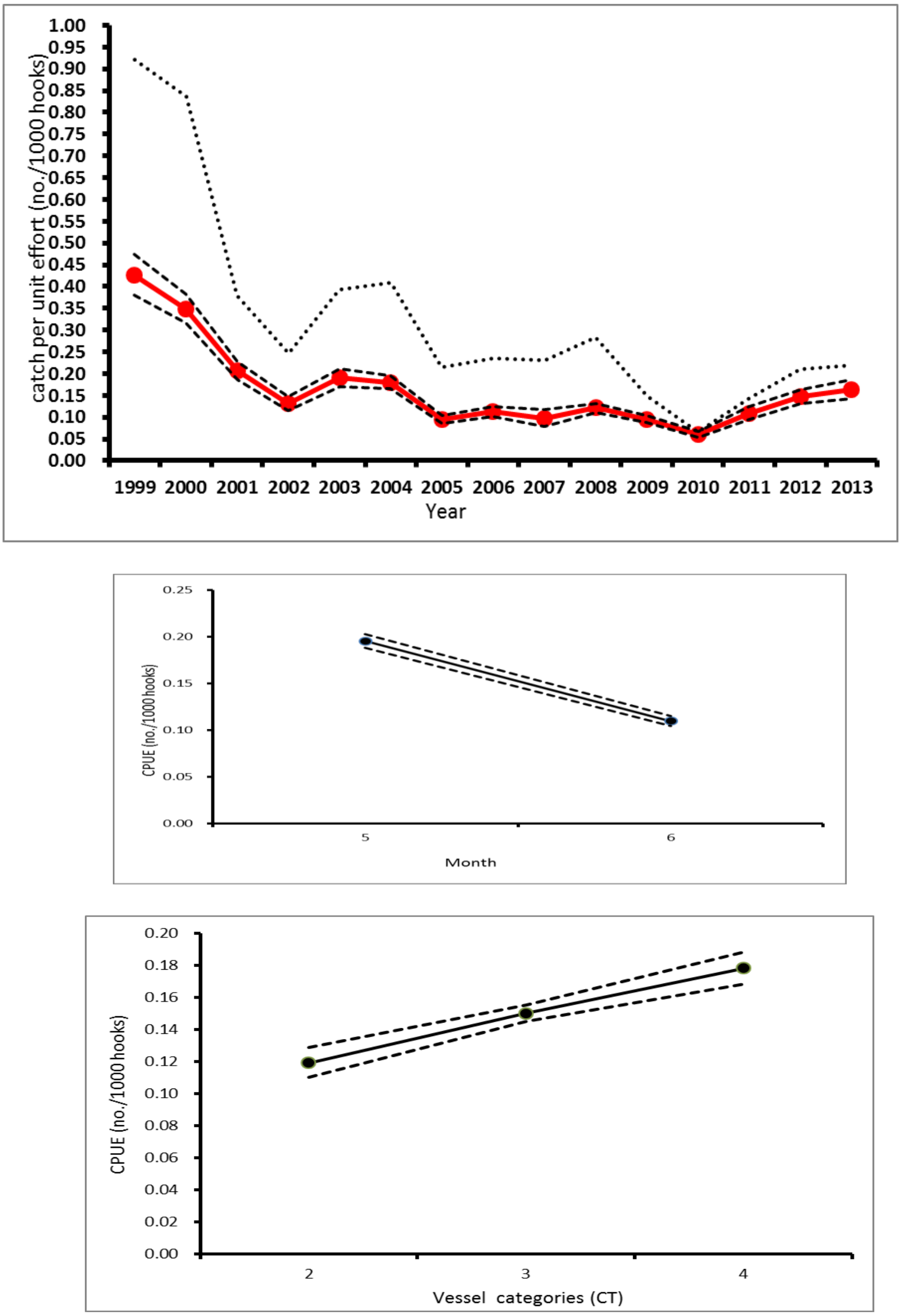


Figure 10. Time series of abundance index (upper panel), monthly variation of standardized catch per unit effort (middle panel) and standardized series by size of vessel (lower panel) of northern Pacific bluefin tuna estimated by general linear model from Taiwanese small-scale longline fishery. Dashed lines represent the 95% confidence intervals for standardized catch per unit effort, and dot line indicates the nominal catch per unit effort.

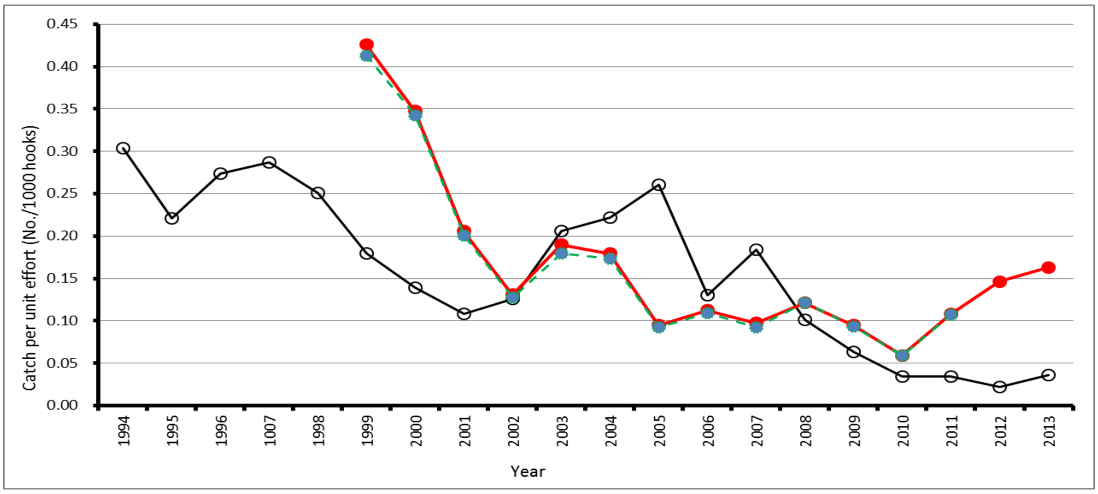


Figure 11. Comparisons among abundance indices of Pacific Bluefin tuna, estimated between 2012 and 2014 Pacific Bluefin tuna workshop (ISC/2012-2/PBFWG/14), caught by Taiwanese longline fleet by general linear models under lognormal error structure; and the standardized Japanese longline series is included as the symbol of open circles.