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Revised standardized catch rates and catch estimate of shortfin mako shark by Taiwanese large-scale tuna longline fishery in the North Pacific Ocean

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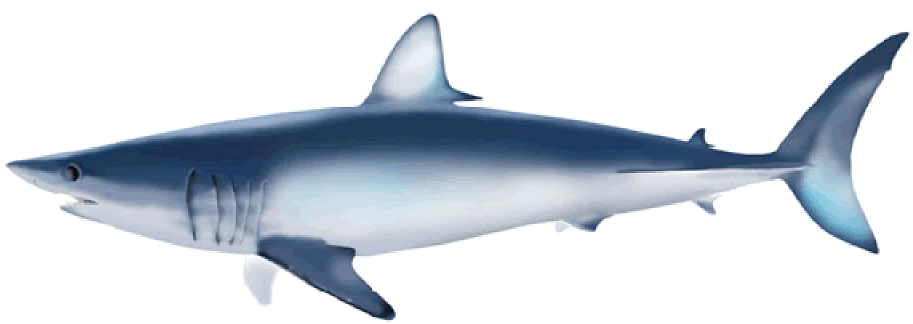

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ABSTRACT

In the present study, the shortfin mako shark catch and effort data from the logbook records of Taiwanese large-scale tuna longline fishing vessels operating in the North Pacific Ocean from 2005-2012 were analyzed. Due to the large percentage of zero shortfin mako shark catch, the catch per unit effort (CPUE) of shortfin mako shark, as the number of fish caught per 1,000 hooks, was standardized using a delta lognormal model. Both nominal and standardized CPUE of shortfin mako sharks showed stable but slightly decreasing trends. Estimated shortfin mako shark by-catch in weight from the Taiwanese large-scale tuna longline fishery ranged from 0 metric tons (MT) in 1973 to 154 MT in 2006, and it decreased thereafter. The results obtained in this study can be improved if longer time logbook data are available and environmental factors are included in the model.

1. Introduction

Shortfin mako shark, *Isurus oxyrinchus*, is one of the most commonly caught shark species in the Taiwanese commercial offshore longline fishery and the major by-catch of tuna longline fisheries in the far seas. Shortfin mako is a large apex predator that exhibits slow growth, low fecundity and late maturity, and is particularly susceptible to exploitation owing to its life-history characteristics. Clarke *et al.* (2006) mentioned that about half a million shortfin mako sharks were utilized in the global shark fin trade in 2000. Given the high fishing pressure on this species and declining population trends, the shortfin mako is currently listed as "Vulnerable" on the IUCN Red List of Threatened Species (Dulvy *et al*., 2008), but very little is known about the stock status of this species in the North Pacific Ocean despite of several studies using per recruit analyses and demographic approaches in the Northwest Pacific Ocean (Chang and Liu 2009, Tsai *et al.* 2011, Tsai *et al.* 2014, Tsai *et al.* (in press)). Since the International organizations and regional fisheries management organizations (RFMO's) have concerned on the conservation of elasmobranchs in recent years, it is necessary to examine the recent trend of shark species by examining the logbook of tuna fisheries. Shortfin mako and blue shark (*Prionace glauca*) are the major shark species for Taiwanese large-scale tuna longline (LSTL) fisheries. Reliable catch estimate for shortfin mako shark can be developed because the logbook records of shortfin mako sharks were representative of actual catches as all sharks were retained due to its high market value. Thus, the objectives of this study are to standardize the CPUE and to estimate the historical catches of shortfin mako sharks in the North Pacific based on the logbook data.

A large proportion of zero values is commonly found in by-catch data obtained from fisheries studies involving counts of abundance or CPUE standardization. The delta-lognormal modeling, which can account for a large proportion of zero values, is an appropriate approach to model zero-heavy data (Lo *et al*., 1992). As sharks are common by-catch species in the tuna longline fishery, the delta lognormal model (DLN) was therefore applied to address these excessive zeros of shark catch for CPUE standardization in this study. The CPUEs of shortfin mako sharks in the North Pacific Ocean were standardized using delta-lognormal model based on logbook data and hopefully these CPUE series can be used in the shortfin mako stock assessment in 2015.

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2. Material and methods

2.1. Source of data

The logbook data of Taiwanese large-scale tuna longline fishery from 1971 to 2012, provided by the Overseas Fisheries Development Council of the Republic of China, were used in this study. These logbook data contain basic information on fishing time, area, number of hooks and catches of 18 species (14 species before 2005) including major tunas, billfishes and sharks. The shark by-catch of Taiwanese tuna longline fleets was never reported until 1981 because of its low economic value compared with tunas. During the period from 1981 to 2004, only one category "sharks" was recorded in the logbook. The category "sharks" on the logbook has been further separated into four sub-categories namely the blue shark, mako shark, *Isurus spp*., silky shark, *Carcharihnus falciformis*, and others since 2005. As the Taiwanese longline fishery has widely covered the Pacific Ocean, our fishery statistics must be one of the most valuable information that can be used to describe the population status of pelagic sharks.

The species-specific catch data including tunas, billfishes, and sharks from logbook records in 2005-2012 were used to standardize CPUE of shortfin mako shark of Taiwanese large-scale longline fishery in the North Pacific Ocean. In addition, the nominal CPUE was applied to back-estimate the historical shortfin mako catch (before 2005) of Taiwanese large-scale longline fleets.

2.2. CPUE standardization

Shortfin mako sharks caught by Taiwanese LSTL fishery in the North Pacific Ocean were mainly observed in the equatorial waters where bigeye tuna, *Thunnus obesus*, was the targeting species and in the subtropical and temperate waters where albacore tuna, *Thunnus alalunga*, was the targeting species (**Figure 1**). Based on the distributions of logbook efforts (**Figure 1 and Appendix Figure 1**.), the North Pacific Ocean was stratified as 4 areas namely A (north of 25ºN), B (0ºN-25ºN, west of 0ºW), C (0ºN-25ºN, 0ºW-40ºW), and D (0ºN-25ºN, west of 40ºW). The area strata used for the analysis were shown in **Figure 2**. For standardization, CPUE was calculated by set of operations based on logbook records during the period of 2005-2012.

A large proportion of sets with zero catch of shortfin mako shark (~90%) was found in logbook records. Hence, to address these excessive zeros, the delta lognormal model (DLN) (Lo *et al*. 1992) was applied to the standardization of shortfin mako shark CPUE. The DLN is a combination of two models, one model is used to estimate the proportion of positive catches and another model is to estimate the positive catch rate. The model was fit using glm function of statistical computing language R (R Development Core and Team, 2013) to eliminate some biases by change of targeting species, fishing ground and fishing seasons.

The standardized CPUE series for shortfin mako shark was constructed with interaction effects. The main variables chosen as input into the DLN analyses were year (Y), quarter (Q), area (A), sea surface temperature (SST) and the number of hooks per basket (HPB). The effect of gear configuration of HPB

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was used to account for the shift of targeting species. The following multiplicative model was applied to the data in this study:

For the DLN modeling, the catch rates of the positive catch events (sets with positive shortfin mako shark catch) were modeled assuming a lognormal error distribution:

Part 1: Lognormal model

$$\ln(CPUE) = \mu + Y+Q+A+HPB+SST+Q*A+Q*HPB+A*HPB+ \varepsilon_1 \quad (1)$$

where μ is the mean, Q*A, Q*HPB, A*HPB are interaction terms, ε_1 is a normal random error term. The effect of gear configuration, HPB, was categorized into two classes: shallow set (HPB $\leqq$ 15), and deep set (HPB > 15) (Walsh, 2011), and quarter was categorized into 4 classes: the 1st quarter (Jan-Mar), the 2nd quarter (Apr-Jun), the 3rd quarter (Jul-Sep), and the 4th quarter (Oct-Dec). Continuous variables tested was the SST. The area strata used for the analysis were shown in **Figure 2**. To estimate the proportion of positive shortfin mako catch (*P*), we used a model assuming a binomial error distribution (ε_2):

Part 2: Binomial model

$$P= \mu + Y+Q+A+HPB+SST+Q*A+Q*HPB+A*HPB + \varepsilon_2 \quad (2)$$

The best model for both Lognormal and Binominal models were selected using the stepwise AIC method (Venables and Ripley, 2002). For model diagnostics, the Cook's distance (Cook and Weisberg, 1982) was used to assess the influence of observations that exert on the model. The distribution of residuals was used to verify the assumption of the lognormal distribution of the positive catches. These diagnostic plots were used to evaluate the fitness of the models. In addition, deviance analysis tables for the proportion of positive observations and for the positive catch rates were also provided. The final estimate of annual abundance index was obtained by the product of the main annual effect of the Lognormal and Binomial components (Lo *et al.* 1992):

$$\text{Standardized CPUE} = \ln(CPUE)* P \quad (3)$$

2.3. Estimate of historical shortfin mako shark catch

Annual shortfin mako by-catch in number (C_y) was obtained by using the logbook catch divided by coverage rate. The shortfin mako by-catch in number before 2005 was back-estimated using the following equation:

$$C_y = \sum_i^4 \frac{\text{Nominal } CPUE_{i,} \times Logbook\ effort_i}{Coverage\ rate}, \quad (4)$$

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where y is year, $i = 1$ is area A, $i = 2$ is area B, $i = 3$ is area C and $i = 4$ is area D. Coverage rate is the total catch (bigeye tuna, albacore tuna, yellowfin tuna, and swordfish) in logbook to that in Task 1. The nominal CPUE before 2005 was represented by the mean of nominal CPUE in the period of 2005-2012 because there were no species-specific shark catch data in logbook before 2005.

The catch in weight of shortfin mako shark was estimated by using the mean weight (assumed to be constant) multiplied by the estimated/back-estimated catch in number. The mean TL of shortfin mako sharks was calculated from observers' data in the period of 2004-2012 and the mean weight was obtained by substituting the mean TL into the W-TL relationship as following: $W = 9.1\times10^{-6}\ TL^{2.98}$ (Joung and Hsu, 2005).

3. Results and discussion

The mean TL of shortfin mako sharks recorded by observers was 210 cm (n = 312) and the estimated mean weight was 75.72 kg. The frequency distributions of shortfin mako shark by-catch per set are characterized by many zero values and a long right tail (**Figure 3**). Overall, 90.67% of total sets had zero shortfin mako shark by-catch (**Table 1**).

The best models for Lognormal and Binomial models chosen by AIC were " $\ln(CPUE) = \mu + Y + Q + A + HPB + SST + Q*A + Q*HPB + A*HPB$ " and " $P = \mu + Y + Q + A + HPB + SST + Q*A + Q*HPB$ ", respectively. The best models were then used for the later analyses.

The nominal CPUE of shortfin mako shark showed an inter-annual fluctuation. However, this variability was reduced in the standardized CPUE series (**Figure 4**). The standardized CPUE series contains the combined effects from two models, one that calculates the probability of a zero observation and the other one estimates the count per year. In general, the standardized CPUE series of the shortfin mako sharks caught by Taiwanese LSTL fishery decreased from 2006 to 2010 and increased slightly thereafter (**Figure 4**).

The residuals distribution and Q-Q normal plots (the left hand panel) for lognormal model showed that the error distributions are close to normal (**Figures 5 and 7**). The right hand panel showed the standard diagnostics of residuals vs. fitted and Cook's distance plot (**Figures 5-8**). Overall, the diagnostic results and additional residuals plots (**Figures 9-12**) indicated that DLN model does not have severe departure from the model assumptions. The ANOVA tables for each model indicated that the main effects were significant (mostly $P < 0.01$) and were selected in the final model (**Table 2**). Estimated shortfin mako shark by-catch in number ranged from 1 in 1973 to 2,032 in 2006. The back-estimated shortfin mako shark by-catch in weight of Taiwanese LSTL fishery ranged from almost 0 metric tons (MT) in 1973 to 154 MT in 2006, with a mean of 41 MT and 541 individuals in the North Pacific Ocean (**Table 3**). The estimated catch was relative low before 1995 and increased to more than 10 MT and fluctuated thereafter, peaked at 154 MT in 2006, and decreased thereafter (**Table 3**).

The back-estimations of historical shark by-catch in this report were based on logbook records from 2005-2012. However, many factors may affect the standardization of CPUE trend. In addition to the temporal and spatial effects, environmental factors are important which may affect the representation of standardized CPUE of pelagic fish i.e., swordfish and blue shark in the North Pacific (Bigelow *et al.*, 1999), and big-eye tuna in the Indian Ocean (Okamoto *et al.*, 2001). However, environmental effects were not included in the standardization models in this report. The results obtained in this study can be improved if longer time-series logbook data are available and environmental factors are included in the model.

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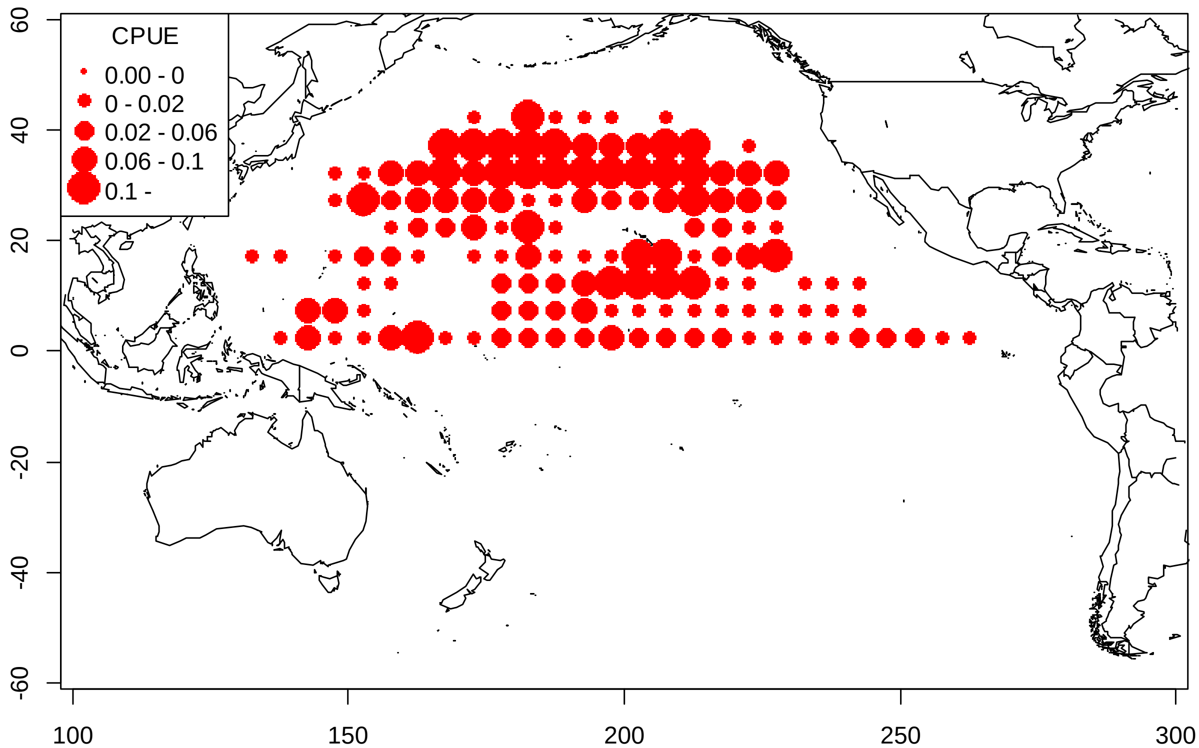

Figure 1. Nominal CPUE distribution of shortfin mako sharks caught by Taiwanese large-scale tuna longline fishery in the North Pacific Ocean from 2005-2012.

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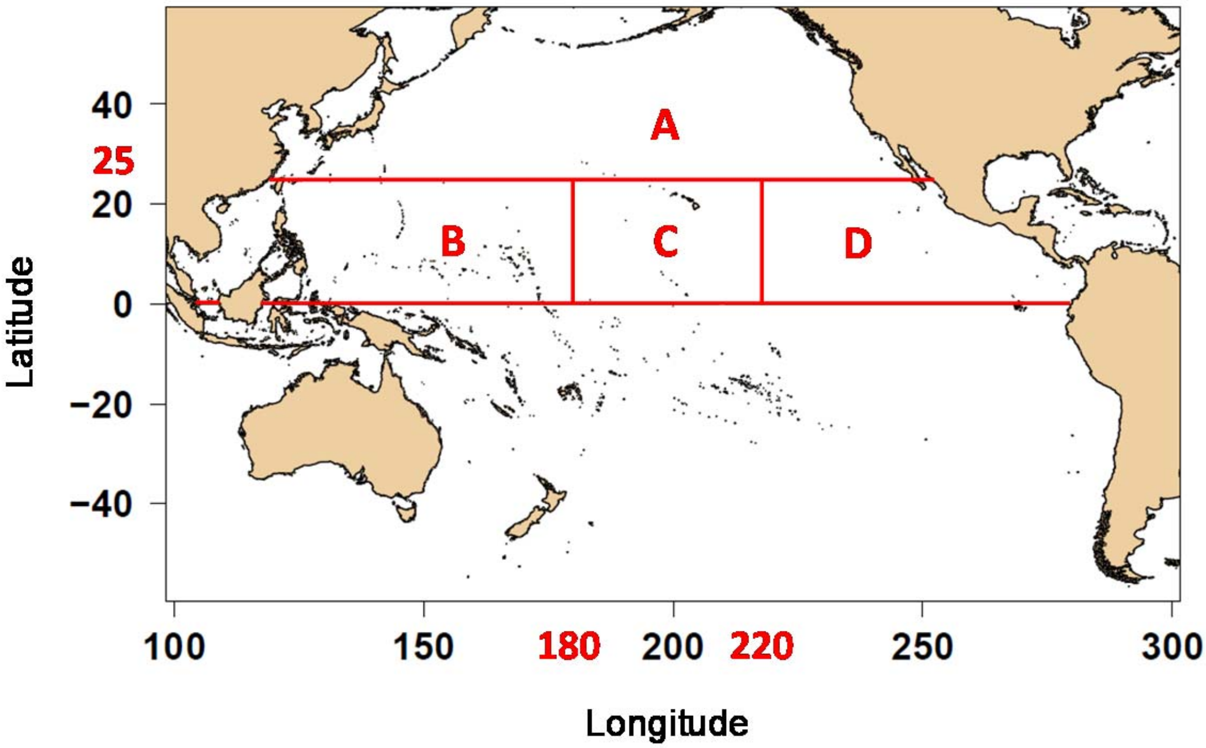

Figure 2. Area stratification used for the estimate of shortfin mako shark by-catch of the Taiwanese large-scale tuna longline fishery in North Pacific Ocean.

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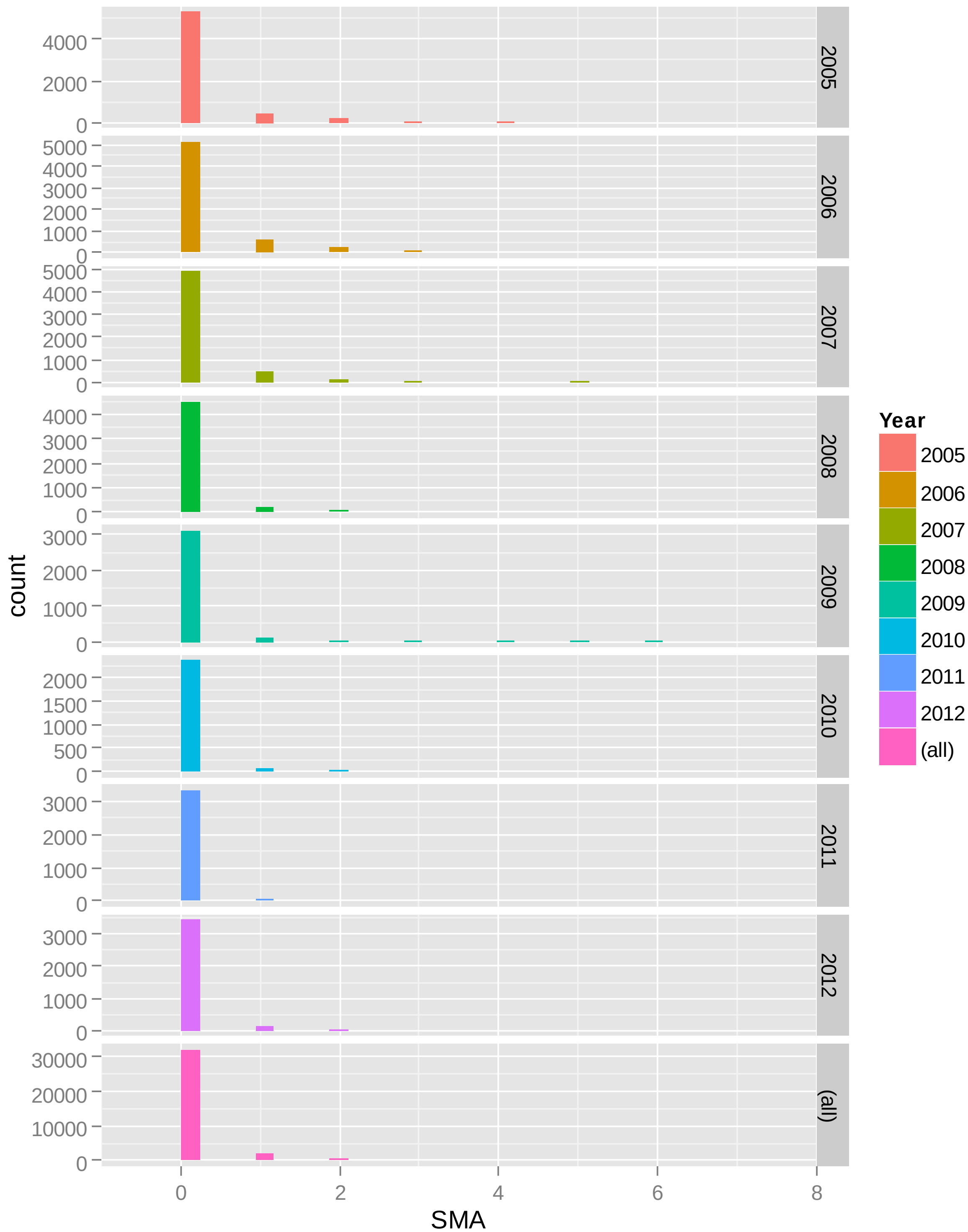

Figure 3. Frequency distribution of shortfin mako shark by-catch per set, 2005–2012.

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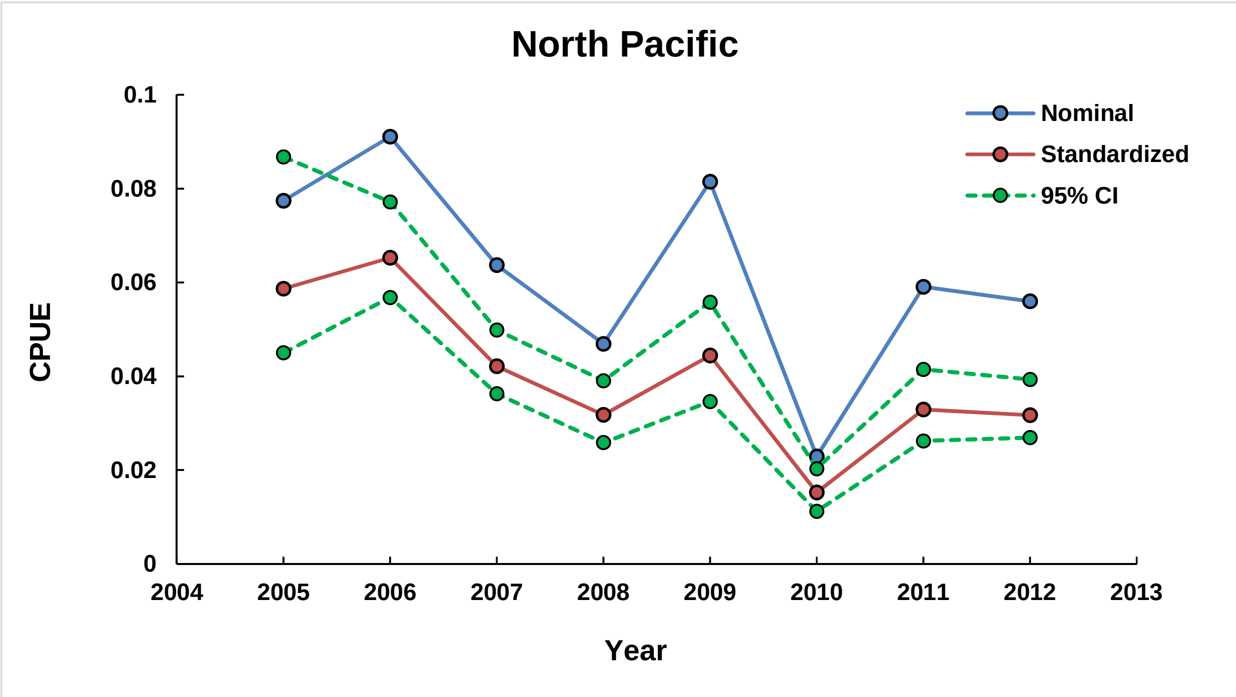

Figure 4. Nominal and standardized CPUE with 95% C.I. of shortfin mako shark by Taiwanese large-scale tuna longline fishery in the North Pacific Ocean from 2005 to 2012.

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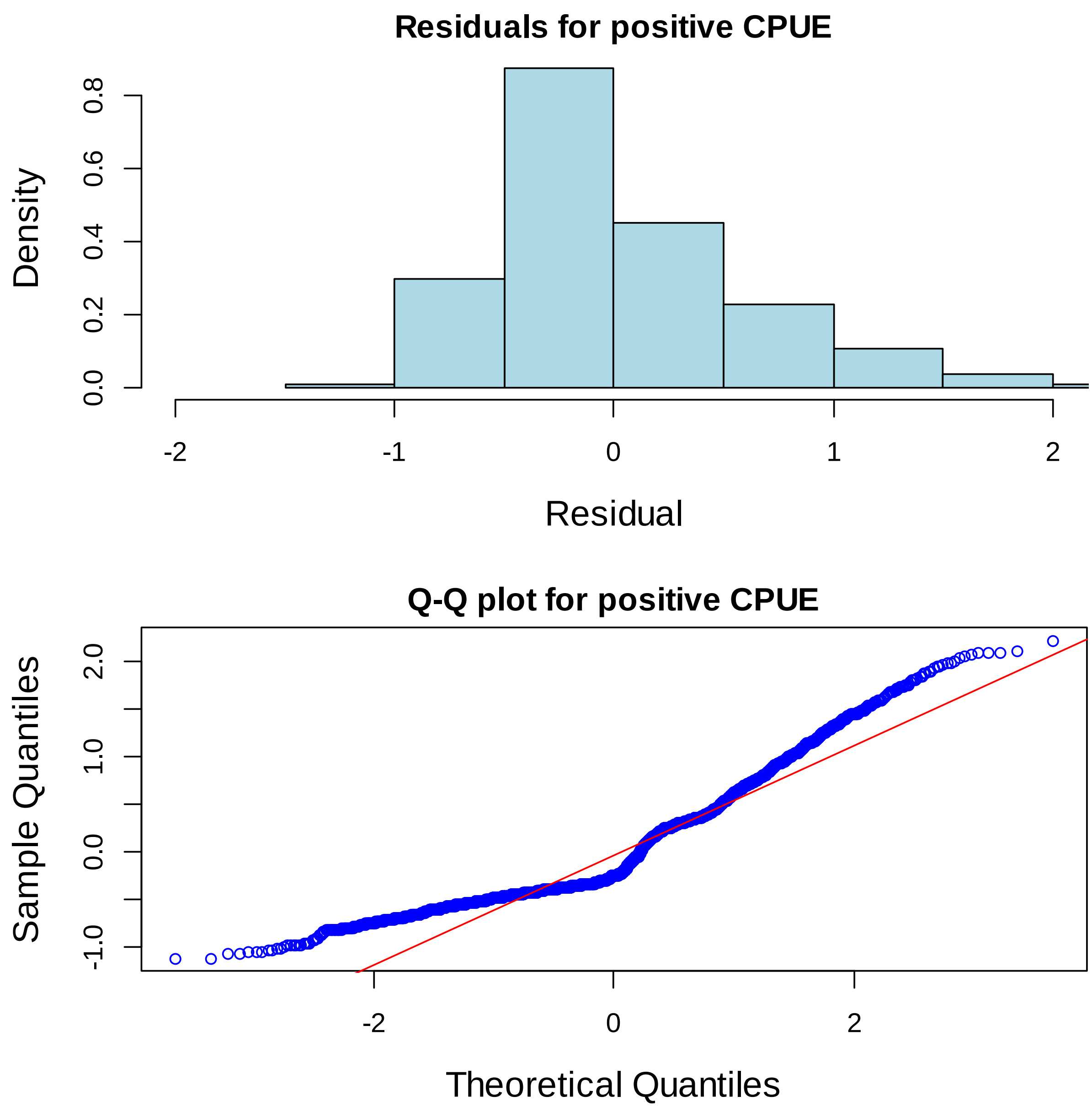

Figure 5. Diagnostic results from the lognormal model fit to the shortfin mako shark by-catch data.

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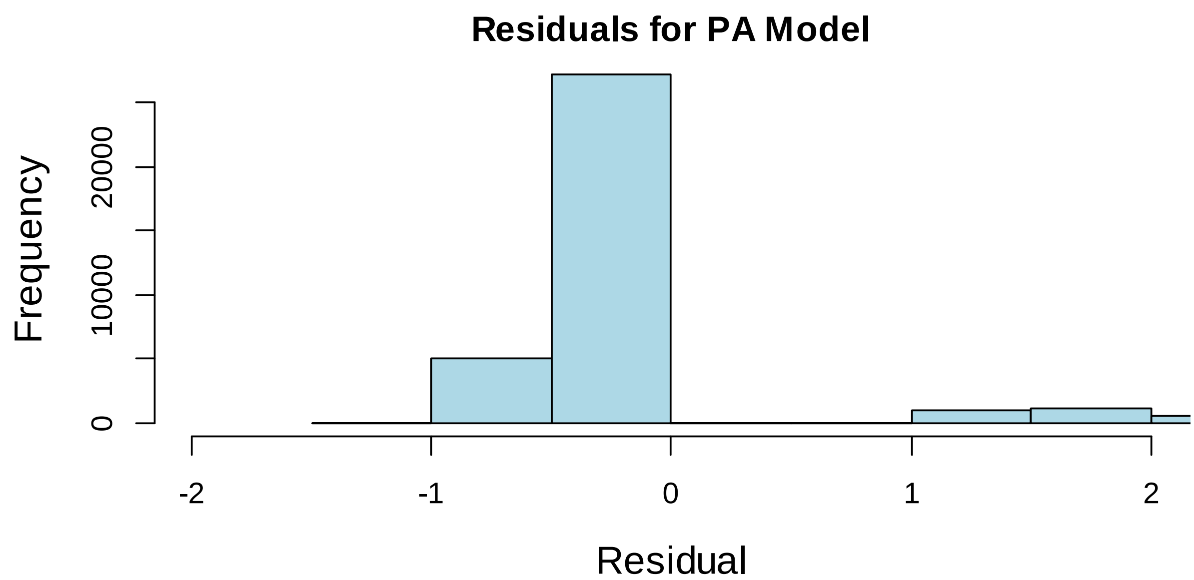

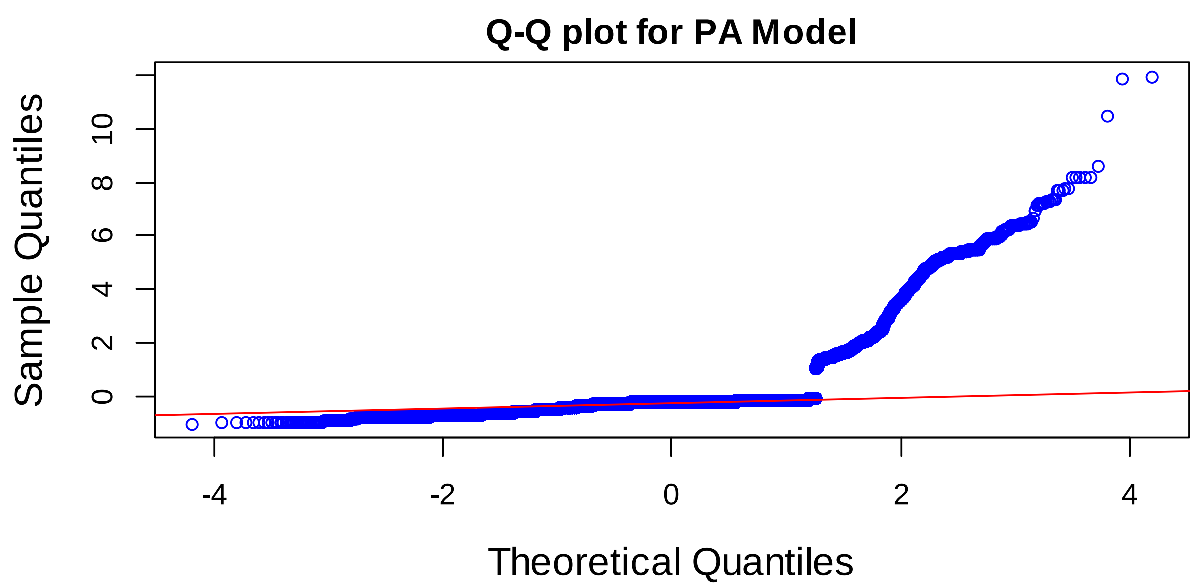

Figure 6. Diagnostic results from the binomial model fit to the shortfin mako shark by-catch data.

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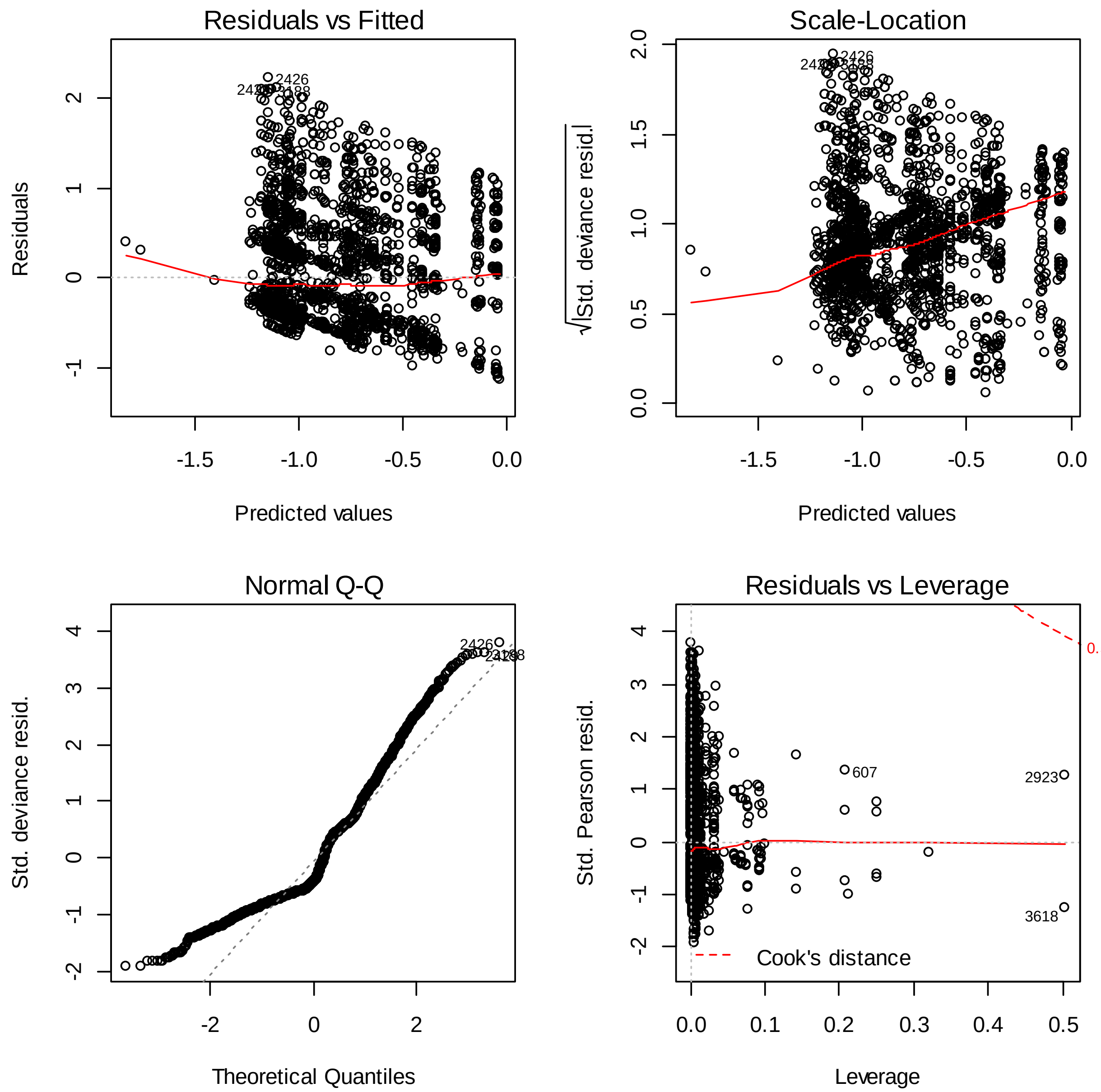

Figure 7. Residual plots for the lognormal model fit to the shortfin mako shark by-catch data.

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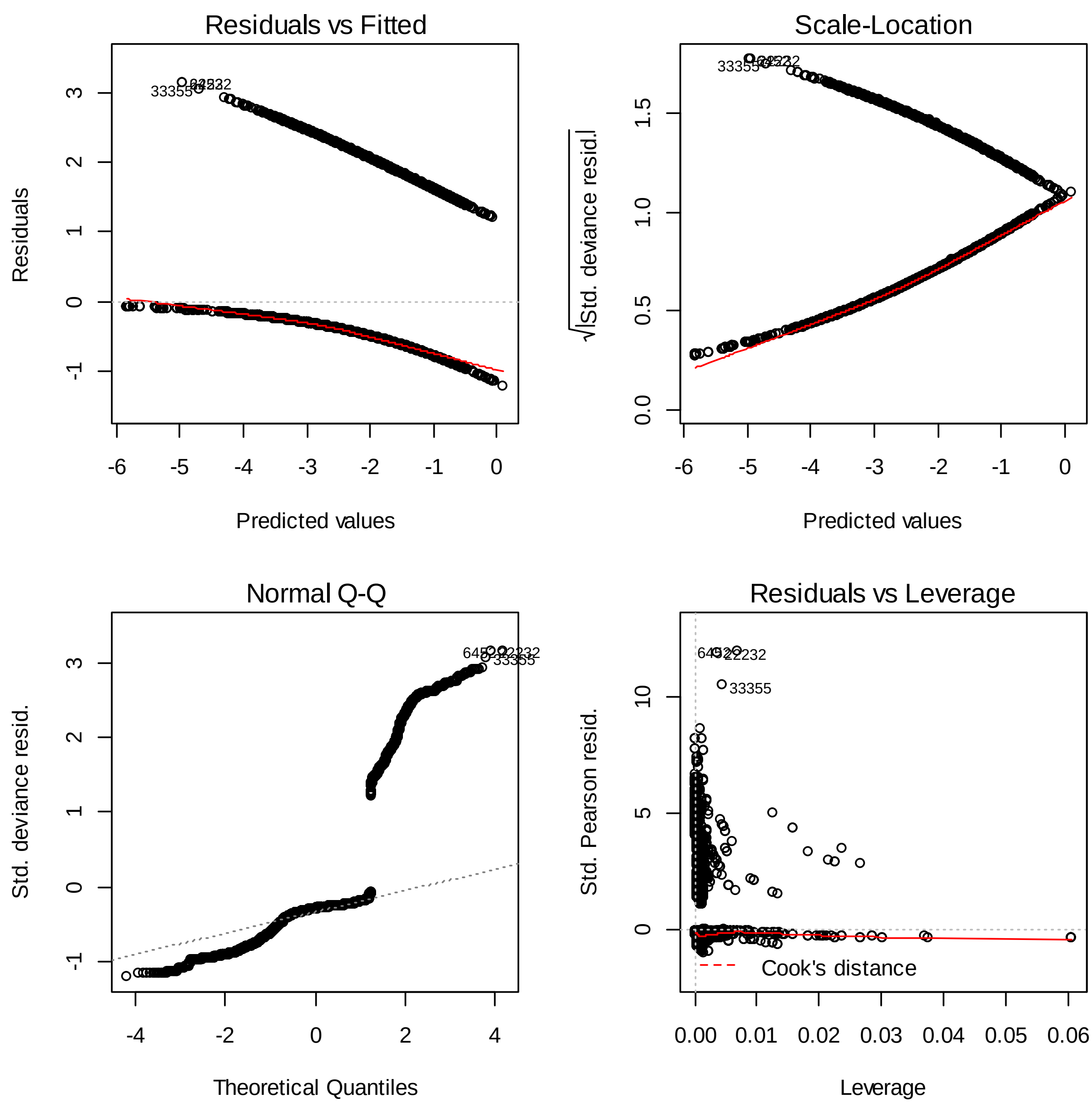

Figure 8. Residual plots for the binomial model fit to the shortfin mako shark by-catch data.

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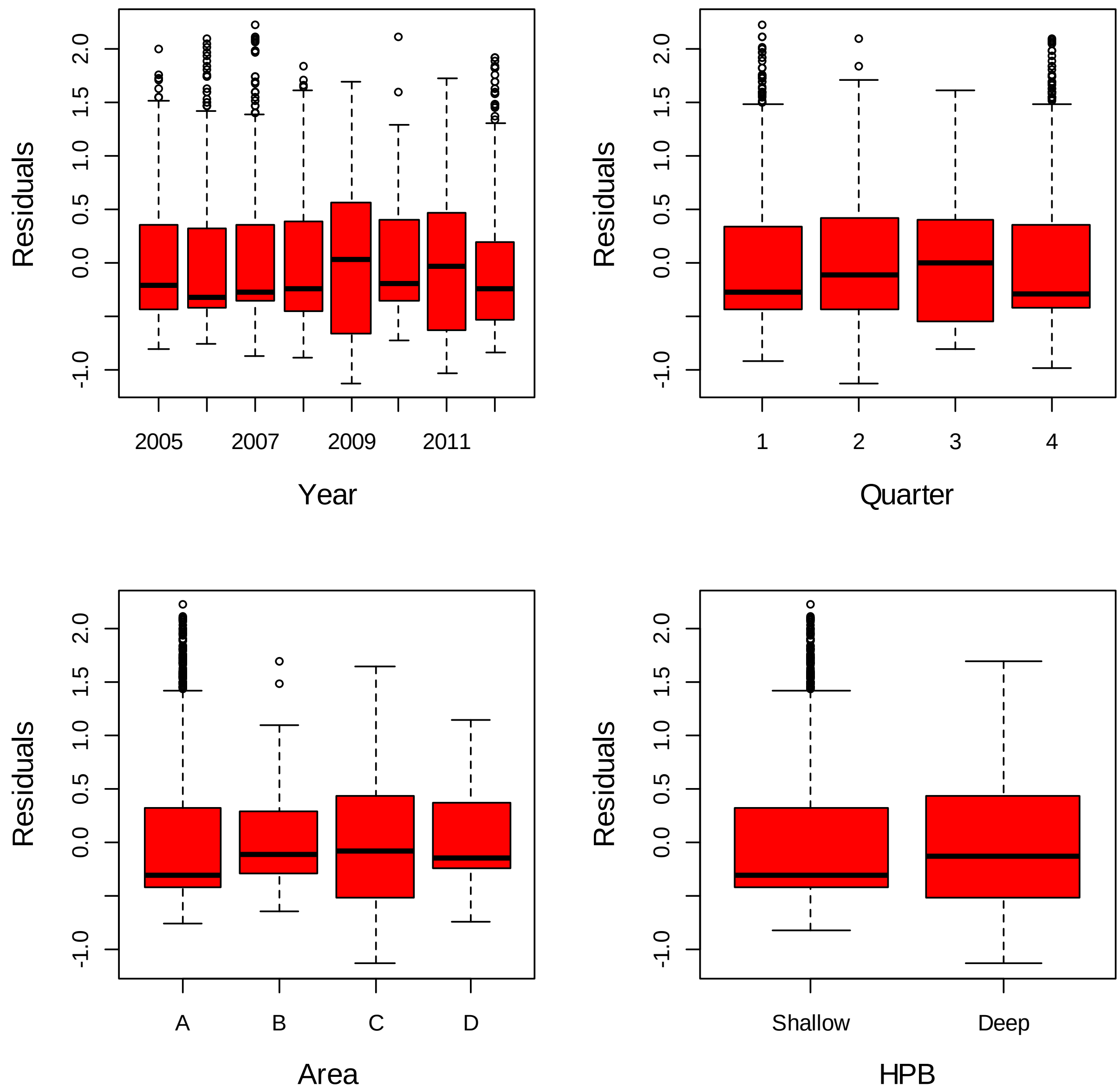

Figure 9. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and HPB for lognormal model.

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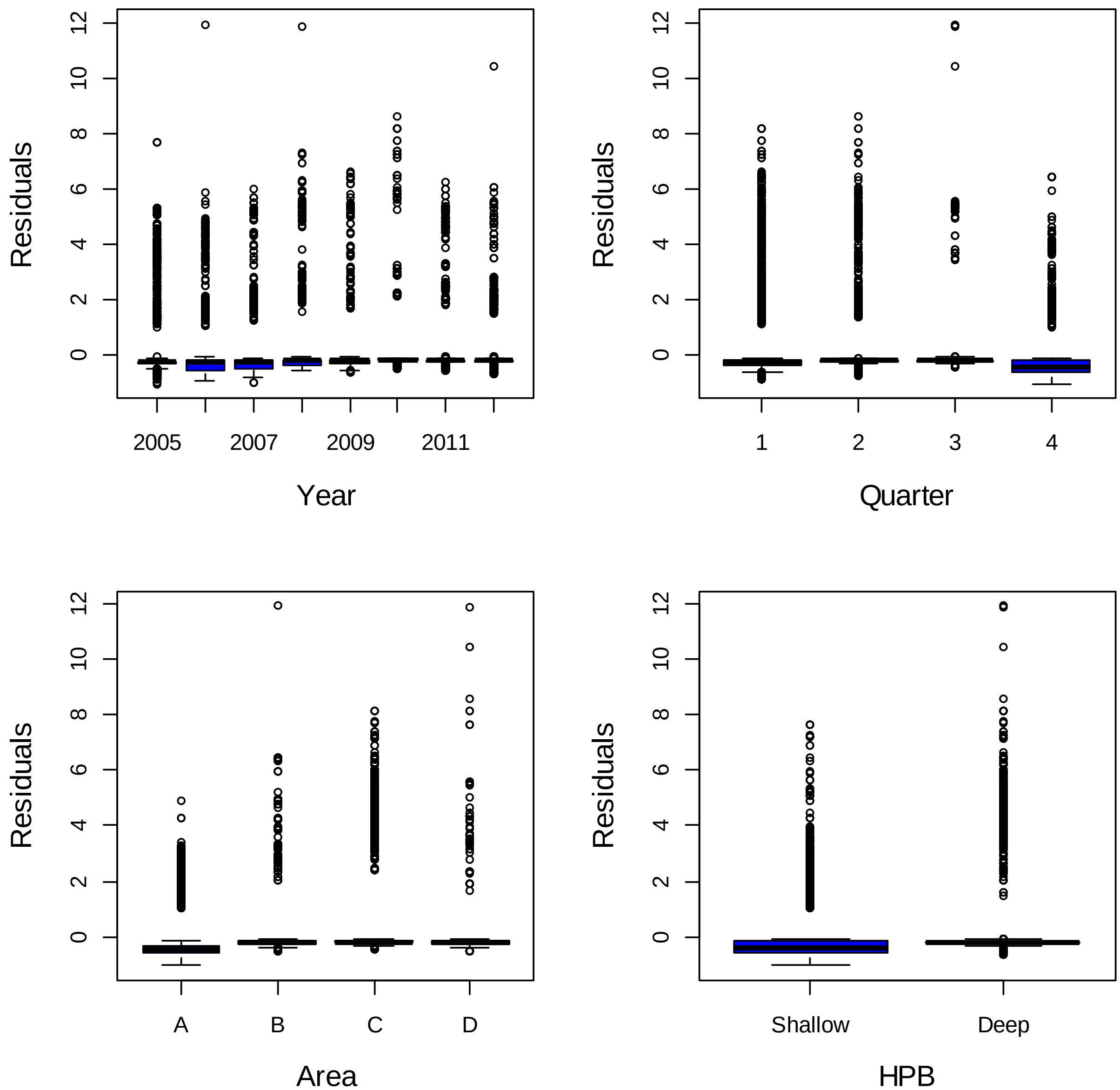

Figure 10. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and HPB for binomial model.

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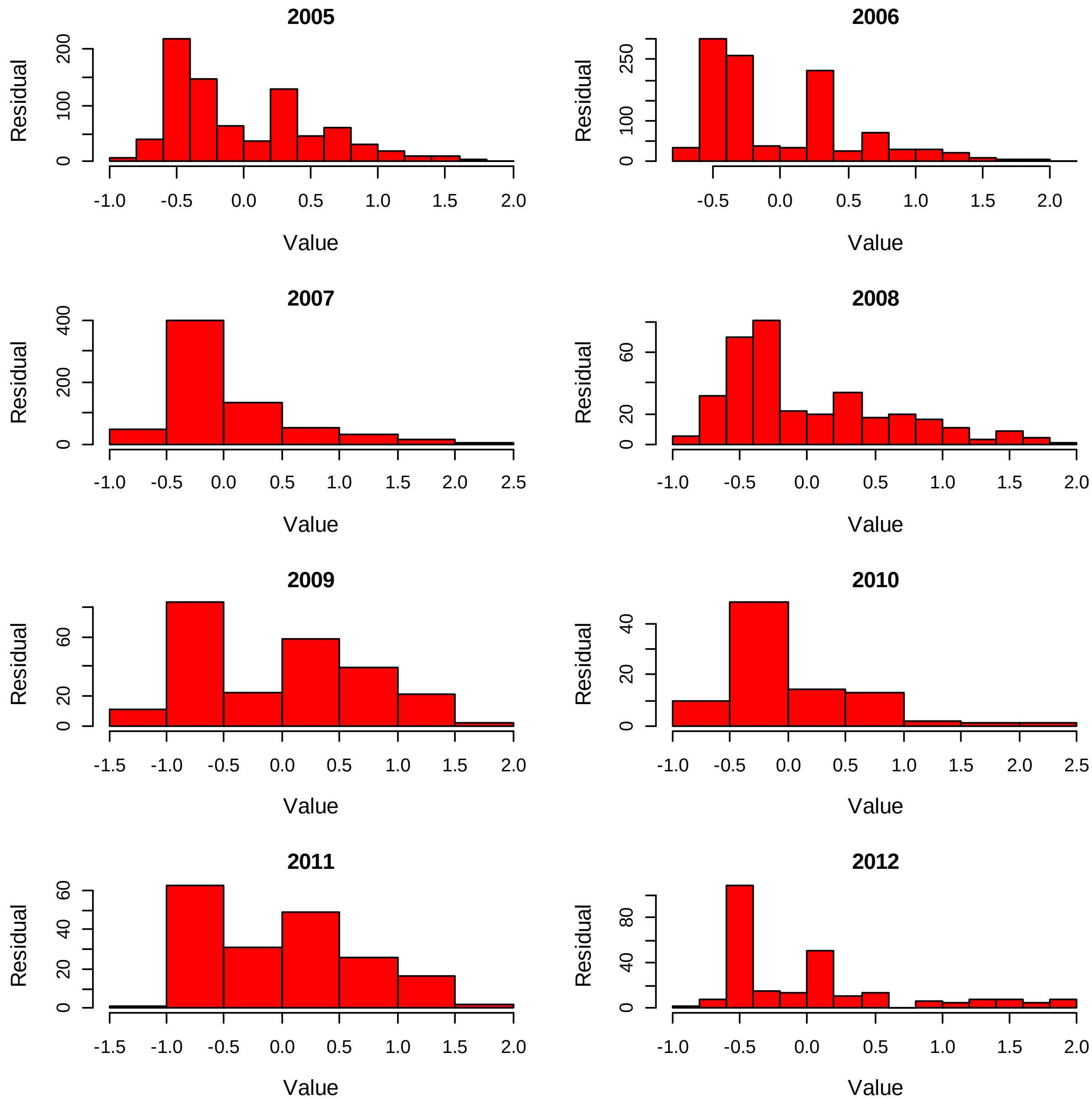

Figure 11. Annual residual plots from the lognormal model.

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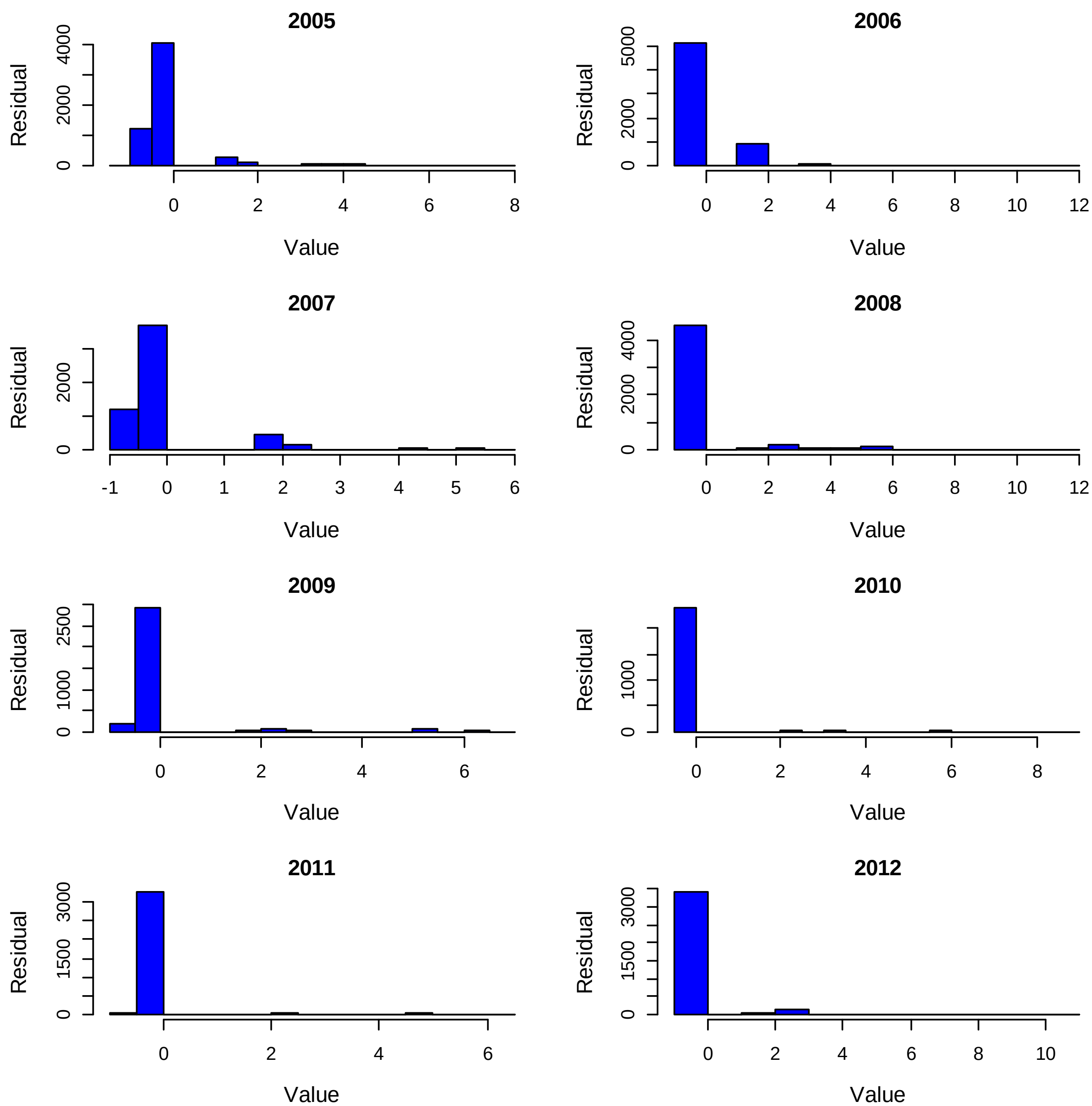

Figure 12. Annual residual plots from the binomial model.

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Table 1. Estimated annual shortfin mako shark (SMA) zero-catch percentage of Taiwanese large-scale tuna longline fishery in the North Pacific Ocean.

Year	SMA Zero %
2005	86.38%
2006	82.43%
2007	87.73%
2008	92.84%
2009	92.36%
2010	96.35%
2011	94.39%
2012	92.88%
Average	90.67%

Table 2. Deviance table for final GLM results of delta-lognormal model.

Log-normal Positive Catch rate

Source	Df	Deviance	Resid. Df	Resid. deviance	P value
Intercept			3719	1547.6	
yy	7	104.450	3712	1443.2	<0.001
Q	3	53.775	3709	1389.4	<0.001
A	3	93.433	3706	1296.0	<0.001
HPB	1	3.178	3705	1292.8	<0.001
SST	1	2.495	3704	1290.3	<0.005
Q:A	9	15.556	3695	1274.7	<0.001
Q:HPB	2	2.269	3693	1272.5	<0.001
A:HPB	3	5.205	3690	1267.2	<0.001

Binomial Model

Source	Df	Deviance	Resid. Df	Resid. deviance	P value
Intercept			35860	23899	
yy	7	800.24	35853	23098	<0.001
Q	3	635.71	35850	22463	<0.001
A	3	1710.01	35847	20753	<0.001
HPB	1	1.97	35846	20751	<0.005
SST	1	199.59	35845	20551	<0.001
Q:A	9	57.62	35836	20493	<0.001
Q:HPB	3	45.24	35833	20448	<0.001

Table 3. Estimated annual shortfin mako shark by-catch in number and weight (MT) of Taiwanese large-scale tuna longline fishery in the North Pacific Ocean.

Year	EstSMA (N)	EstSMA (MT)
1971	5	0
1972	4	0
1973	0	0
1974	132	10
1975	197	15
1976	13	1
1977	76	6
1978	75	6
1979	14	1
1980	45	3
1981	42	3
1982	5	0
1983	5	0
1984	0	0
1985	113	9
1986	136	10
1987	56	4
1988	10	1
1989	53	4
1990	213	16
1991	228	17
1992	74	6
1993	59	4
1994	12	1
1995	1558	118
1996	674	51
1997	567	43
1998	679	51
1999	1465	111
2000	1292	98
2001	1206	91
2002	1612	122
2003	1106	84
2004	1885	143

2005	1788	135
2006	2032	154
2007	1316	100
2008	823	62
2009	983	74
2010	193	15
2011	886	67
2012	1077	82

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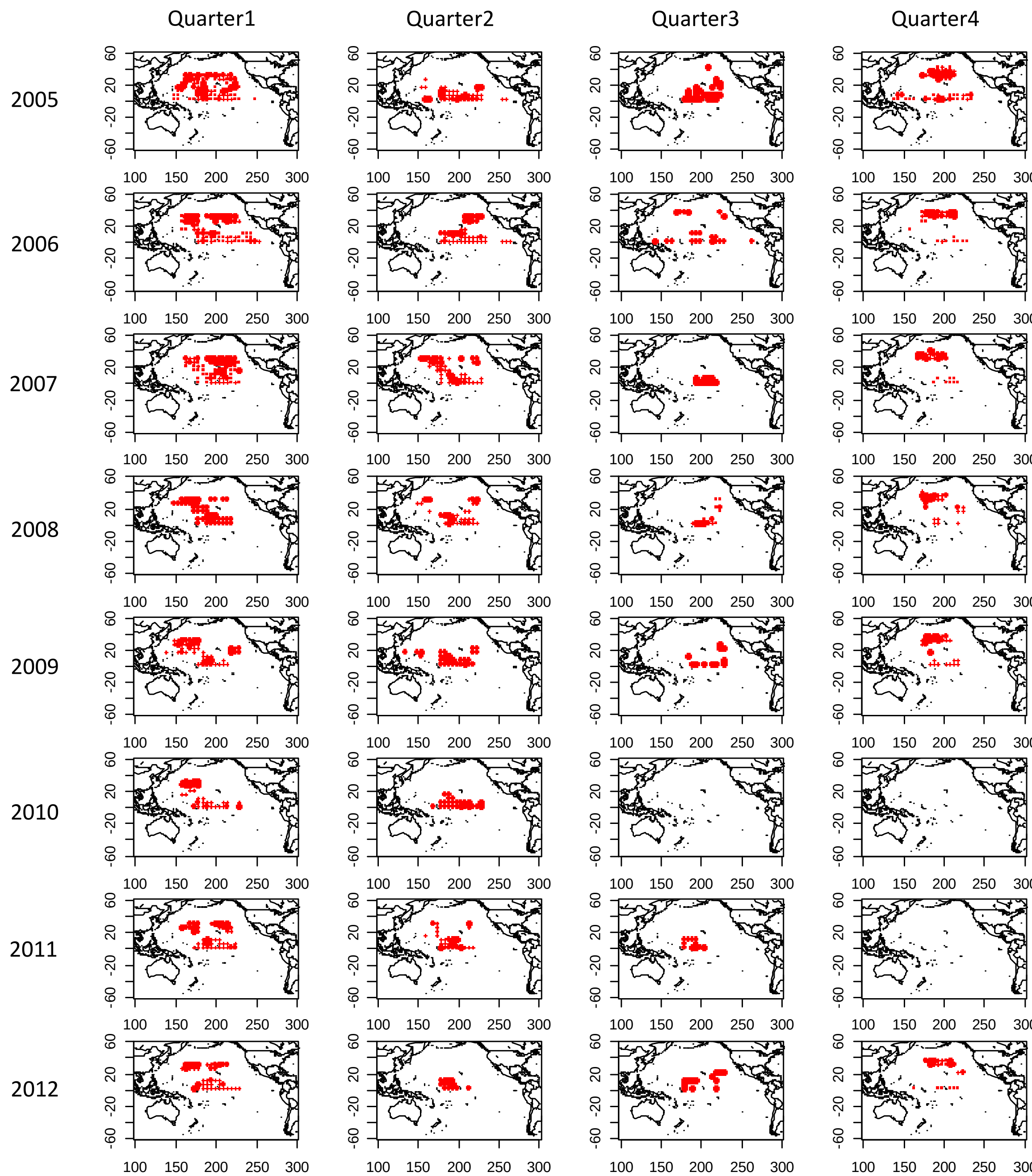

Appendix Fig. 1. Nominal CPUE distribution by year and quarter of shortfin mako sharks caught by Taiwanese large-scale tuna longline fishery in the North Pacific Ocean from 2005-2012.

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