# Catch estimate and CPUE standardization of the blue shark based on observers' records of Taiwanese large-scale tuna longline fisheries in the North Pacific Ocean

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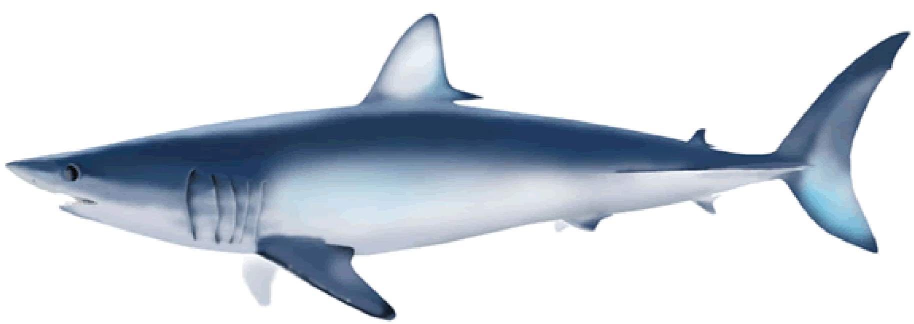

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## ABSTRACT

In the present study, the blue shark catch and effort data from observers' records of Taiwanese large-scale longline fishing vessels operating in the North Pacific Ocean from 2004-2015 were analyzed. Due to the large percentage of zero shark catch, the catch per unit effort (CPUE) of blue shark, as the number of fish caught per 1,000 hooks, was standardized using delta lognormal approach. The analysis of standardized CPUE showed a stable increasing trend for blue sharks. The results suggested that the blue shark stock in the North Pacific Ocean seems at the level of optimum utilization. The blue shark by-catch was estimated using the area-specific standardized CPUE multiplying the fishing effort and accounting for the coverage rate. Estimated blue shark by-catch in weight ranged from 1 ton in 1973 to 1,315 tons in 2002.

## 1. Introduction

Blue shark is the major shark by-catch species of Taiwanese large longline fishery. Since FAO and international environmental groups has concerned on the conservation of elasmobranchs in recent years, it is necessary to examine the recent trend of sharks by examining the logbook of tuna fisheries. However, standardization of Taiwanese catch rate on sharks is not straightforward because the data have been confounded with many factors, such as target-shifting effects. Therefore, the observer program for the large longline fishery was conducted to obtain detailed data for more comprehensive stock assessment and management studies. Recently, the increase of coverage rate of observations enabled us to get a better estimation of shark by-catch. Thus, the objective of this study is to update the historical catches and CPUE of blue shark in the North Pacific based on observers' records.

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 also applied to address these excessive zeros of shark catch for CPUE standardization in this study.

## 2. Material and methods

## 2.1. Source of data

The logbook data of Taiwanese large-scale longline fishery from 1971 to 2015, provided by the Overseas Fisheries Development Council, Taiwan were used in this study. These logbook data contain basic

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information on fishing time, area, number of hooks and catches of 14 species including major tunas, billfishes and sharks. The species-specific catch data including tunas, billfishes, and sharks from observers' records in 2004-2015 were used to standardize CPUE of blue shark of Taiwanese large-scale longline fishery in the North Pacific Ocean. The summary of these data were shown in **Table 1**. In addition, the standardized CPUE was applied to back-estimate the historical blue shark catch of Taiwanese large-scale longline fleets.

Blue sharks caught by Taiwanese large-scale longline fishery were mainly observed in the equatorial waters (**Figure 1**). Based on the suggestion of the ISC shark working group in 2012, the North Pacific Ocean was stratified as 2 areas namely A (north of 25ºN) and B (0ºN-25ºN). For standardization, CPUE was calculated by set of operations based on observers' records during the period of 2004-2012.

In last ISC blue shark meeting, the CPUE of Taiwanese LTLL fleet based on observers' data was considered lower than the CPUE series from other countries. We found the fishing effort of the Taiwanese LTLL fleet before 2014 was overestimated because the observers used to be requested to report all the catch during their observations but actually they could not. Hence, we adjusted the fishing effort from the observer's report in this study. The average operation time was 16 and 14 hours for bigeye and albacore fleets, respectively. However, the maximum observing time period for the observer is 10 hours. So, the observed effort (hooks) before 2014 was adjusted by using the reported hooks divided by the adjusted factor 10/16 and 10/14 for bigeye and albacore fleet, respectively. The adjusted fishing effort was used to estimate the nominal and standardized CPUE.

## 2.2. CPUE standardization

A large proportion of sets with zero catch of blue shark (~50%) were found in observers' records. Hence, to address these excessive zeros, the delta lognormal model (DLN) (Lo *et al.* 1992) was applied to the standardization of blue shark CPUE. The DLN is a mixture of two models, one model is used to estimate the proportion of positive catches and a separate 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 blue shark was constructed with interaction. The main variables chosen as input into the DLN analyses were year (Y), quarter (Q), area (A), latitude (LAT), longitude (LON) and HPB (number of hooks per basket, HPB). The following additive model was applied to the data in this study:

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

Part 1: Lognormal model

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ln(CPUE) = μ + Y + Q + A + HPB + LAT + LON + Q*A + Q*HPB + A*HPB + $\varepsilon_1$ (1)

where μ is the mean, Q*A, Q*HPB, A*HPB are interaction terms, $\varepsilon_1$ is a normal random error term. The effect of gear configuration, HPB, was categorized into two classes: shallow set (HPB ≦ 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). The area strata used for the analysis were shown in **Figure 2**. To estimate the proportion of positive blue shark catch (P), we used a model assuming a binomial error distribution ($\varepsilon_2$):

Part 2: Binomial model

P = μ + Y + Q + A + HPB + LAT + LON + Q*A + Q*HPB + A*HPB + $\varepsilon_2$
(2)

To estimate the historical blue shark catch, the area-specific CPUE standardization was used and the DLN models were as follows:

Part 1: Lognormal model

ln(CPUE) = μ + Y + Q + HPB + LAT + LON + Q*HPB + $\varepsilon_3$
(3)

Part 2: Binomial model

P = μ + Y + Q + HPB + LAT + LON +Q*HPB + $\varepsilon_4$
(4)

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 relative annual abundance index was obtained by the product of the main annual effect of the Lognormal and Binomial components (Lo et al., 1992):

Standardized CPUE = CPUE*P (5)

Empirical confidence interval of standardized CPUE was estimated by using a bootstrap resampling method (Efron and Tibshirani, 1993). The number of bootstrapped sub-samples was generated based on the sample size of CPUE in each year. The 95% confidence intervals were then constructed based on bias corrected percentile method with 10,000 replicates (Efron and Tibshirani, 1993).

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## 2.3. Estimate of historical blue shark catch

Annual blue shark by-catch in number ($C_y$) from 2004 to 2015 was estimated by the following equations:

$$C_y = \sum_{i}^{2} \frac{\text{Nominal } CPUE_{i,y} \times Logbook\ effort_{i,y}}{Coverage\ rate_y} \text{, and} \tag{6}$$

$$C_y = \sum_{i}^{2} \frac{\text{Standarized } CPUE_{i,y} \times Logbook\ effort_{i,y}}{Coverage\ rate_y} \tag{7}$$

where y is year, $i$ = 1 is area A and $i$ = 2 is area B. Coverage rate is the total catch (bigeye tuna, albacore tuna, yellowfin tuna, and swordfish) in logbook to that in Task 1 (Nominal annual catch). Annual blue shark by-catch in number before 2004 was back-estimated using the same equation but annual nominal CPUE or area-specific standardized CPUE was replaced by the mean of nominal CPUE and the mean of standardized CPUE in the period of 2004-2015 because no observers' records were available before 2004. As the weight records from observers were inconsistent (often recorded as processed weight instead of whole weight) and might be biased, the catch in weight of blue shark was estimated using the multiplication of mean weight (assumed to be constant) and estimated or back-estimated catch in number. The mean FL of blue sharks was calculated from observers' data and the mean weight was obtained by substituting the mean FL into the W-FL relationship as following: $W = 5.009\times10^{-6}\ FL^{3.054}$ (Kohin and Wraith, 2010).

# 3. Results and discussion

The mean length of blue sharks reported by observers was 212 cm FL (n = 3,281) and the estimated mean weight was 63.74 kg. The blue shark bycatch data are characterized by many zero values and a long right tail (**Figure 3**). Overall, there were 51.69% of sets had zero bycatch of blue sharks (**Table 2**).

The best models for Lognormal and Binomial models chosen by AIC values were " ln(CPUE) =μ + Y + Q + A + HPB + LAT + LON + Q*A + Q*HPB (AIC= 3,006)" and " PA=μ + Y + Q + A + HPB + LAT + LON + Q*A + Q*HPB + A*HPB (AIC= 3,750) ", respectively. The best models were then used for the later analyses. In addition, the best models for area-specific CPUE standardization were shown as follows:

Area A: " ln(CPUE) =μ + Y + LAT + LON (AIC= 1,050)" and " PA =μ + Y + LAT + LON (AIC= 1,218) "and for Area B: "ln(CPUE) =μ + Y + Q + HPB + LAT + Q*HPB (AIC= 1,752)" and " PA =μ + Y + Q + HPB + LAT + LON + Q*HPB (AIC= 2,273) "

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The standardized CPUE series for the blue shark using the DLN model was shown in **Figures 4.** The detail values for nominal and standardized CPUE were listed in **Tables 3-4**. The standardized CPUE trend contains the combined effects from two models, one that calculates the probability of a zero observation and the other one that estimates the count per year.

The nominal CPUE of blue shark showed a strong inter-annual fluctuation. However, this variability was smoothed in the standardized CPUE series (**Figure 4**). This indicated that the standardization process removed certain variability attributes to the explanatory variables. The standardized CPUE series for blue shark using the DLN model was shown in **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 blue sharks caught by the Taiwanese LTLL fishery decreased from 2005 to 2009 and showed a slightly increasing trend thereafter (**Figure 4**).

The diagnostic results from the DLN model do not indicate severe departure from model assumptions (**Figures 5-9**). Additional residual plots for each factor were provided in **Appendix A**. The ANOVA tables for each model are given in **Appendix B**. Most main effects tested were significant (mostly $P < 0.01$) and included in the final model. Furthermore, the diagnostic results for area-specific CPUE standardization could also be found in **Appendix C**.

Estimated blue shark bycatch based on nominal CPUE produced higher values than those estimated through standardized CPUE. The detail values for each method were showed in **Table 5**. In this study, the historical blue shark by-catch obtained from area-specific standardized CPUE were chosen as the input values of stock assessment models. The results based on this method indicated that the estimated blue shark by-catch in number ranged from 5 in 1973 to 20,547 in 2002. The blue shark by-catch in weight of Taiwanese long-scale longline fishery ranged from 1 ton (1973) to 1,315 tons (2002) in the North Pacific Ocean (**Table 5**). The estimated catch was relative low before 1995 and increased to more than 500 MT and fluctuated thereafter and peaked at 1,315 MT, 1,152 MT, and 1186 MT in 2002 2004, and 2015, respectively (**Table 5**).

The back-estimations of historical blue shark by-catch in this report were based on the mean of observers' records and standardized CPUE from 2004-2015. 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 North Pacific (Bigelow *et al.,* 1999), and big-eye tuna in Indian Ocean (Okamoto *et al.,* 2001). In this report, environmental effects were not included in the model for standardization. The results obtained in this study can be improved if longer time series observers' data are available and environmental factors were included in the model.

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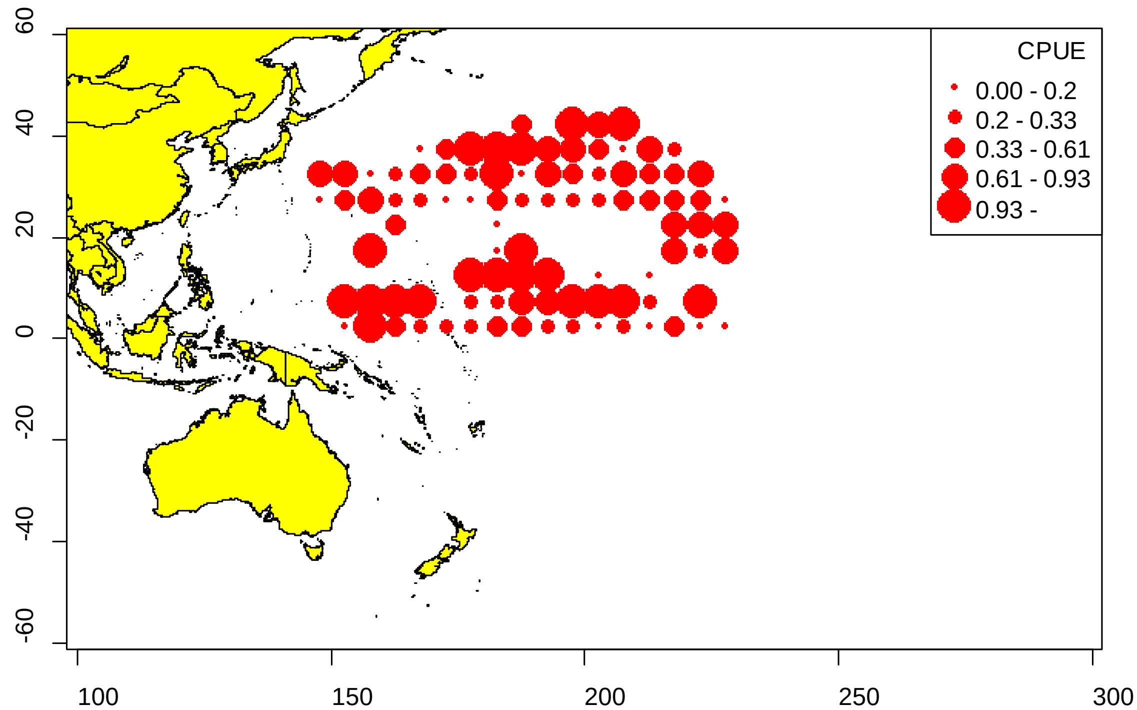


**Figure 1.** Distribution of CPUE of blue shark from Taiwanese large-scale tuna longline fisheries from 2004-2015.

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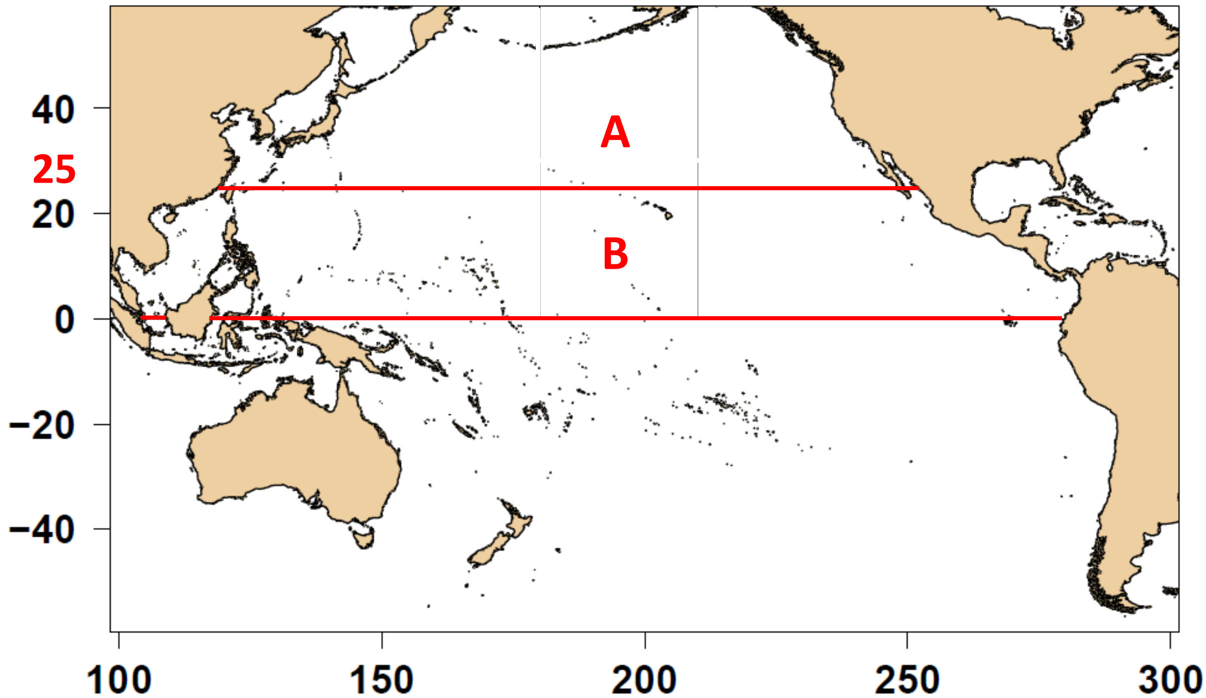


**Figure 2.** Area stratification used for the estimate of blue shark by-catch of the Taiwanese large-scale longline fishery in North Pacific Ocean.

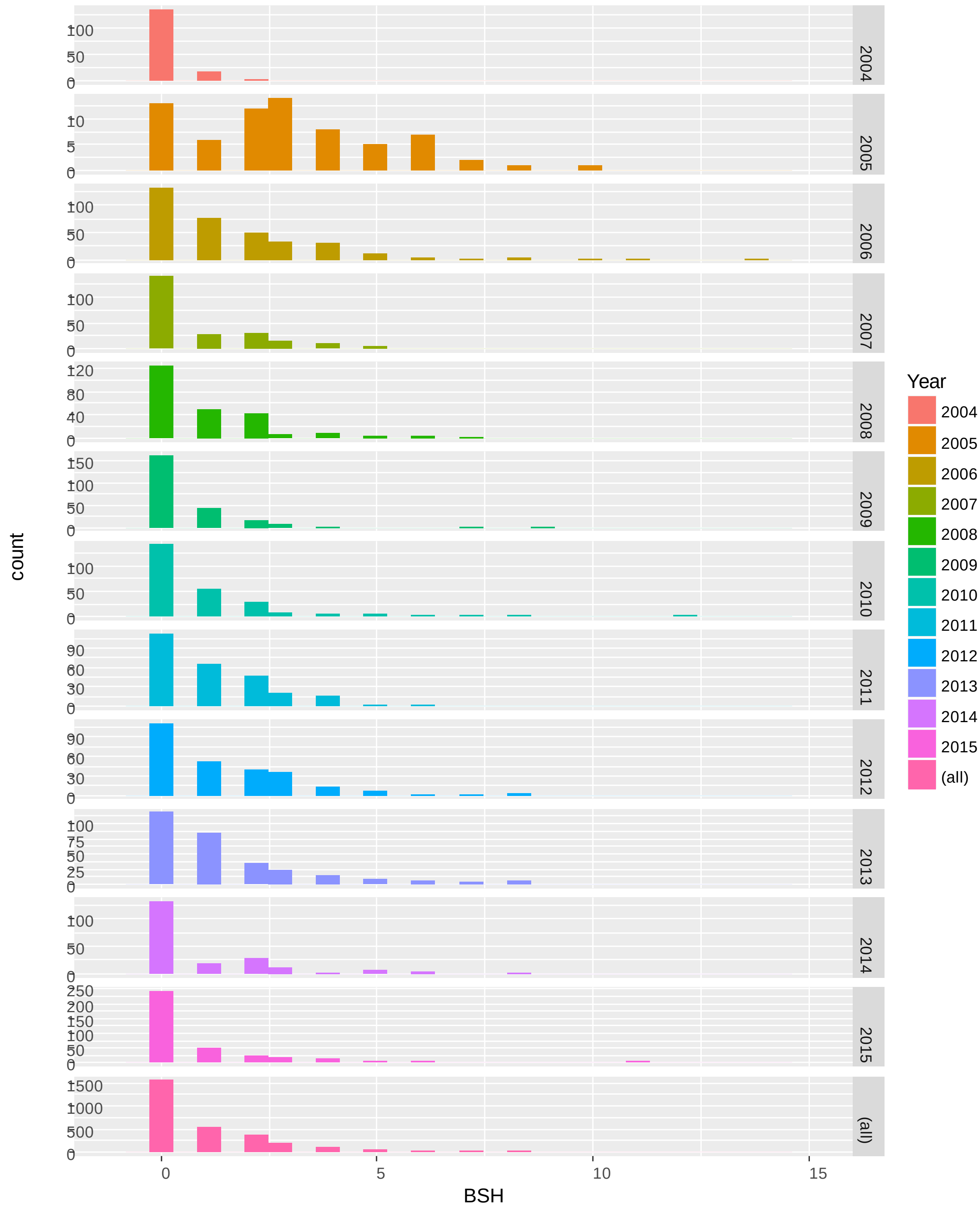


**Figure 3.** Frequency distribution of Taiwanese large-scale longline blue shark bycatch per set, 2004–2015.

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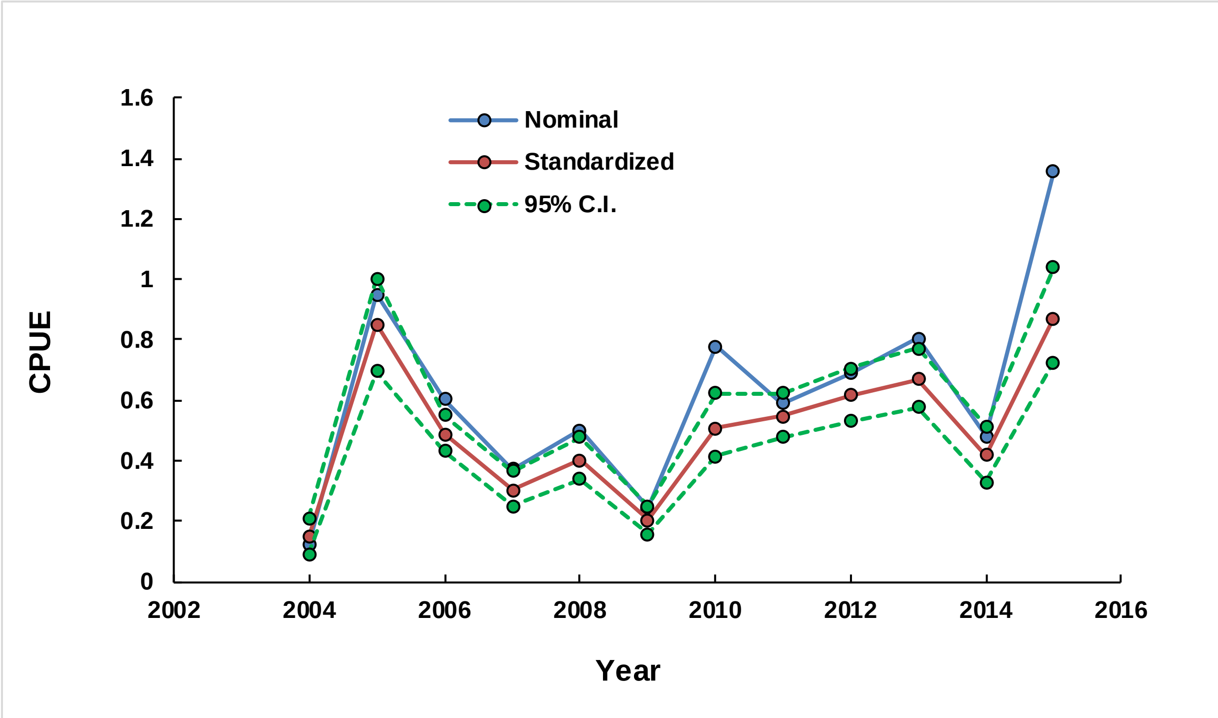


**Figure 4.** Nominal and standardized CPUE with 95% confidence interval of blue sharks by Taiwanese large-scale longline fishery from 2004 to 2015.

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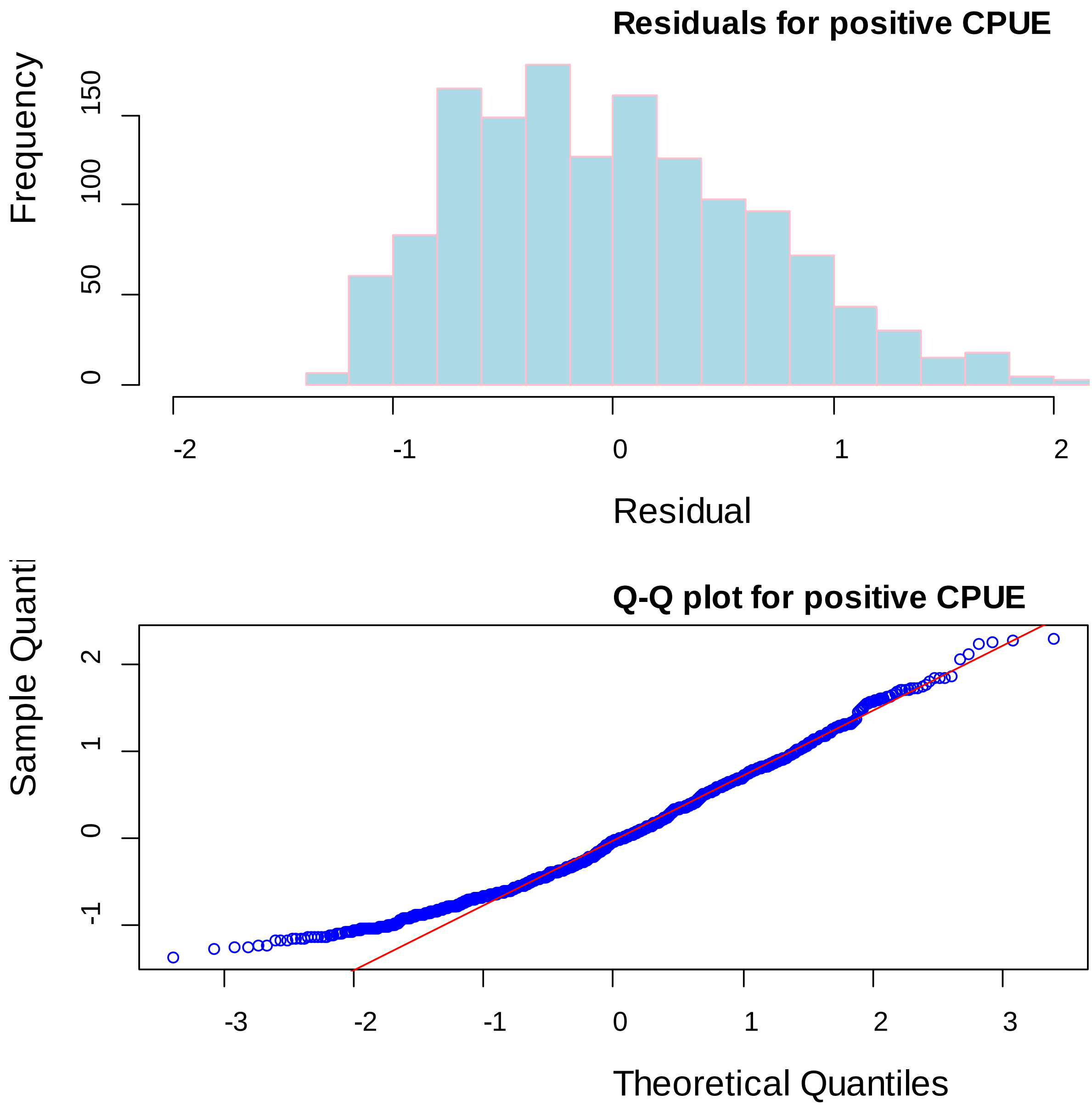


**Figure 5.** Diagnostic results from the lognormal model fit to the Taiwanese large-scale longline blue shark bycatch data.

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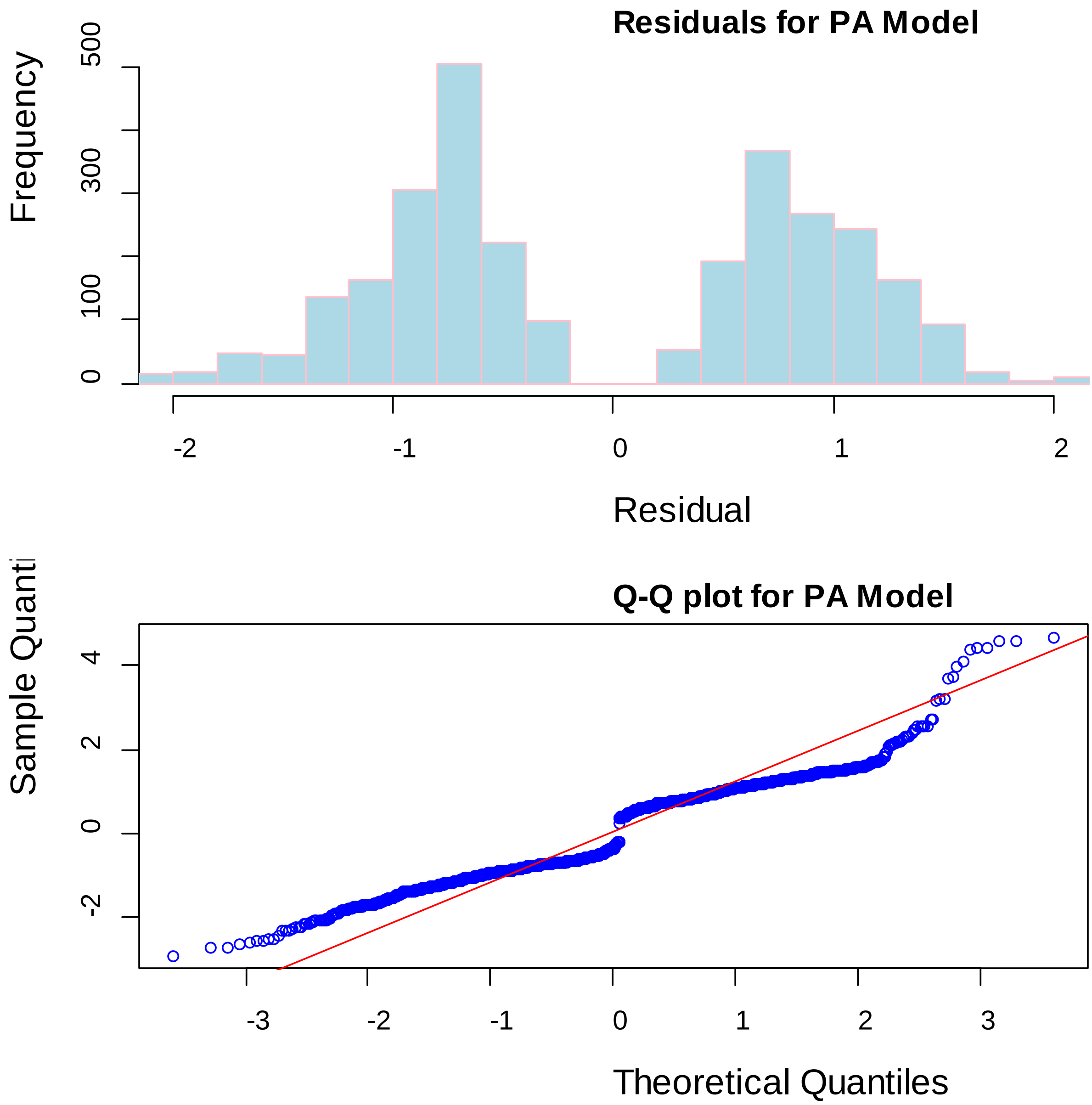


**Figure 6.** Diagnostic results from the binomial model fit to the Taiwanese longline blue shark bycatch data.

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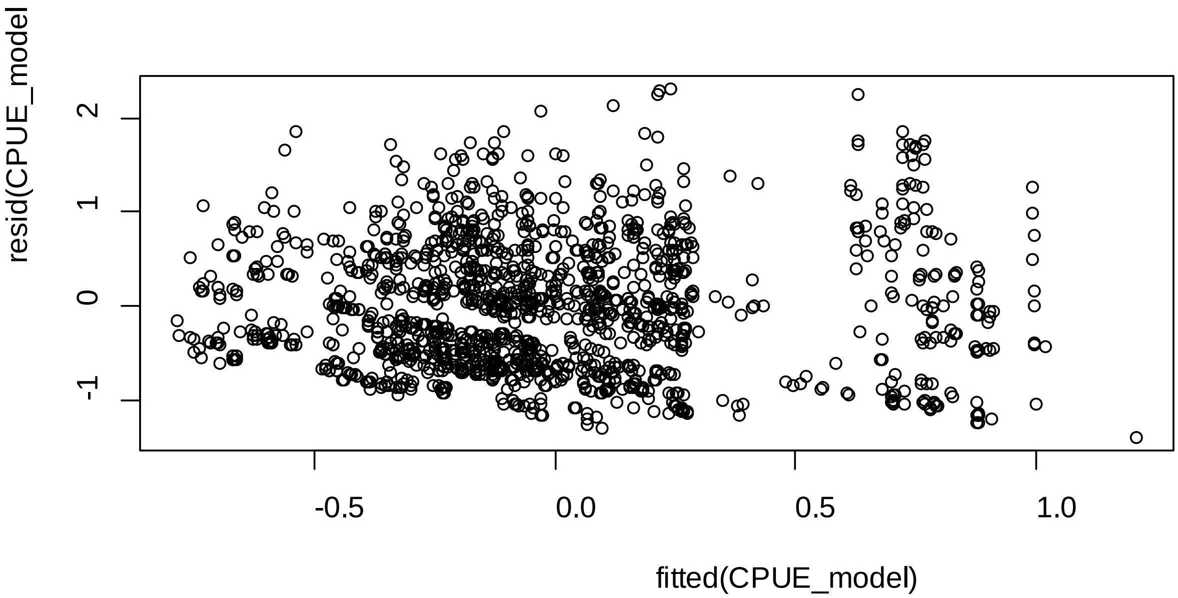


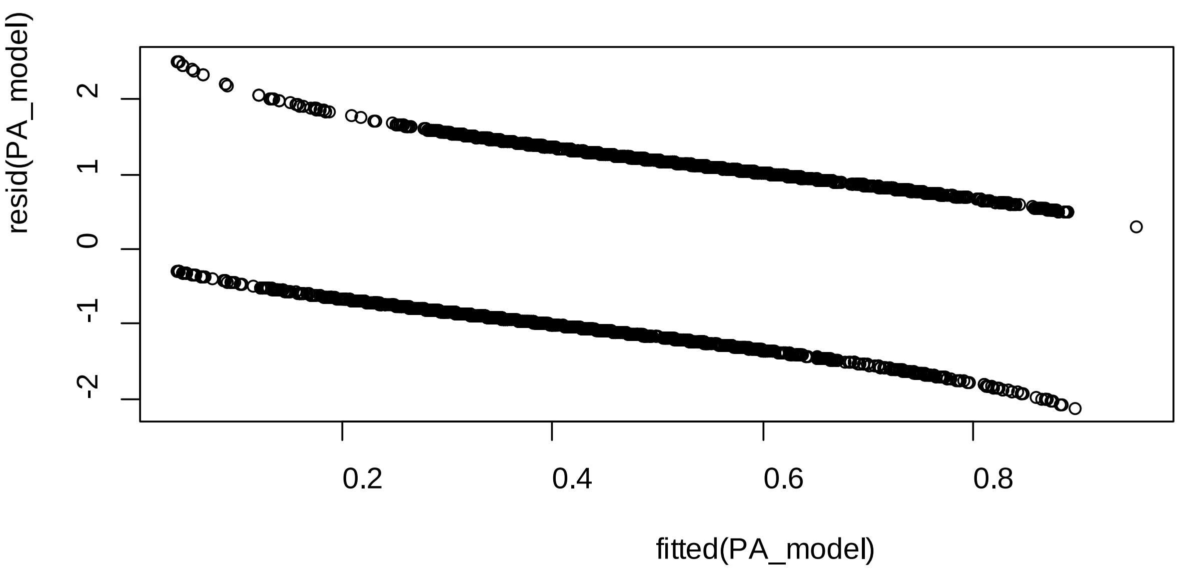


**Figure 7.** Residual plots for the DLN model fit to the Taiwanese large-scale longline blue shark bycatch data.

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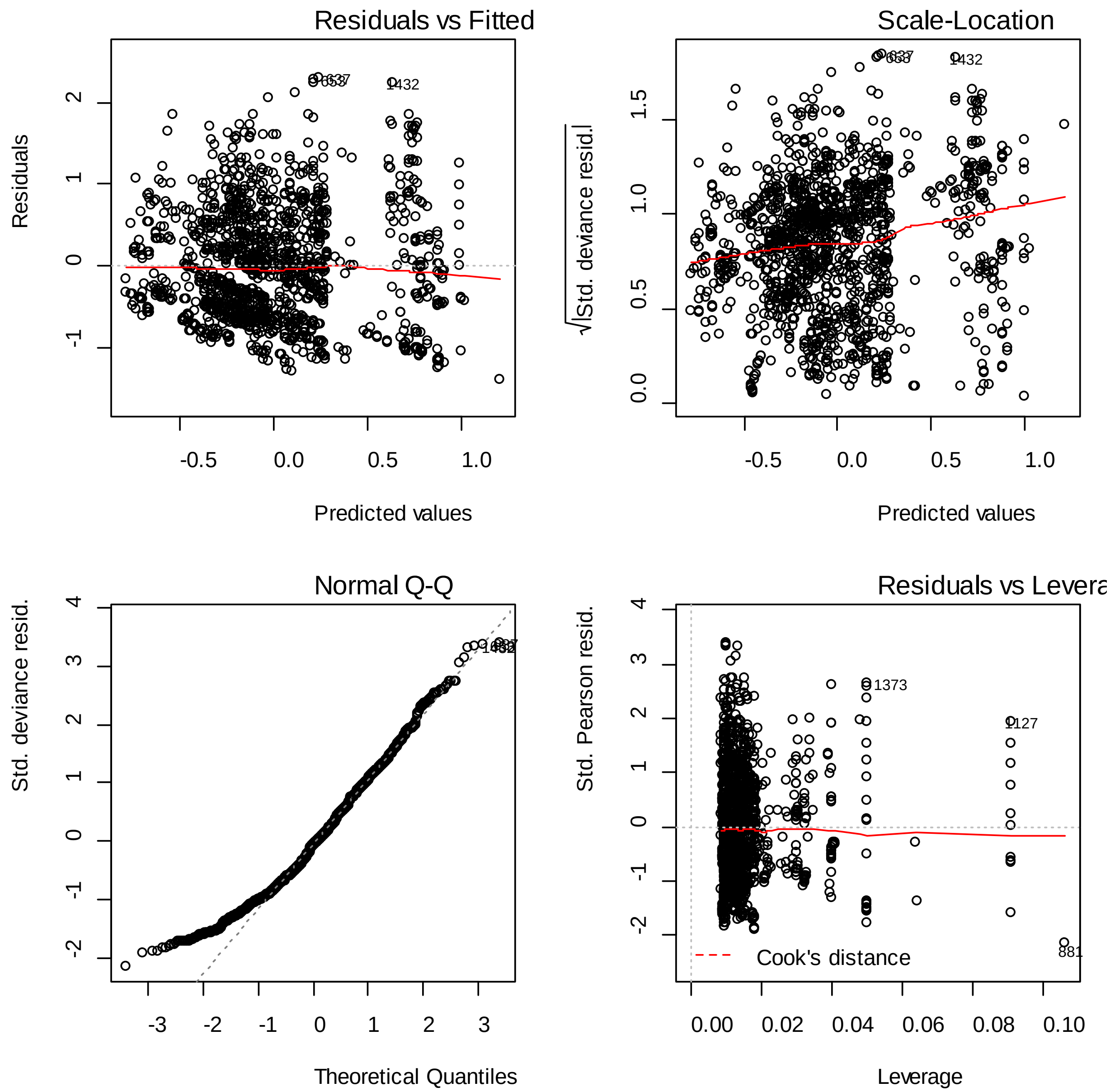


**Figure 8.** Residual plots for the lognormal model fit to the large-scale longline blue shark bycatch data.

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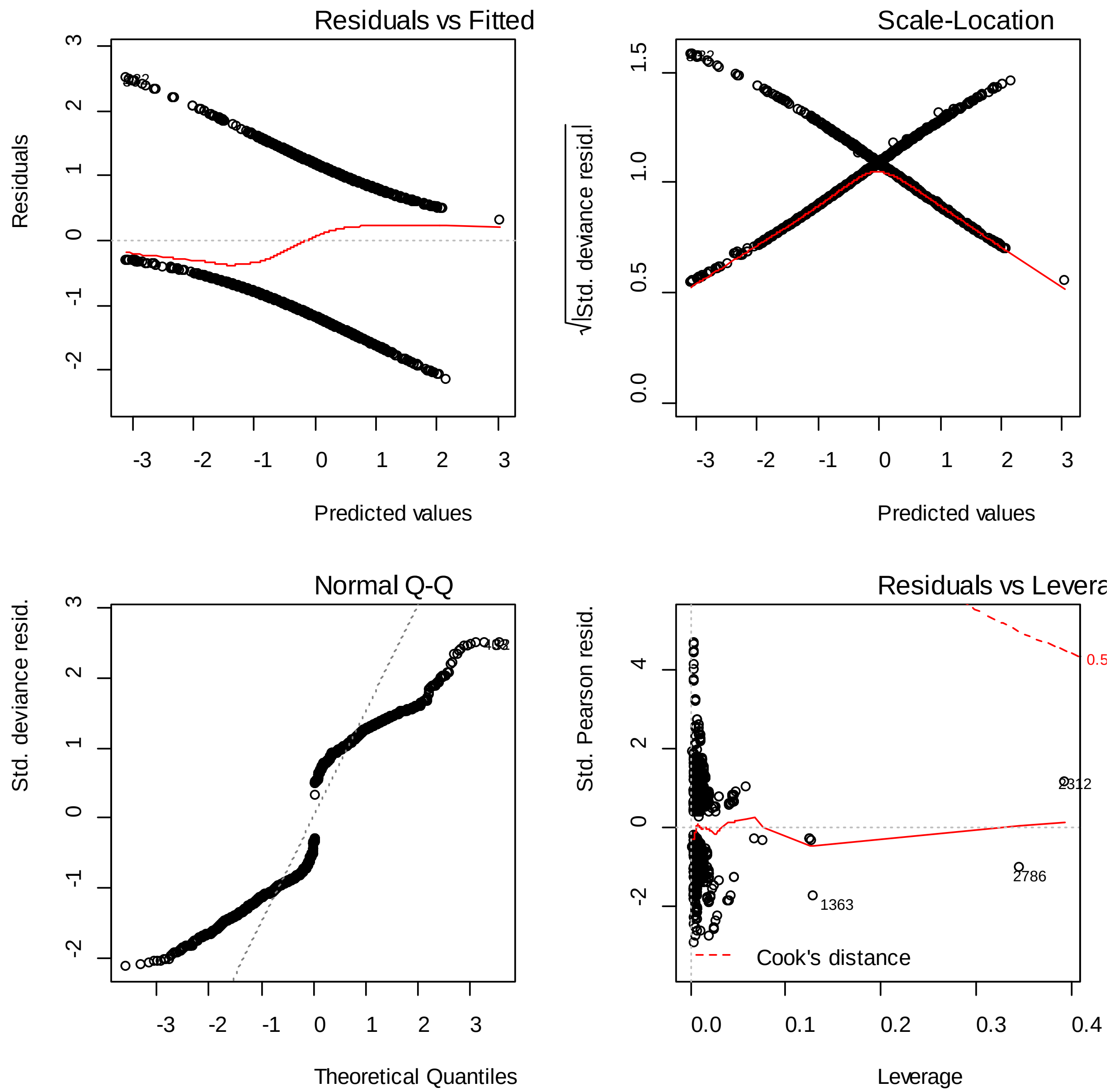


**Figure 9.** Residual plots for the binomial model fit to the large-scale longline blue shark bycatch data.

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**Table 1.** Summary of information of the observers' data from Taiwanese large-scale longline fishery used in this study.

| Year | North Pacific | |
|---|---|---|
| | No. of Hooks | No. of Sets |
| 2004 | 395982 | 162 |
| 2005 | 213504 | 69 |
| 2006 | 921451 | 347 |
| 2007 | 581333 | 232 |
| 2008 | 576726 | 245 |
| 2009 | 528401 | 237 |
| 2010 | 565870 | 267 |
| 2011 | 503306 | 265 |
| 2012 | 560976 | 269 |
| 2013 | 590922 | 307 |
| 2014 | 388927 | 206 |
| 2015 | 579551 | 407 |
| Average | 533912 | 251 |

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**Table 2.** Estimated annual blue shark zero-catch percentage of the Taiwanese large-scale tuna longline fishery in the North Pacific Ocean.

| Year | BSH Zero % |
|---|---|
| 2004 | 83.33% |
| 2005 | 18.84% |
| 2006 | 38.33% |
| 2007 | 59.91% |
| 2008 | 50.61% |
| 2009 | 68.78% |
| 2010 | 53.18% |
| 2011 | 42.64% |
| 2012 | 41.64% |
| 2013 | 38.76% |
| 2014 | 64.08% |
| 2015 | 60.20% |
| Average | 51.69% |

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**Table 3.** Estimated nominal and standardized CPUE values for blue shark of the Taiwanese tuna longline fishery in the North Pacific Ocean.

| | Original values | | Bias-corrected bootstrap confidence intervals | | | | |
|---|---|---|---|---|---|---|---|
| Year | Nominal | Standardized | Lower CI | Upper CI | Mean | STD | CV |
| 2004 | 0.1212 | 0.1458 | 0.0922 | 0.2116 | 0.1472 | 0.0304 | 0.2065 |
| 2005 | 0.9508 | 0.8500 | 0.6964 | 1.0030 | 0.8536 | 0.0804 | 0.0942 |
| 2006 | 0.6045 | 0.4880 | 0.4308 | 0.5503 | 0.4877 | 0.0309 | 0.0634 |
| 2007 | 0.3733 | 0.3036 | 0.2487 | 0.3637 | 0.3036 | 0.0291 | 0.0960 |
| 2008 | 0.4994 | 0.4024 | 0.3381 | 0.4776 | 0.4022 | 0.0356 | 0.0886 |
| 2009 | 0.2422 | 0.2027 | 0.1589 | 0.2500 | 0.2028 | 0.0230 | 0.1135 |
| 2010 | 0.7776 | 0.5085 | 0.4152 | 0.6218 | 0.5100 | 0.0524 | 0.1028 |
| 2011 | 0.5901 | 0.5483 | 0.4778 | 0.6231 | 0.5481 | 0.0365 | 0.0666 |
| 2012 | 0.6899 | 0.6149 | 0.5297 | 0.7054 | 0.6156 | 0.0449 | 0.0730 |
| 2013 | 0.8038 | 0.6700 | 0.5782 | 0.7705 | 0.6703 | 0.0488 | 0.0728 |
| 2014 | 0.4808 | 0.4172 | 0.3287 | 0.5133 | 0.4184 | 0.0474 | 0.1132 |
| 2015 | 1.3545 | 0.8715 | 0.7241 | 1.0383 | 0.8734 | 0.0801 | 0.0917 |

**Table 4.** Nominal and standardized CPUE values of area A and B used in blue shark historical catch correction.

| Year | Area A | | Area B | |
|---|---|---|---|---|
| | N.CPUE | S.CPUE | N.CPUE | S.CPUE |
| 2004 | 0.0038 | 0.0054 | 0.3523 | 0.3017 |
| 2005 | 0.9523 | 0.8433 | 0.8945 | 1.1268 |
| 2006 | 0.5932 | 0.4906 | 0.6337 | 0.5095 |
| 2007 | 0.4815 | 0.4327 | 0.1657 | 0.1602 |
| 2008 | 0.5918 | 0.4955 | 0.4359 | 0.3617 |
| 2009 | 0.4698 | 0.4102 | 0.0987 | 0.0966 |
| 2010 | - | - | 0.7776 | 0.5076 |
| 2011 | 0.6838 | 0.6813 | 0.5867 | 0.5451 |
| 2012 | 0.0438 | 0.0475 | 0.8155 | 0.7262 |
| 2013 | 0.3912 | 0.3309 | 1.2570 | 1.0740 |
| 2014 | 0.4977 | 0.4346 | 0.3527 | 0.3969 |
| 2015 | 2.7198 | 2.3137 | 0.7567 | 0.6001 |

**Table 5**. Estimated annual blue shark by-catch in number and weight (ton) of the Taiwanese tuna longline fishery in the North Pacific Ocean based on nominal and standardized CPUE.

| Year | Nominal CPUE | | Standardized CPUE by Area | |
|---|---|---|---|---|
| | EstBSH (N) | EstBSH (ton) | EstBSH (N) | EstBSH (ton) |
| 1971 | 92 | 6 | 73 | 5 |
| 1972 | 87 | 6 | 69 | 4 |
| 1973 | 7 | 1 | 5 | 1 |
| 1974 | 2549 | 163 | 2021 | 129 |
| 1975 | 3817 | 244 | 3027 | 194 |
| 1976 | 152 | 10 | 120 | 8 |
| 1977 | 920 | 59 | 729 | 47 |
| 1978 | 1138 | 73 | 902 | 58 |
| 1979 | 276 | 18 | 219 | 14 |
| 1980 | 867 | 55 | 688 | 44 |
| 1981 | 758 | 49 | 601 | 38 |
| 1982 | 98 | 6 | 78 | 5 |
| 1983 | 94 | 6 | 74 | 5 |
| 1984 | 7 | 1 | 5 | 1 |
| 1985 | 2191 | 140 | 1737 | 111 |
| 1986 | 2625 | 168 | 2082 | 133 |
| 1987 | 1074 | 69 | 852 | 55 |
| 1988 | 197 | 13 | 156 | 10 |
| 1989 | 1026 | 66 | 814 | 52 |
| 1990 | 4116 | 263 | 3264 | 209 |
| 1991 | 4401 | 282 | 3490 | 223 |
| 1992 | 1438 | 92 | 1140 | 73 |
| 1993 | 1136 | 73 | 901 | 58 |
| 1994 | 234 | 15 | 186 | 12 |
| 1995 | 12189 | 780 | 9666 | 619 |
| 1996 | 5248 | 336 | 4162 | 266 |
| 1997 | 6119 | 392 | 4852 | 311 |
| 1998 | 6426 | 411 | 5096 | 326 |
| 1999 | 11899 | 762 | 9436 | 604 |
| 2000 | 13054 | 835 | 10352 | 663 |
| 2001 | 18784 | 1202 | 14896 | 953 |
| 2002 | 25910 | 1658 | 20547 | 1315 |
| 2003 | 14833 | 949 | 11762 | 753 |
| 2004 | 22706 | 1453 | 18006 | 1152 |
| 2005 | 17475 | 1118 | 13857 | 887 |
| 2006 | 16882 | 1080 | 13387 | 857 |
| 2007 | 15626 | 1000 | 12392 | 793 |
| 2008 | 13276 | 850 | 10528 | 674 |
| 2009 | 9241 | 591 | 7328 | 469 |
| 2010 | 12675 | 811 | 10051 | 643 |
| 2011 | 17722 | 1134 | 14054 | 899 |
| 2012 | 13084 | 837 | 10375 | 664 |
| 2013 | 10847 | 694 | 8602 | 551 |
| 2014 | 13783 | 882 | 10930 | 700 |
| 2015 | 22346 | 1430 | 18532 | 1186 |

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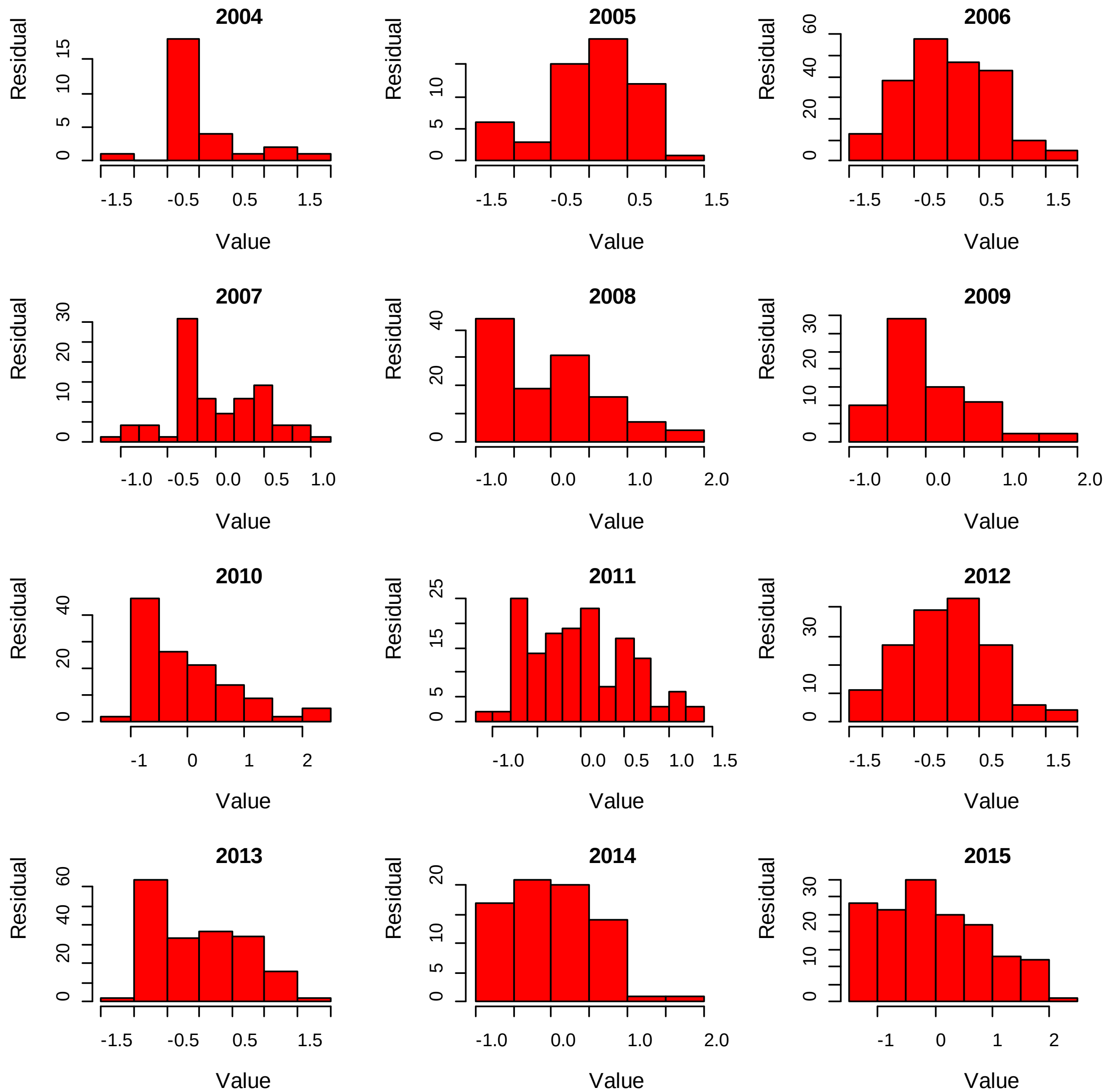
**Appendix A.** Additional residual plots for the Delta-lognormal GLM model.




**Appendix A Fig. 1.** Annual residual plots from the lognormal model.

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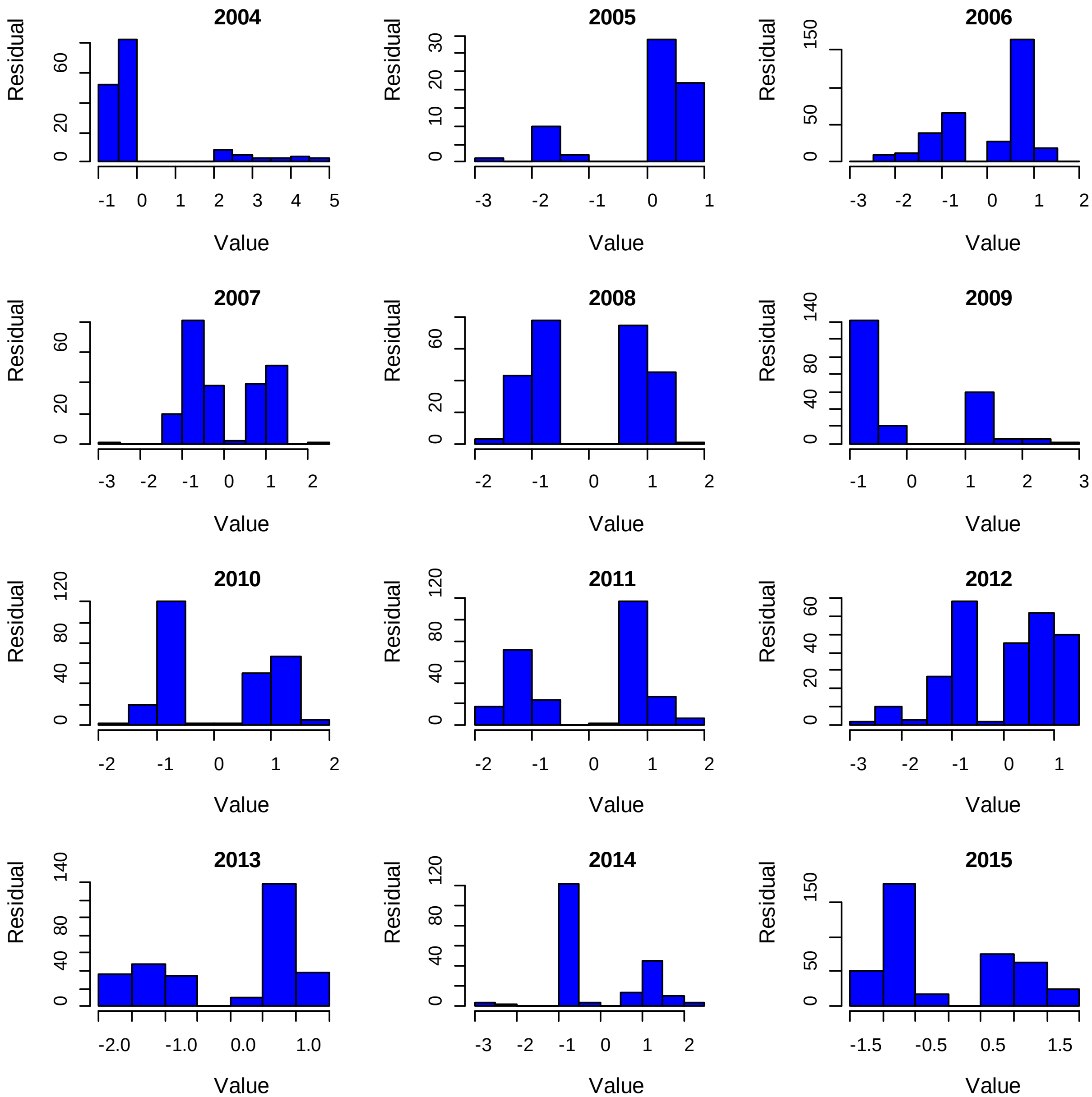


**Appendix A Fig. 2.** Annual residual plots from the binomial model.

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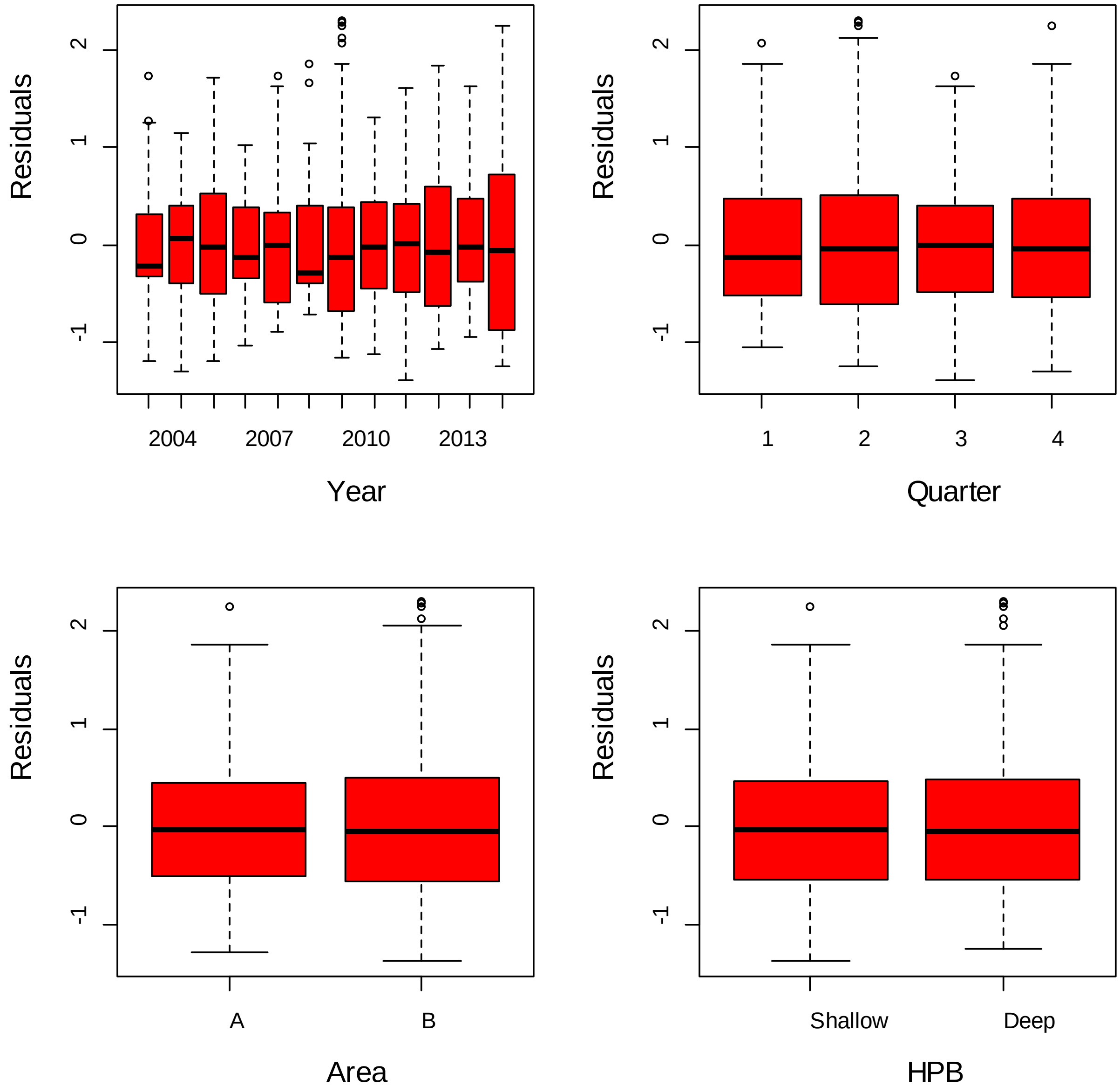


**Appendix A Fig. 3.** Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and HPB for lognormal model.

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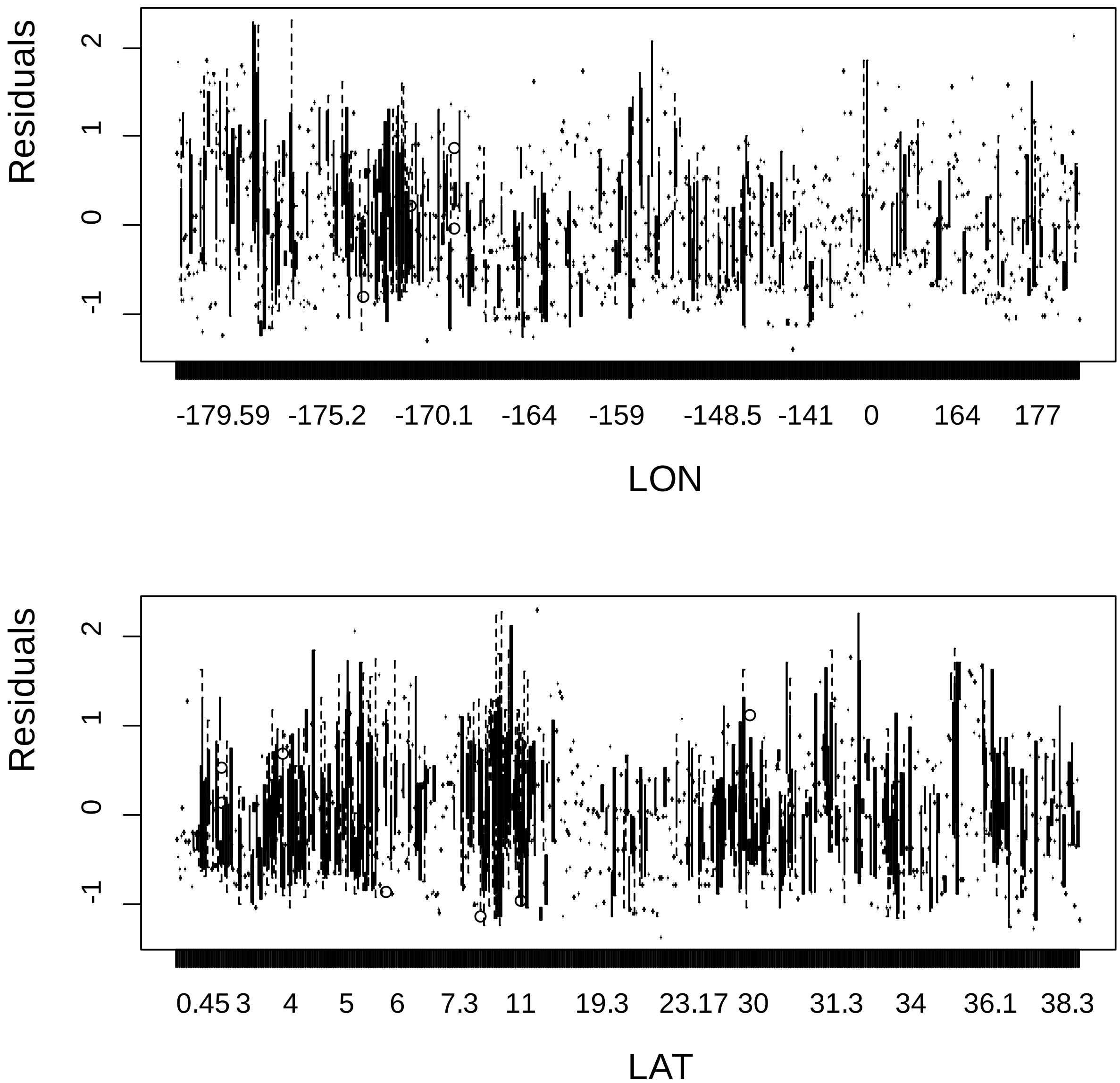


**Appendix A Fig. 4.** Plots of the Pearson residuals vs. the covariates for the variables LON and LAT for lognormal model.

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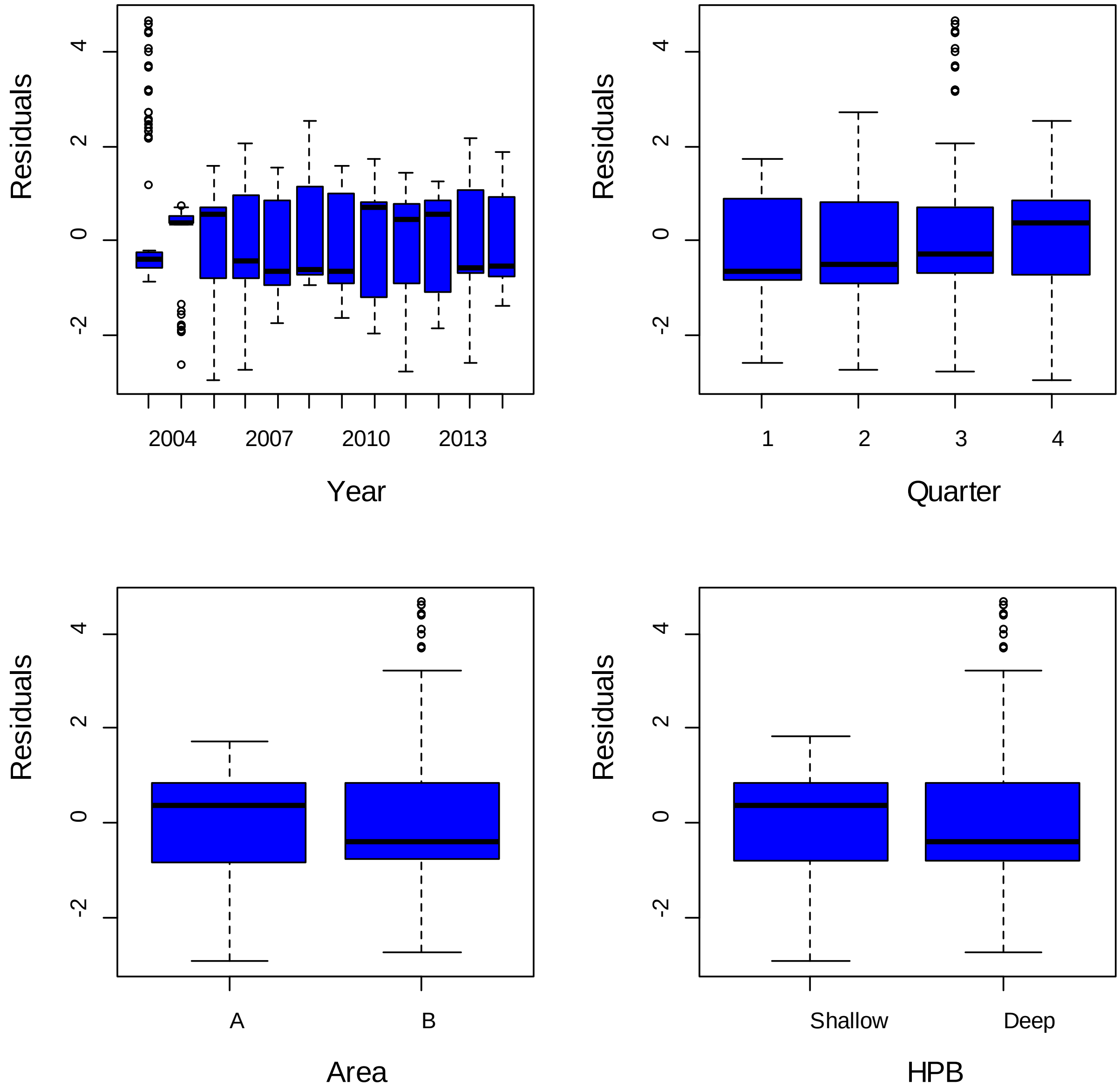


**Appendix A Fig. 5.** Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and HPB for binomial model.

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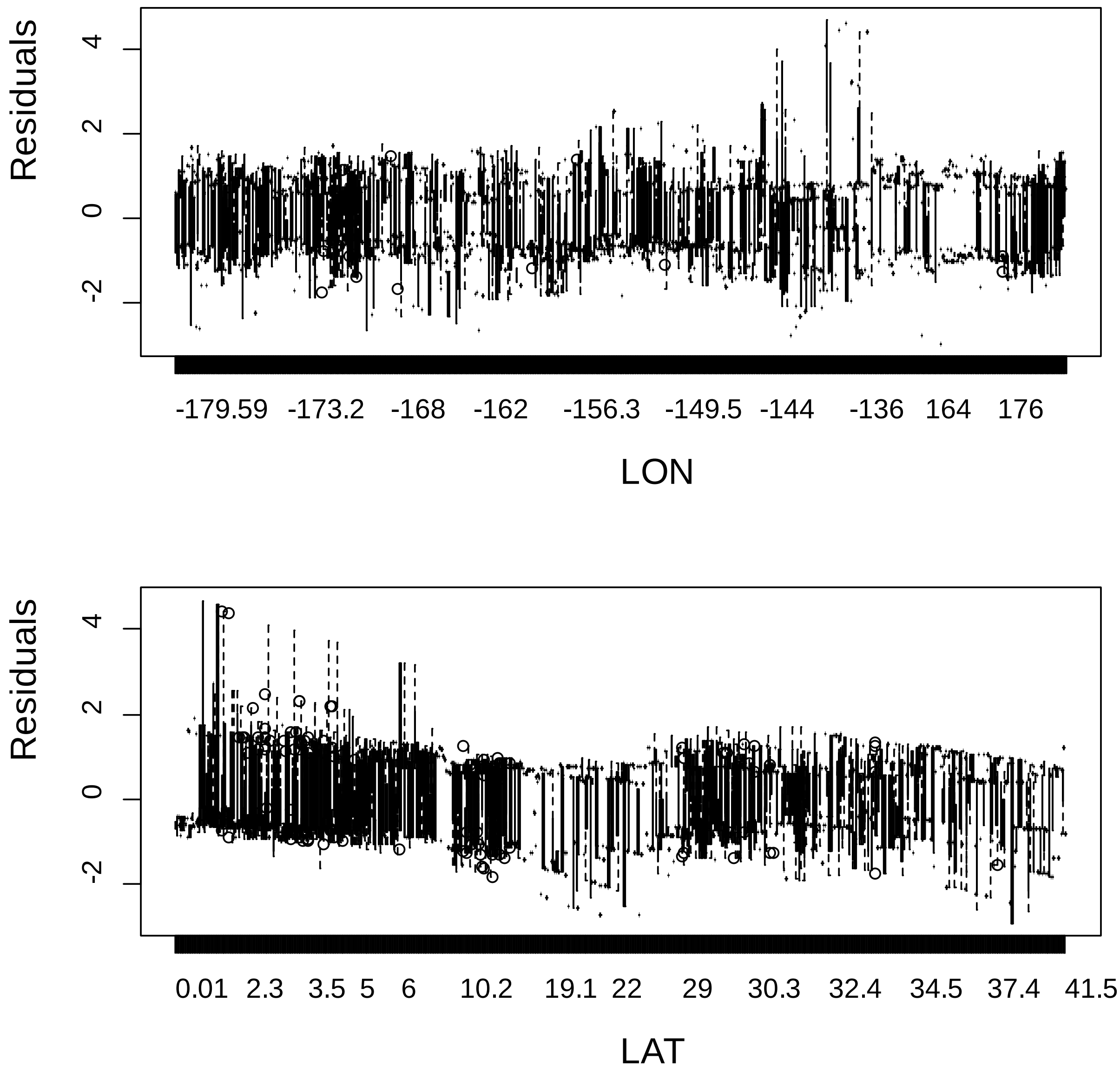


**Appendix A Fig. 6.** Plots of the Pearson residuals vs. the covariates for the variables LON and LAT for binomial model.

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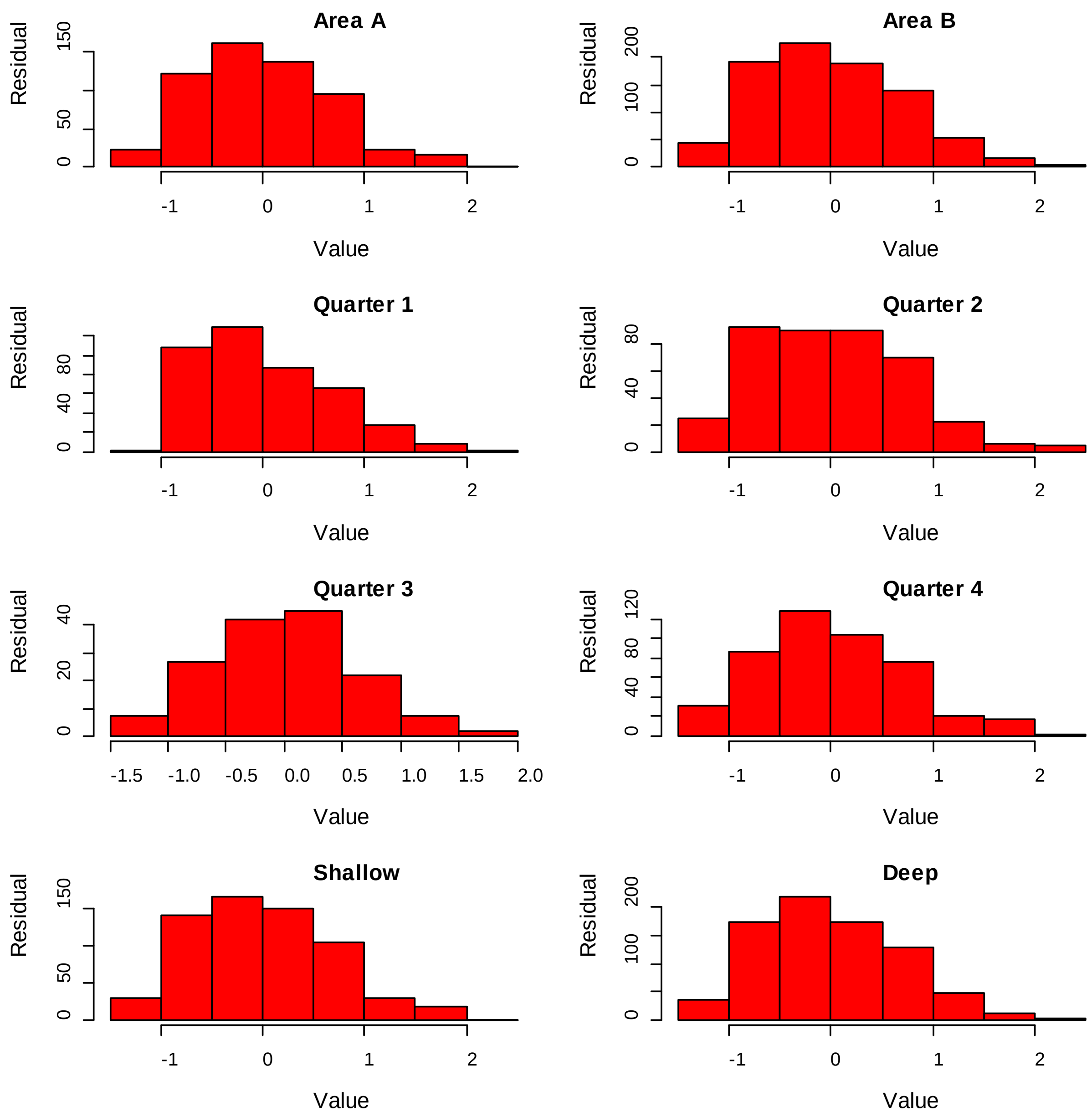


**Appendix A Fig. 7.** Histogram residuals plots for the variables Year, Quarter, Area and HPB from lognormal model.

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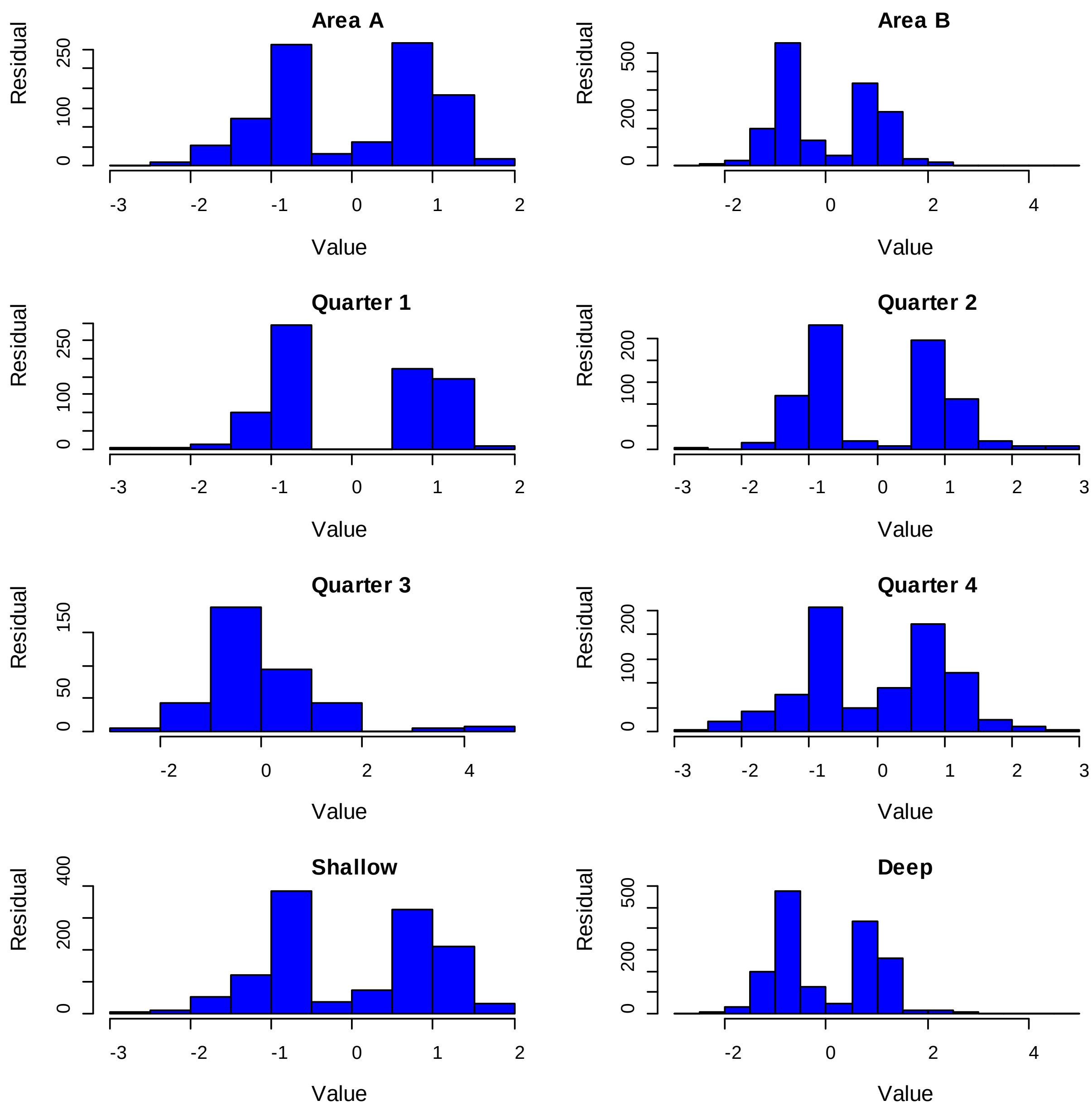


**Appendix A Fig. 8.** Histogram residuals plots for the variables Year, Quarter, Area and HPB from binomial model.

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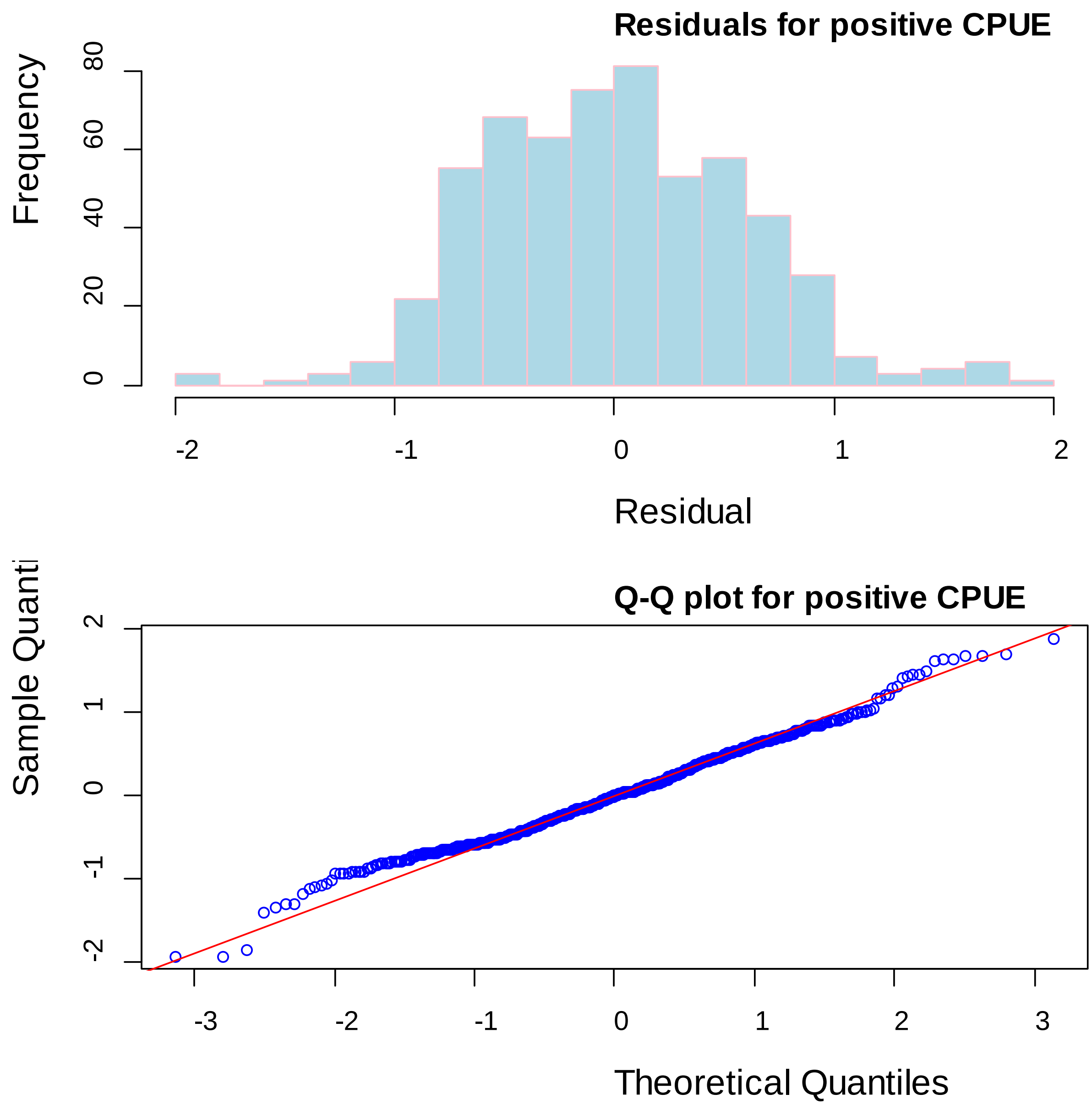
**Appendix B.** Deviance tables for the Delta-lognormal GLM model.

```
Analysis of Deviance Table

Model: gaussian, link: identity

Response: log(DATA$CPUE)

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev       F    Pr(>F)    
NULL                   1442     854.14                      
yy    11  141.830      1431     712.31 27.9241 < 2.2e-16 ***
Q      3   17.953      1428     694.36 12.9607 2.357e-08 ***
A      1    5.286      1427     689.07 11.4477 0.0007353 ***
HPB    1    0.506      1426     688.56  1.0961 0.2952985    
LAT    1   20.015      1425     668.55 43.3473 6.436e-11 ***
LON    1    1.789      1424     666.76  3.8737 0.0492423 *  
Q:A    3    5.674      1421     661.09  4.0959 0.0066076 ** 
Q:HPB  2    5.881      1419     655.21  6.3679 0.0017651 ** 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Model: binomial, link: logit

Response: DATA2$PA

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev        F    Pr(>F)    
NULL                   3012     4171.6                       
yy    11  228.323      3001     3943.2  20.7566 < 2.2e-16 ***
Q      3    9.346      2998     3933.9   3.1154  0.025024 *  
A      1   16.887      2997     3917.0  16.8866 3.968e-05 ***
HPB    1    3.337      2996     3913.7   3.3370  0.067740 .  
LAT    1  174.630      2995     3739.0 174.6302 < 2.2e-16 ***
LON    1    6.995      2994     3732.0   6.9950  0.008174 ** 
Q:A    3    3.725      2991     3728.3   1.2418  0.292681    
Q:HPB  3   21.205      2988     3707.1   7.0684 9.543e-05 ***
A:HPB  1    8.992      2987     3698.1   8.9917  0.002712 ** 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Appendix C.** Diagnostic of area-specific standardization modeling**.**

## Area A:




**Appendix C Fig. 1.** Diagnostic results from the lognormal model fit to the Taiwanese large-scale longline blue shark bycatch data in area A.

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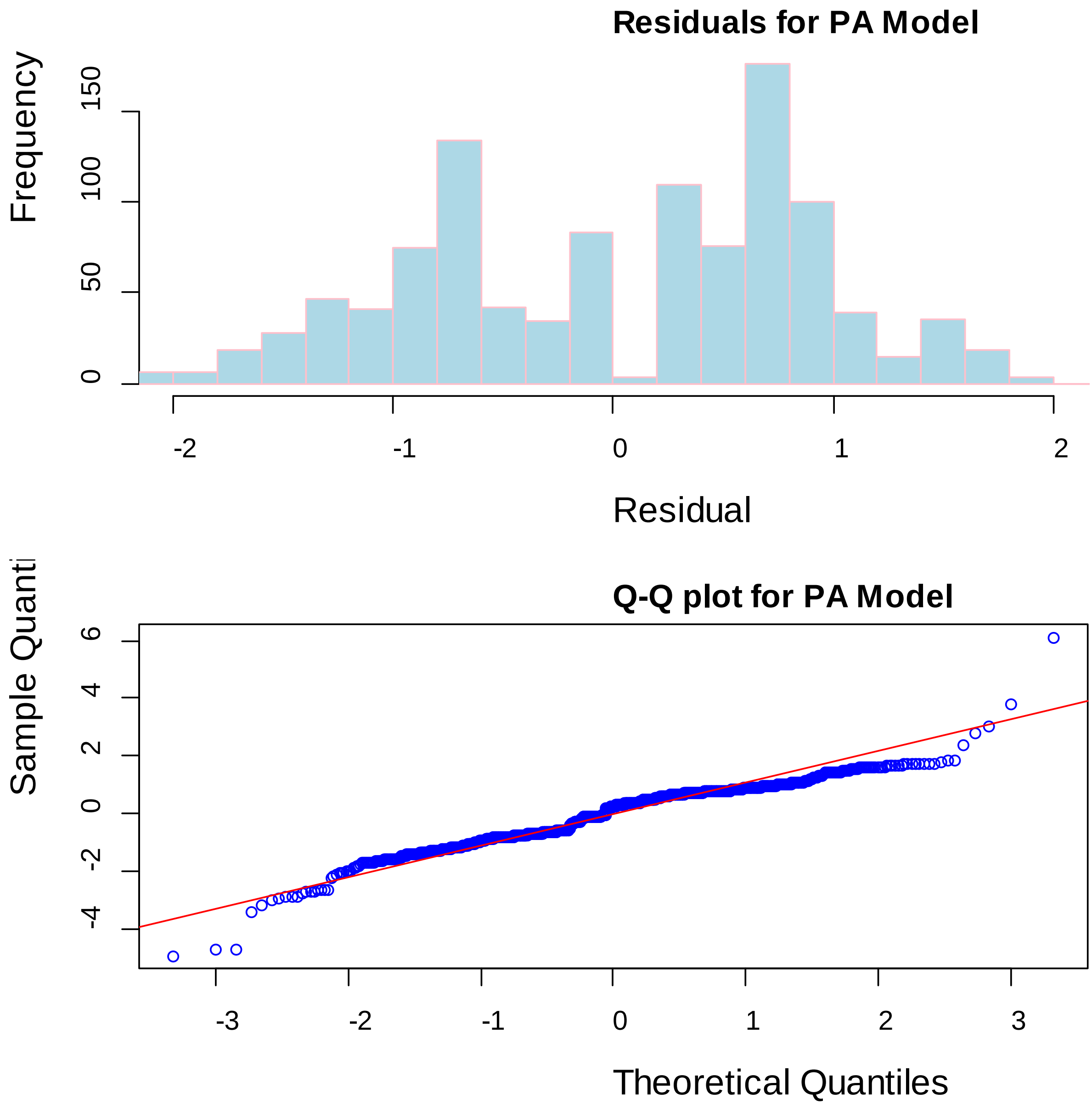


**Appendix C Fig. 2.** Diagnostic results from the binomial model fit to the Taiwanese large-scale longline blue shark bycatch data in area A.

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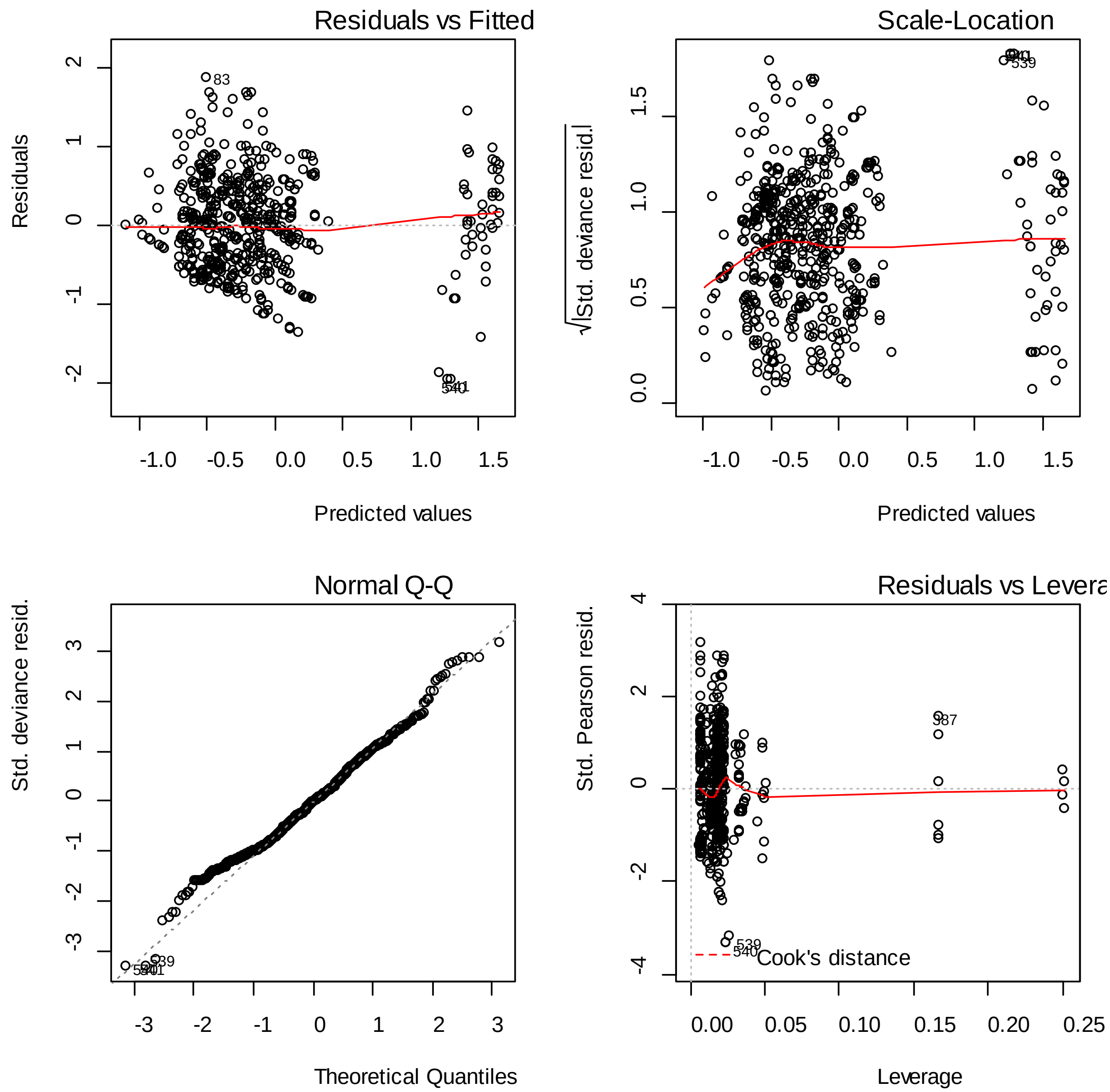


**Appendix C Fig. 3.** Residual plots for the lognormal model fit to the large-scale longline blue shark bycatch data in area A.

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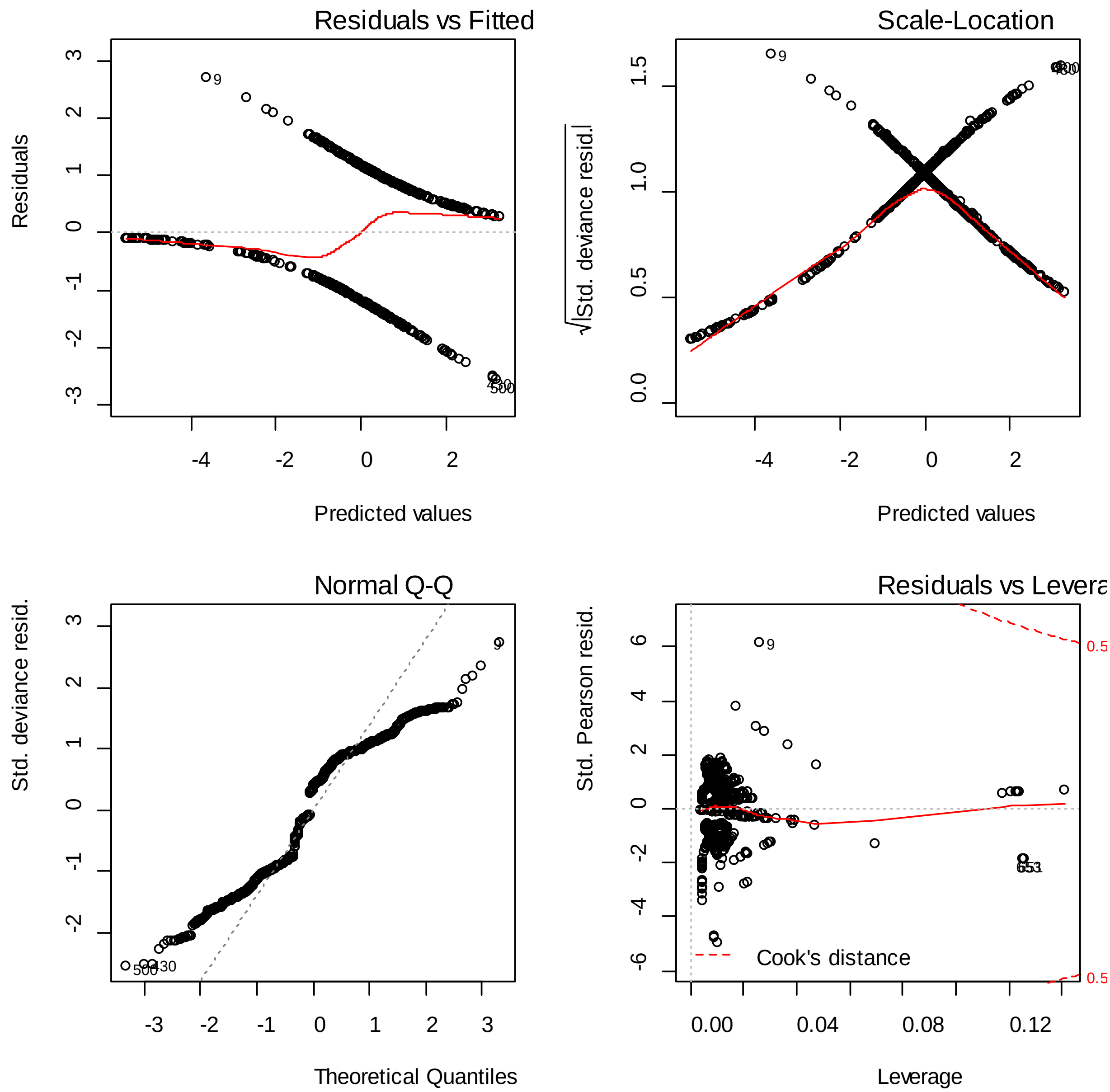


**Appendix C Fig. 4.** Residual plots for the binomial model fit to the large-scale longline blue shark bycatch data in area A.

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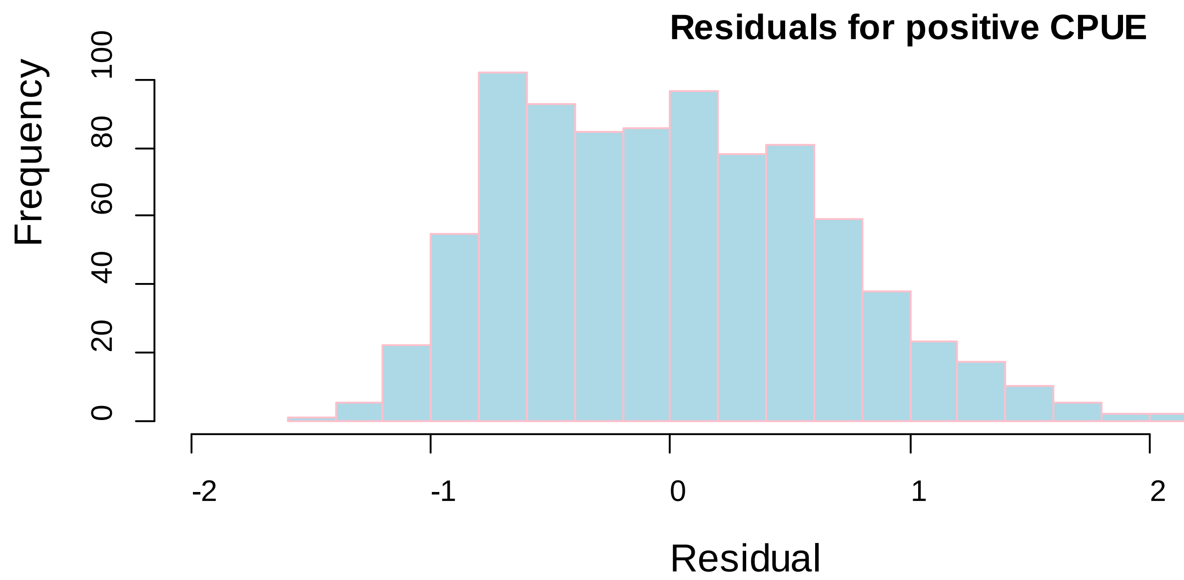
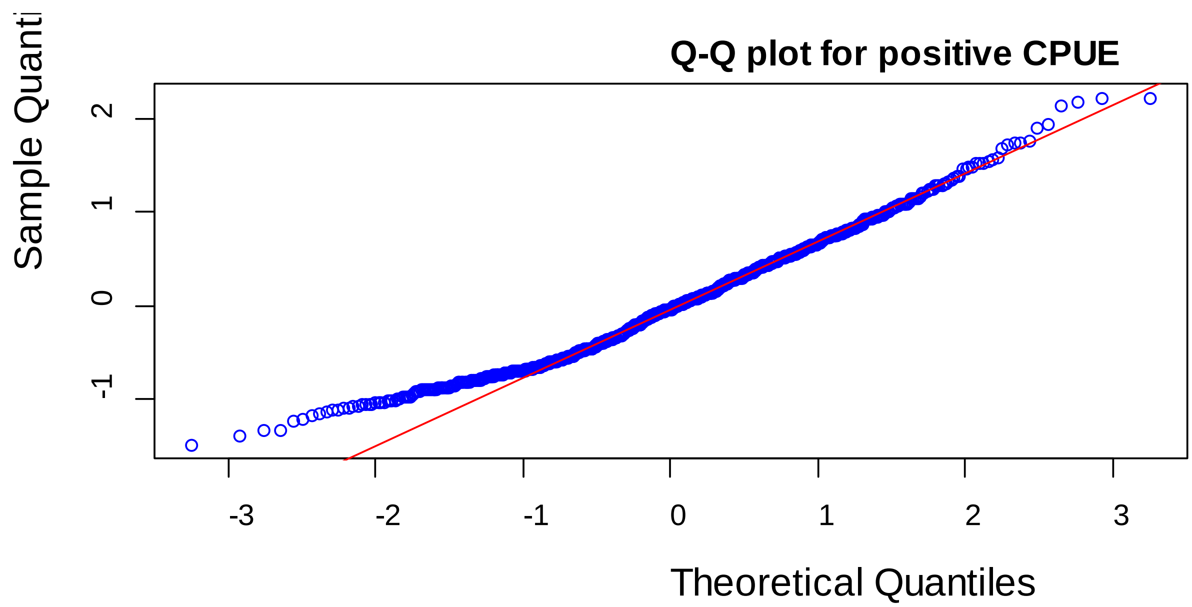
## Area B




**Appendix C Fig. 5.** Diagnostic results from the lognormal model fit to the Taiwanese large-scale longline blue shark bycatch data in area B.

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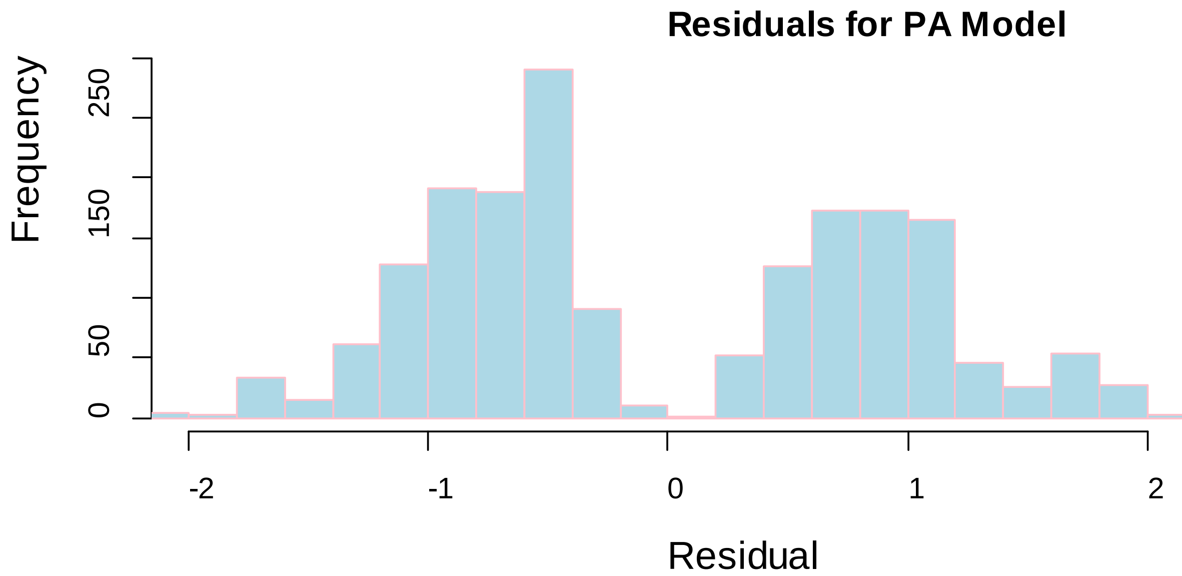


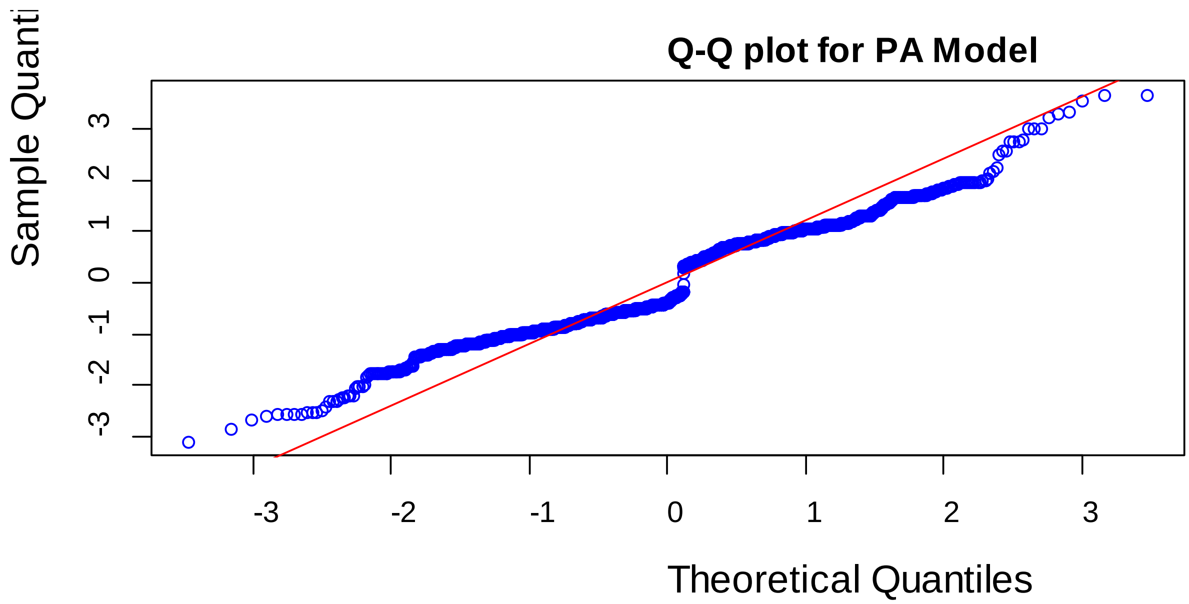


**Appendix C Fig. 6.** Diagnostic results from the binomial model fit to the Taiwanese large-scale longline blue shark bycatch data in area B.

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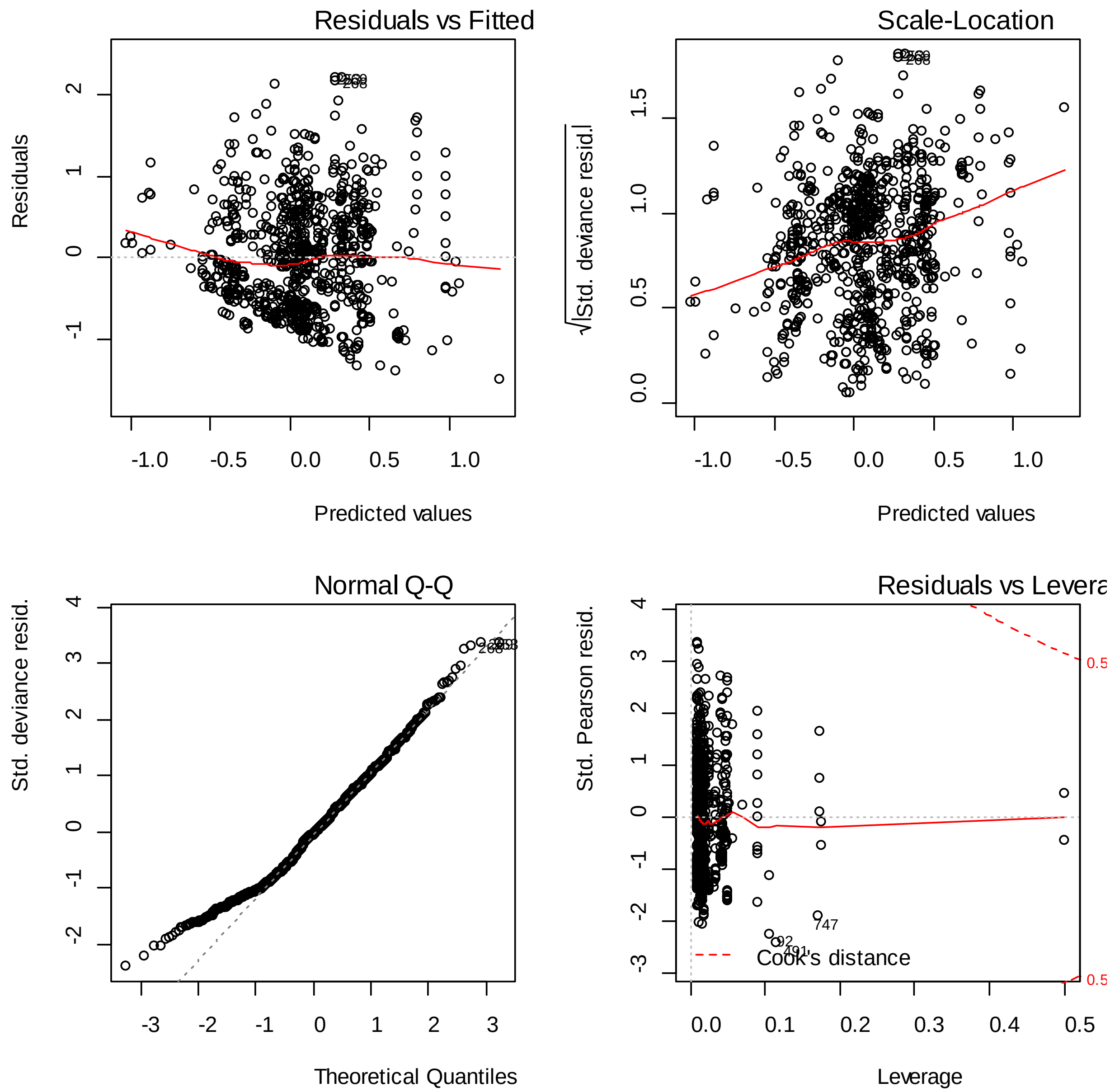


**Appendix C Fig. 7.** Residual plots for the lognormal model fit to the large-scale longline blue shark bycatch data in area B.

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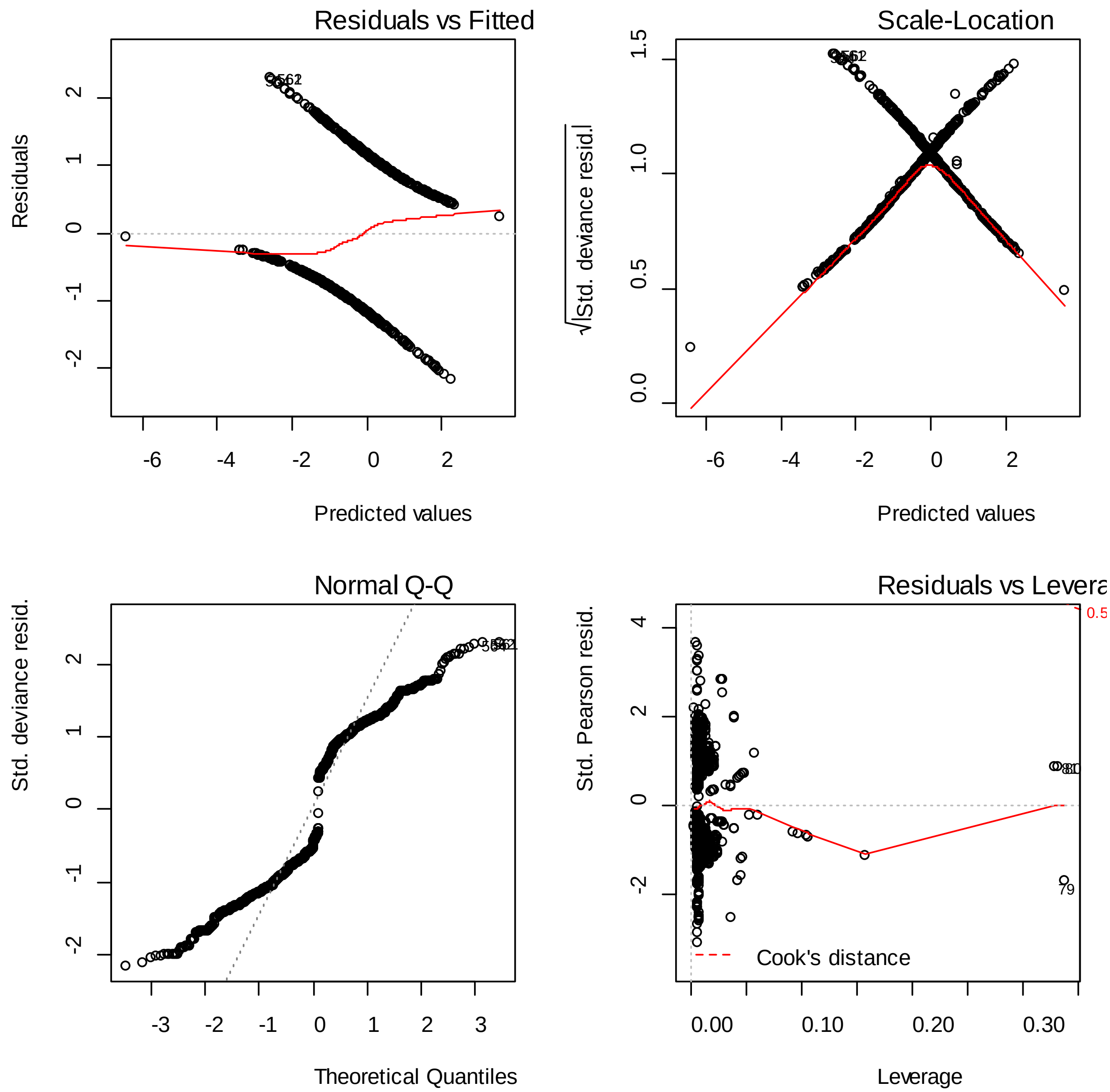


**Appendix C Fig. 8.** Residual plots for the binomial model fit to the large-scale longline blue shark bycatch data in area B.

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