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Updated and revised historical catch and standardized CPUE series of the blue shark by Taiwanese large-scale tuna longline fisheries in the North Pacific Ocean[1]

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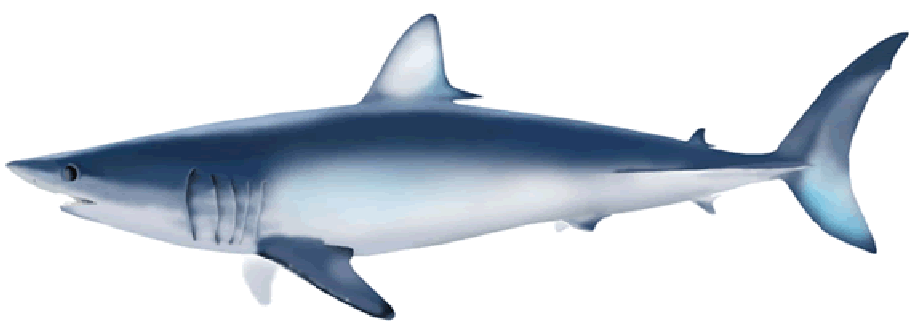

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ABSTRACT

In the present study, the blue shark catch and effort data from observers' records of Taiwanese large longline fishing vessels operating in the North Pacific Ocean from 2004-2012 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. Estimated blue shark by-catch in weight ranged from 1 ton in 1973 to 1,357 tons in 2002. The results obtained in this study can be improved if longer time series observers' data are available.

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 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 14 species including major tunas, billfishes and sharks. The species-specific catch data including tunas, billfishes, and sharks from observers' records in 2004-2012 were used to standardize CPUE of blue shark of Taiwanese large-scale longline fishery in the North Pacific Ocean. 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.

2.2. CPUE standardization

A large proportion of sets with zero catch of blue shark (~50%) was 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 multiplicative model was applied to the data in this study:

The catch rates of the positive catch events (trips with positive catch) were modeled assuming a lognormal error distribution:

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

where μ is the mean, Q*A, Q*HPB, A*HPB are interaction terms, ε_1 is a normal random error term.

To calculate the proportion of positive records we used a model assuming a binomial error distribution (ε_2):

$$PA = \mu + Y + Q + A + HPB + LAT + LON + Q*A + Q*HPB + A*HPB + \varepsilon_2$$

The effect of gear configuration of HPB was categorized into the two classes of 1-15 (shallow set), and >15 (deep set), and quarter into the 4 classes of Jan-Mar (1^{st} quarter), Apr-Jun (2^{nd} quarter), Jul-Sep (3^{rd} quarter) and Oct-Dec (4^{th} quarter). The area strata used for the analysis were shown in **Figure 2**.

The best model for both GLM and Delta models were selected using stepwise AIC method. The final estimate of the annual abundance index was the product of the marginal year means with appropriate bias correction (Lo *et al*., 1992). Empirical confidence intervals for standardized CPUE were calculated using a bootstrap resampling method. The 95% confidence intervals were then constructed based on bias corrected percentile method with 10,000 replicates (Efron and Tibshirani, 1993).

2.3. Estimate of historical blue shark catch

The historical blue shark catch in number can be back-estimated by using the equation below:

$Catch_{back}$ = Nominal CPUE by area × logbook effort
(The nominal CPUE before 2004 is substituted by using the average value of 2004-2012)

As the weight records were incomplete and might be biased, the catch in weight of blue shark was estimated using the multiplication of mean weight and catch in number. The average fork length (FL) from observers' data was converted to total length (TL) for blue shark by using the equation TL = (FL+1.222)/0.829. The mean weight of blue shark was then calculated from whole weights (W) through the equation $W = 10^{-6} * TL^{3.23}$. Annual blue shark catch were obtained by using the back-estimated catch in weight divided by coverage rate.

3. Results and discussion

The estimated mean FL and TL for blue shark were 212 and 257 cm, respectively. The mean weight of blue shark used in this study was 60 kg, which was obtained from the converted average weight of observers' blue shark data. The blue shark bycatch data are characterized by many zero values and a long right tail (**Figure 3**). Overall, there were 51.17% of sets had zero bycatch of blue sharks (**Table 1**).

The best models for GLM and Delta models chosen by AIC values were " $\ln(CPUE) = \mu + Y + Q + A + HPB + LAT + Q*HPB$ " and " $PA = \mu + Y + Q + A + HPB + LAT + LON + Q*HPB$ ", respectively. The best models were then used for the later analyses.

The standardized CPUE series for the blue shark using the DLN model was shown in **Figures 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 oscillation. This high variability was reduced in the standardized CPUE series. In general, the standardized CPUE series of the blue sharks caught by Taiwanese large-scale longline fishery showed a stable trend (**Figure 4**). This stable trend suggested that the blue shark stock in the North Pacific Ocean seems at the level of optimum utilization.

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 1**. The ANOVA tables for each models are given in **Appendix 2**. Most main effects tested were significant (mostly $P < 0.01$) and included in the final model.

Estimated blue shark by-catch in number ranged from 6 in 1973 to 22,617 in 2002. The blue shark by-catch in weight of Taiwanese long-scale longline fishery ranged from 1 ton (1973) to 1,357 tons (2002) in the North Pacific Ocean (**Table 2**).

The back-estimations of historical blue shark by-catch in this report were based on observers' records from 2004-2012. 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 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.

References

Bigelow, K.A., Boggs, C.H., and He, X., 1999. Environmental effects on swordfish and blue shark catch rates in the US North Pacific longline fishery. Fish. Oceanogr. 8(3): 178-198.

Efron B., Tibshirani R.J., 1993. An introduction to the bootstrap. London: Chapman and Hall.

Lo, N. C. H., L. D. Jacobson, J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49(12): 2515-2526.

Okamoto, H., Miyabe, N., and Matsumoto, T., 2001. GLM analyses for standardization of Japanese longline CPUE for bigeye tuna in the Indian Ocean applying environmental factors. IOTC Proceedings 4: 491-522.

R Development Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

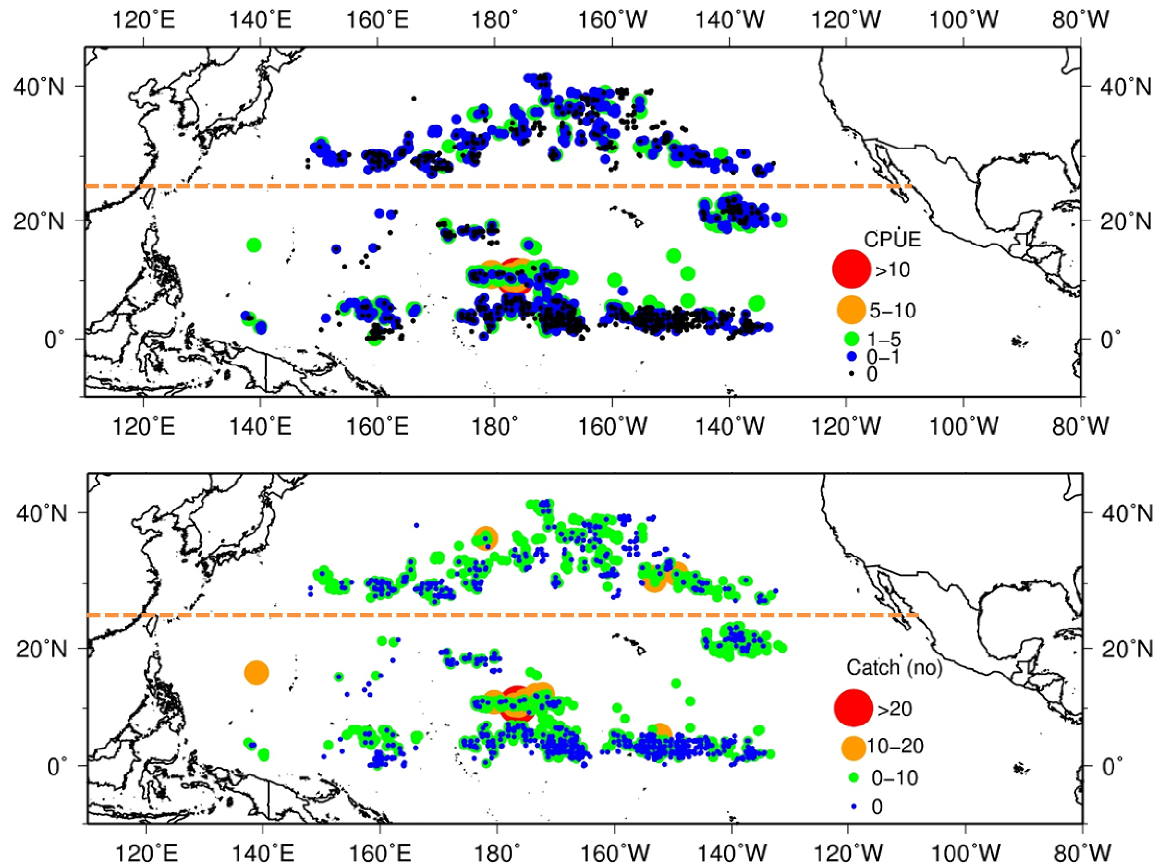


Figure 1. Distribution of fishing effort of Taiwanese tuna longline fisheries for observed blue shark catch and zero catch events from 2004-2012.

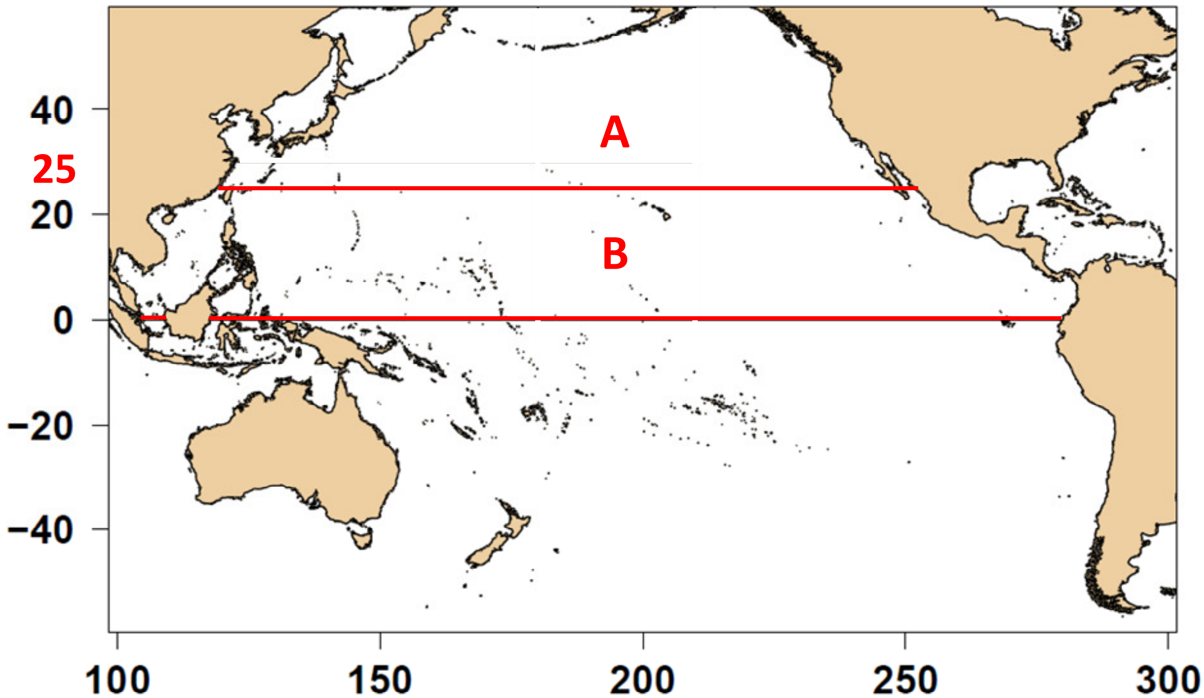


Figure 2. Area stratification used for the estimate of blue shark by-catch of the Taiwanese longline fishery in North Pacific Ocean.

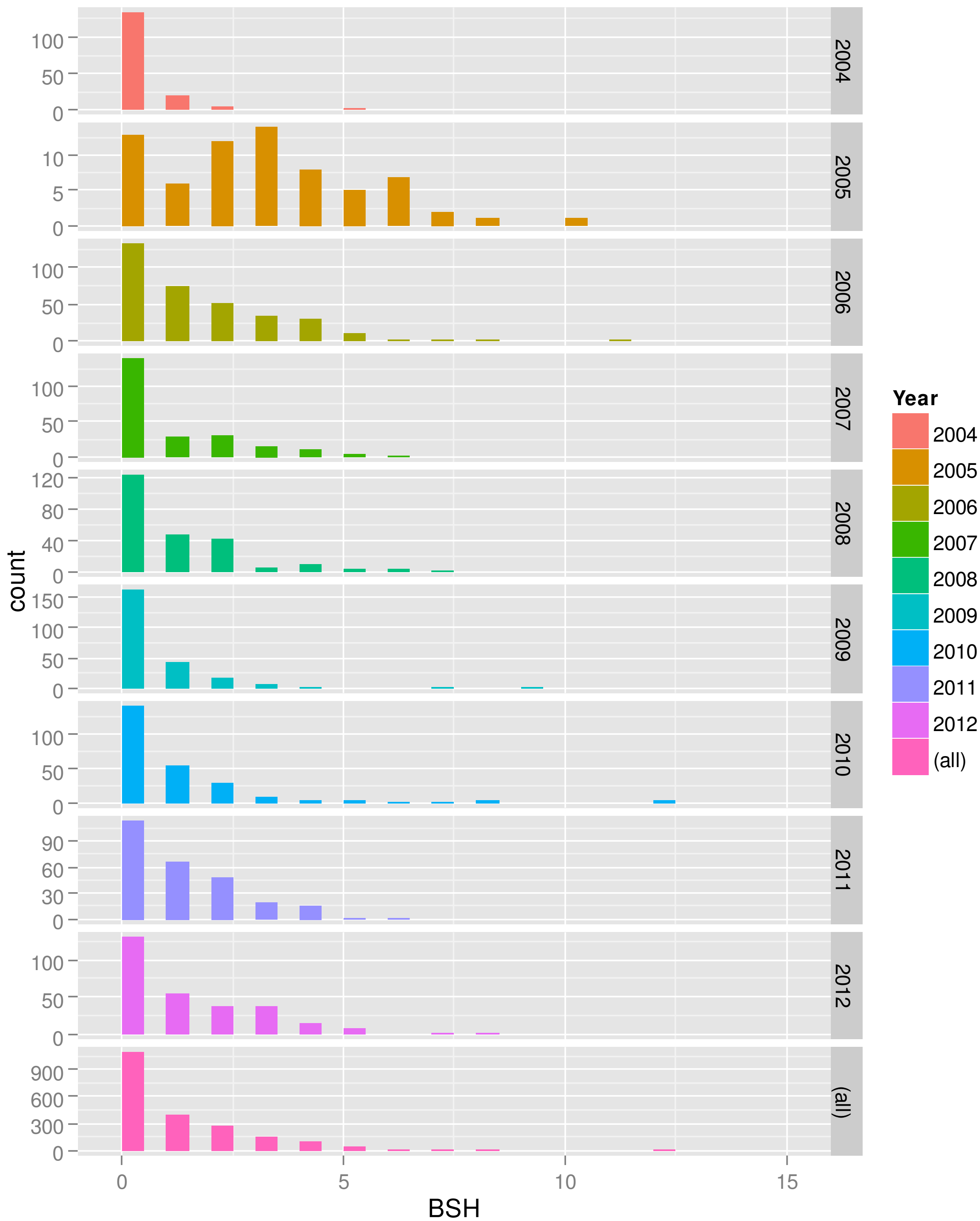


Figure 3. Frequency distribution of blue shark bycatch per set, 2004–2012.

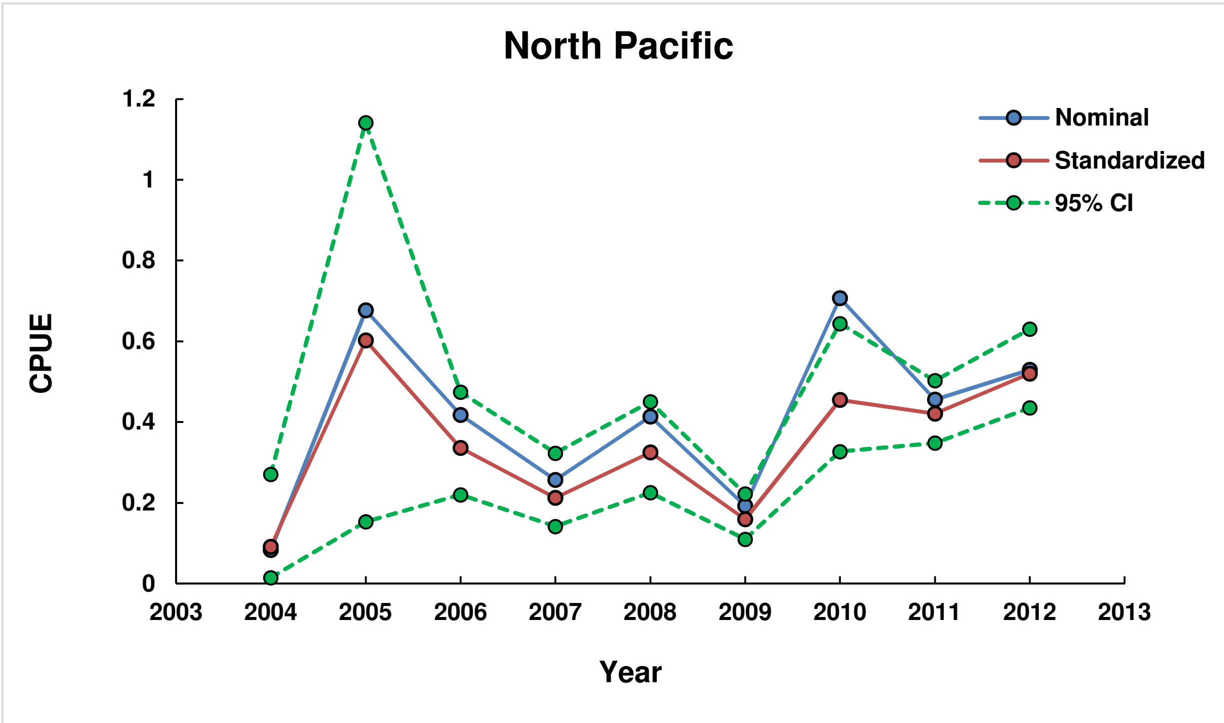


Figure 4. Nominal and standardized CPUE with 95% CI of blue shark by Taiwanese longline fisheries from 2004 to 2012.

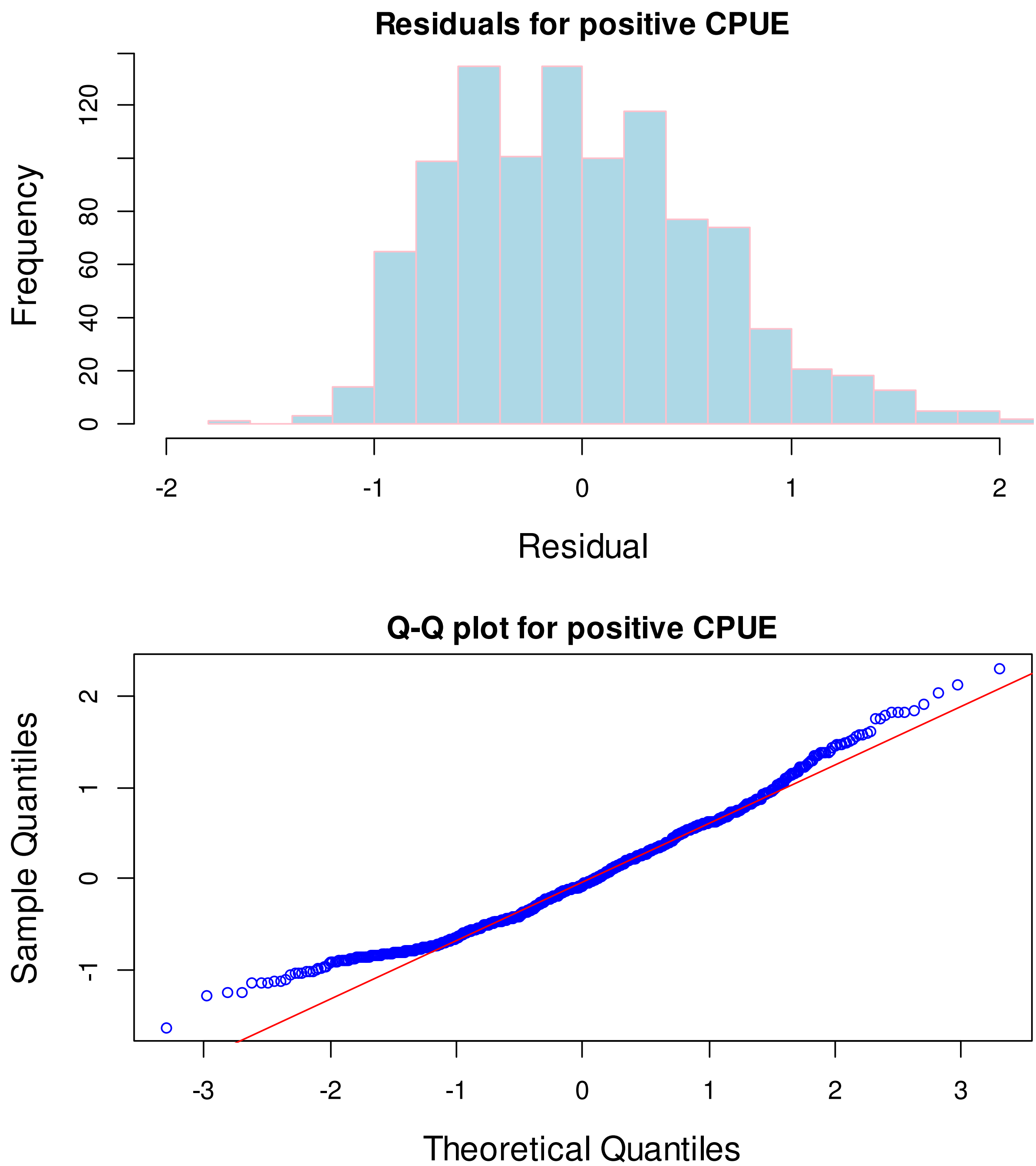


Figure 5. Diagnostic results from the GLM model fit to the longline blue shark bycatch data.

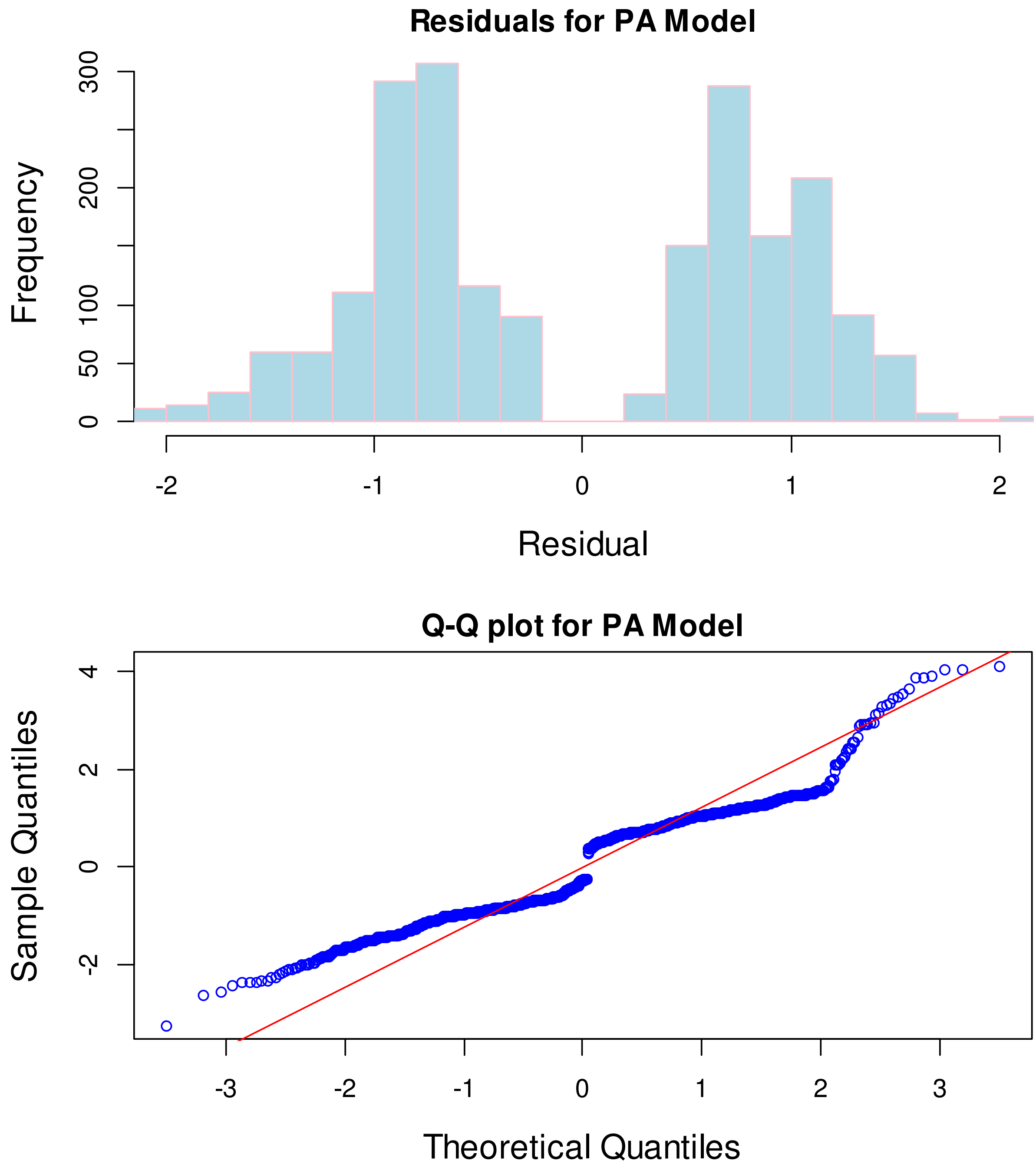


Figure 6. Diagnostic results from the Delta model fit to the longline blue shark bycatch data.

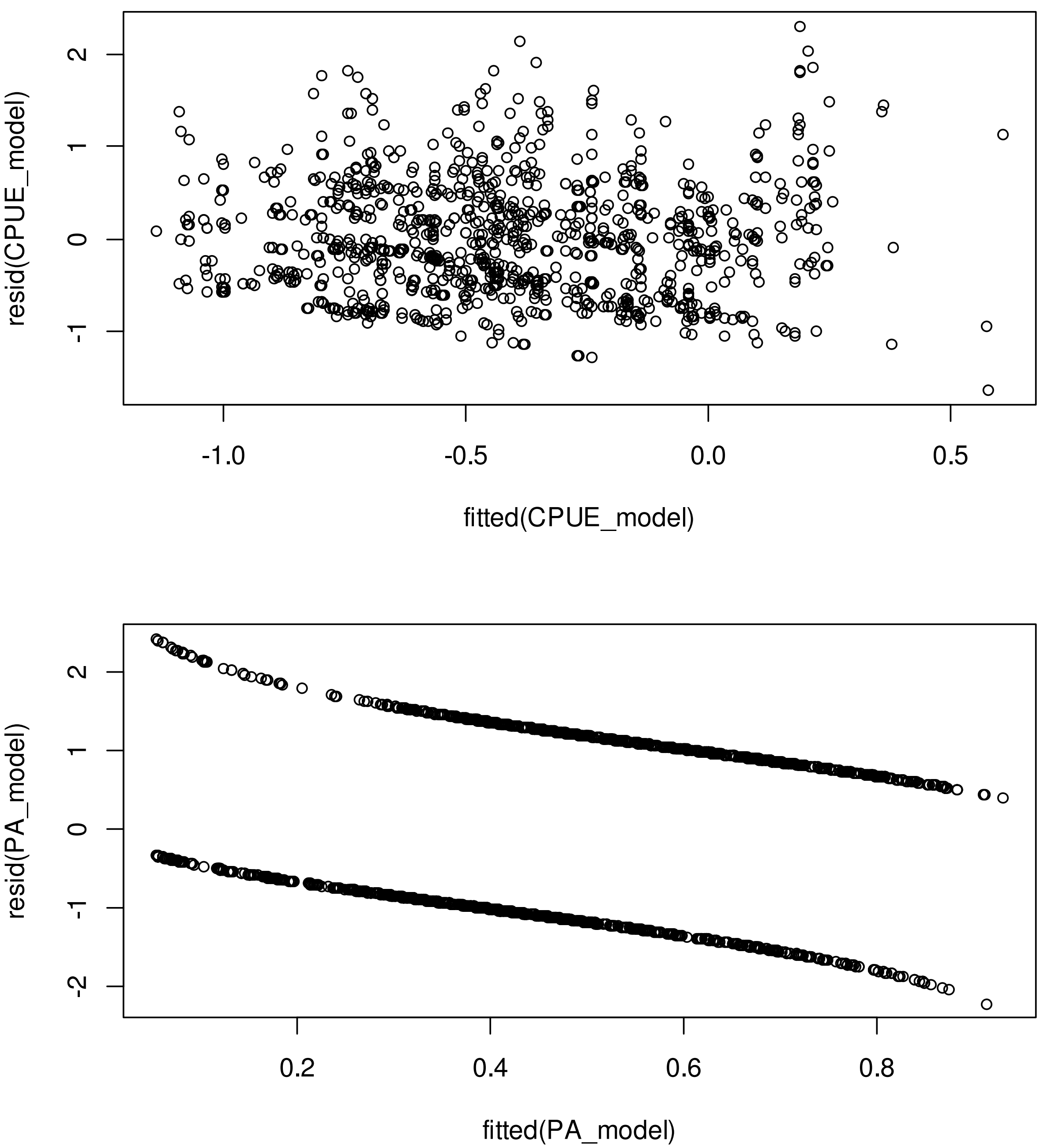


Figure 7. Residual plots for the DLN model fit to the longline blue shark bycatch data.

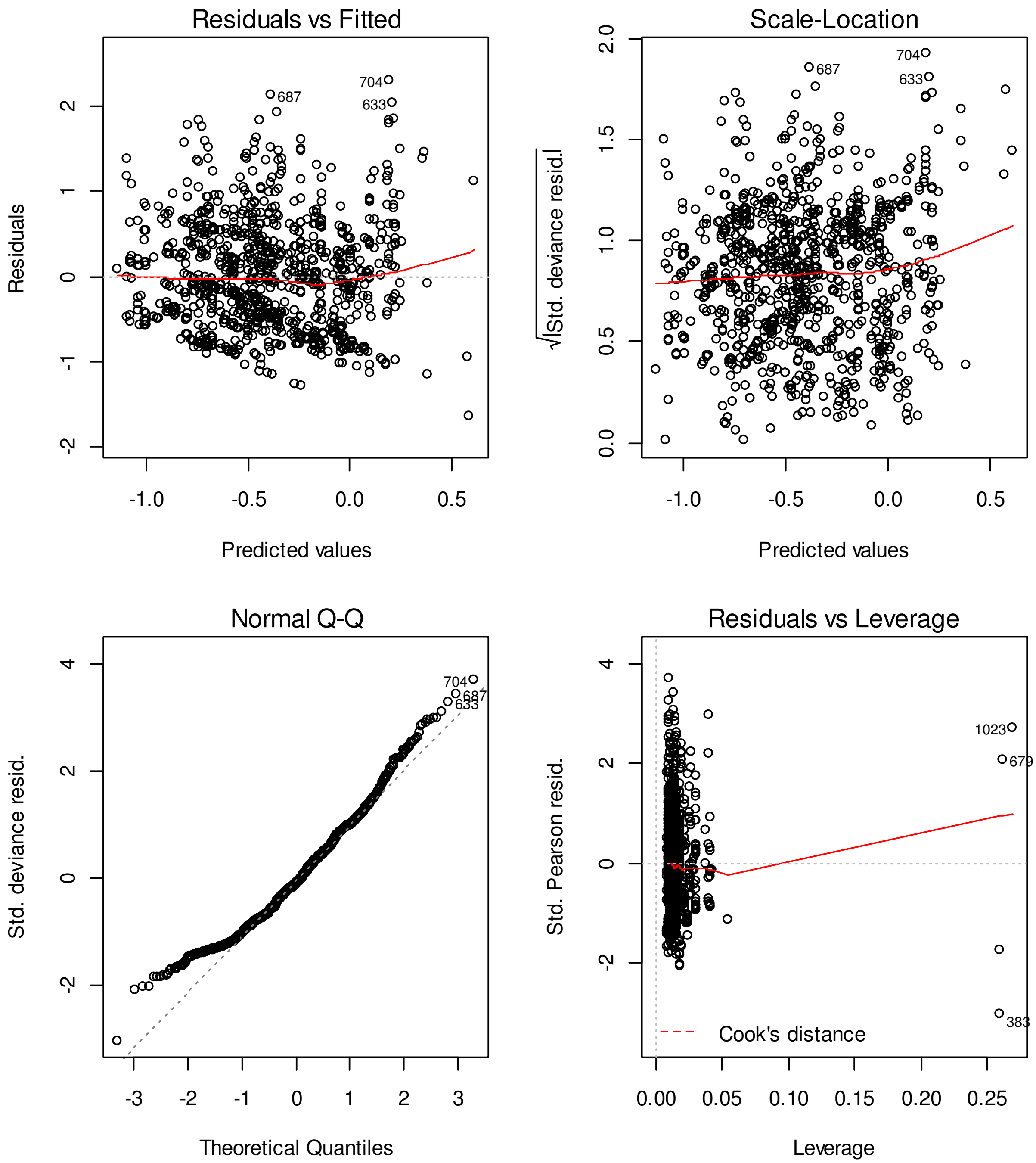


Figure 8. Residual plots for the GLM model fit to the longline blue shark bycatch data.

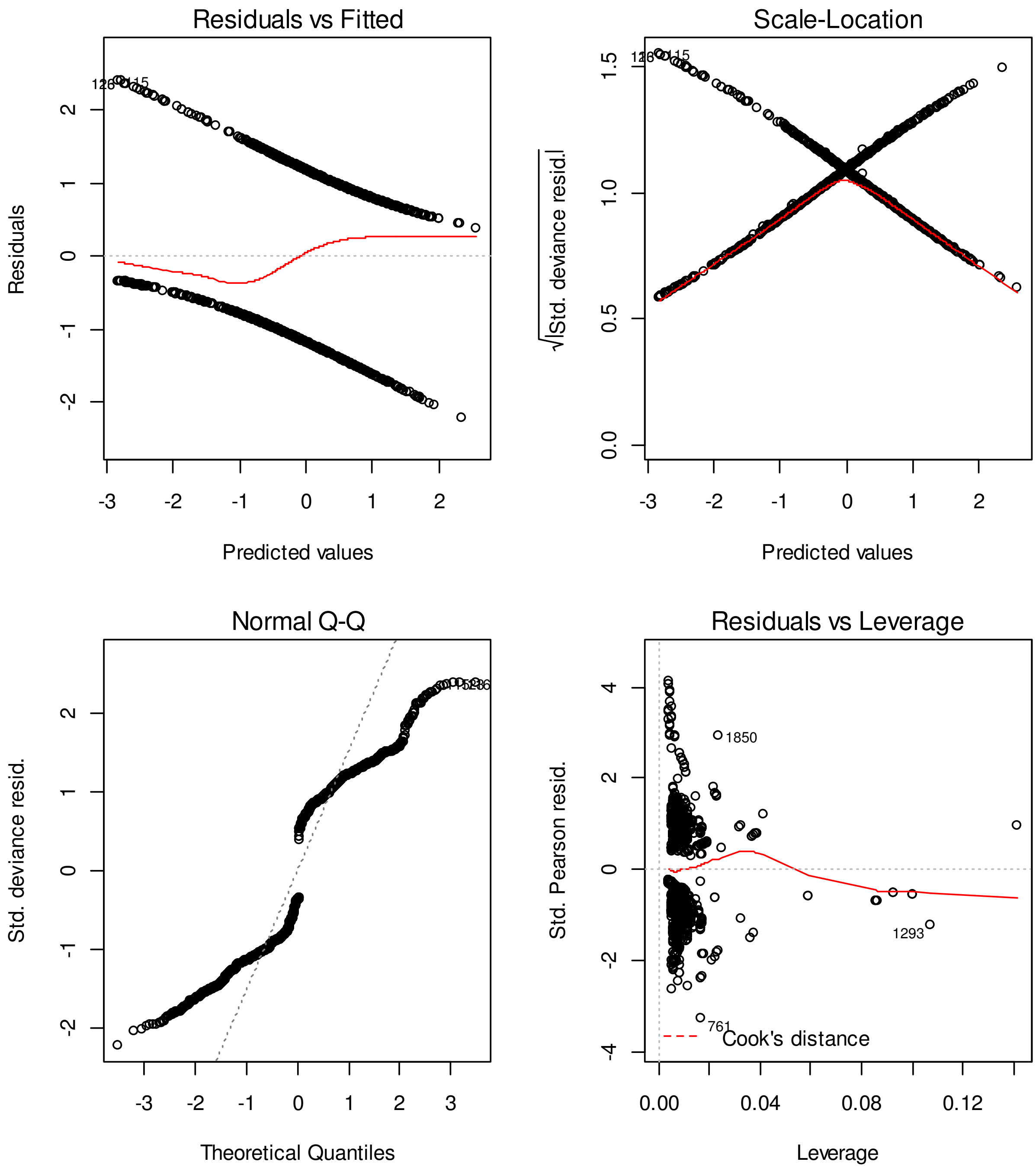


Figure 9. Residual plots for the Delta model fit to the longline blue shark bycatch data.

Table 1. Estimated annual blue shark zero-catch percentage of the Taiwanese tuna longline fishery in the North Pacific Ocean.

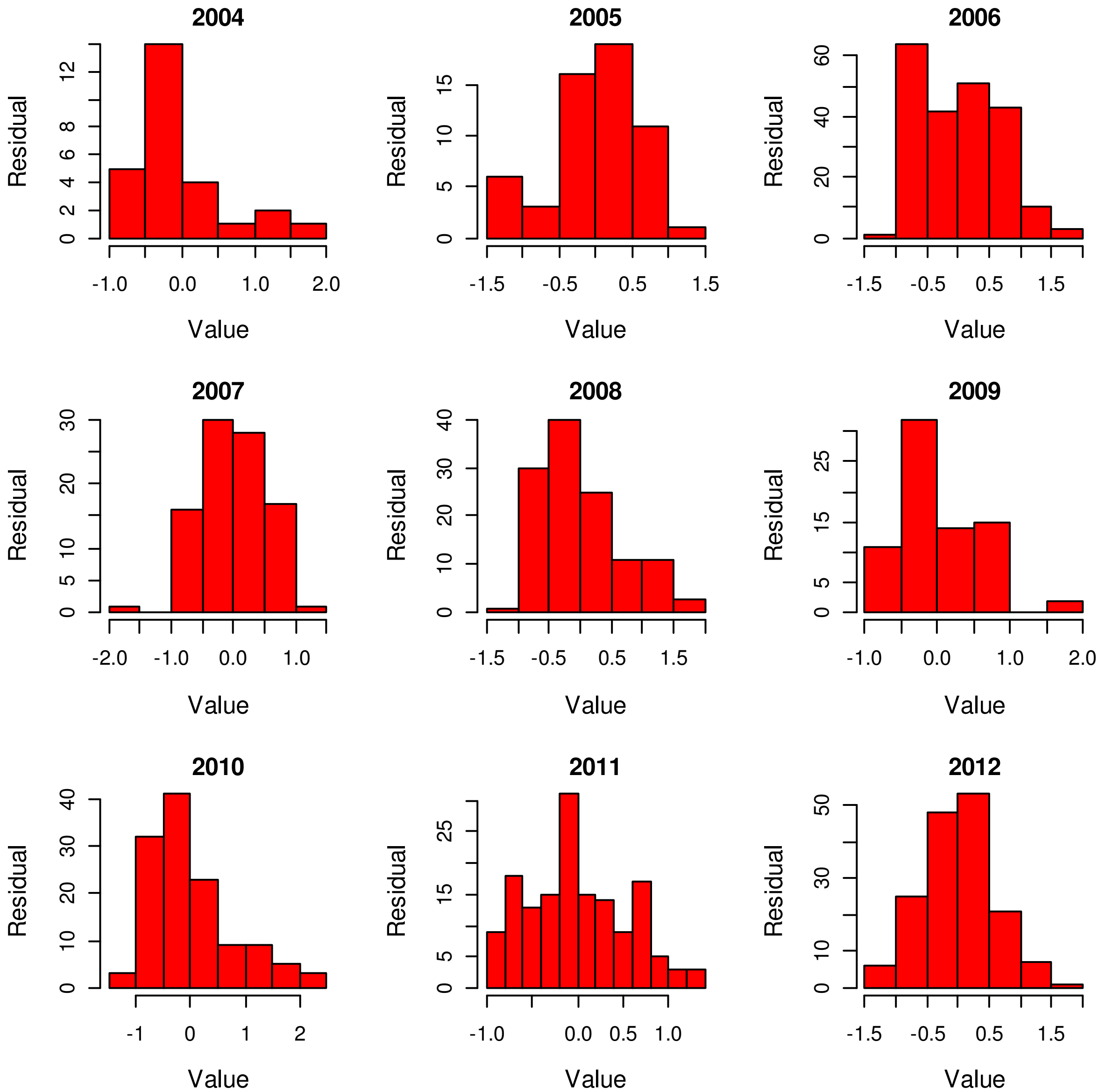
Year	BSH Zero %
2004	83.33%
2005	18.84%
2006	38.33%
2007	59.91%
2008	50.61%
2009	68.78%
2010	53.18%
2011	42.64%
2012	44.86%
Average	51.17%

Table 2. Estimated annual blue shark by-catch in number and weight (ton) of the Taiwanese tuna longline fishery in the North Pacific Ocean.

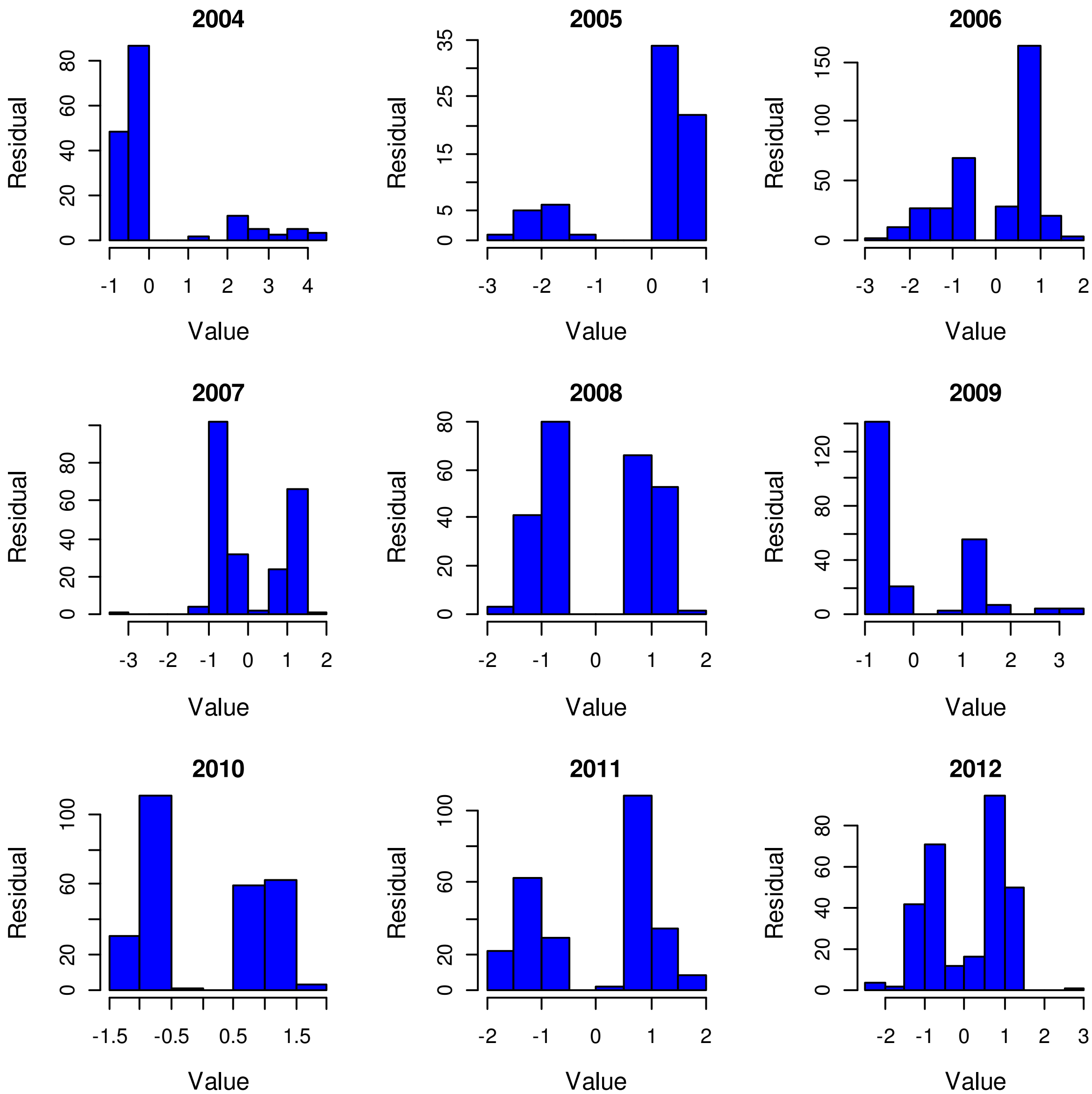
Year	EstBSH (N)	EstBSH (ton)
1971	80	5
1972	76	5
1973	6	1
1974	2225	134
1975	3331	200
1976	132	8
1977	803	48
1978	993	60
1979	241	14
1980	757	45
1981	662	40
1982	86	5
1983	82	5
1984	6	1
1985	1912	115
1986	2292	138
1987	937	56
1988	172	10
1989	895	54
1990	3592	216
1991	3841	230
1992	1255	75
1993	992	60
1994	205	12
1995	10639	638
1996	4581	275
1997	5341	320
1998	5609	337
1999	10387	623
2000	11395	684
2001	16396	984
2002	22617	1357
2003	12947	777
2004	19819	1189
2005	15253	915
2006	14736	884
2007	13640	818
2008	11325	680
2009	7968	478
2010	5570	334
2011	9902	594
2012*	19027	1142

*: preliminary estimate

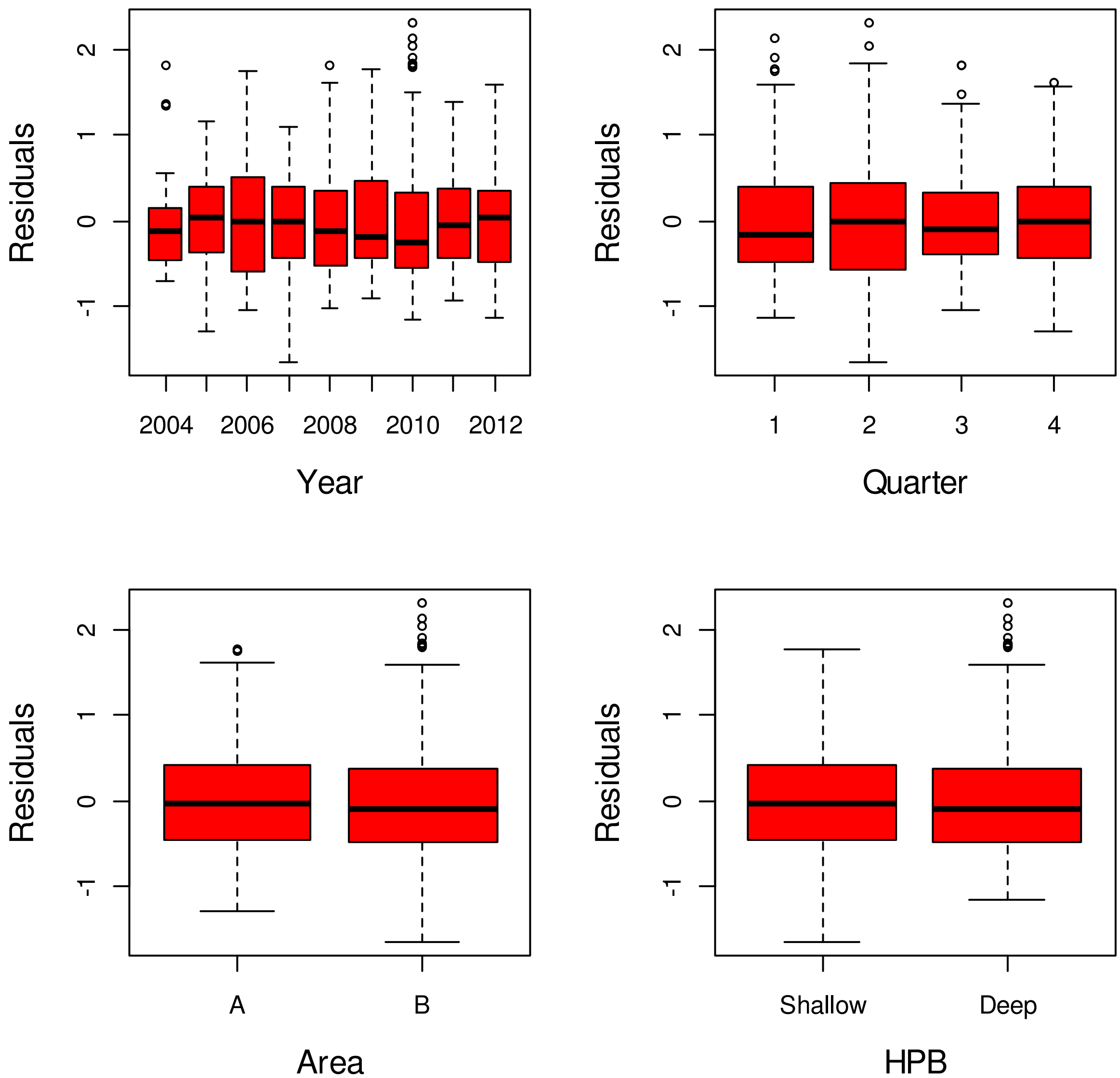
Appendix 1. Additional residual plots for the Delta-lognormal GLM model.



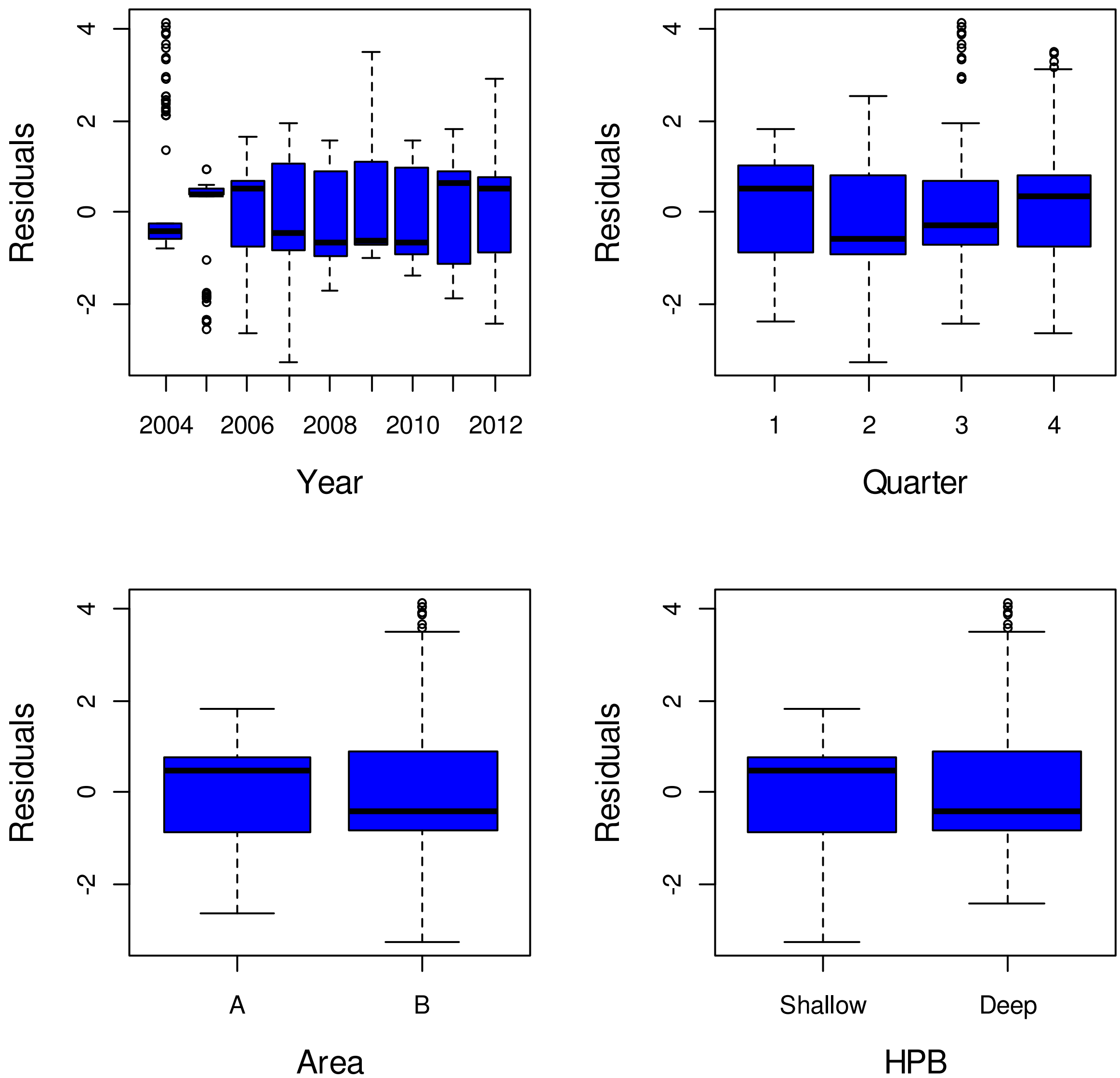
Appendix Fig. 1. Annual residual plots from the GLM model.



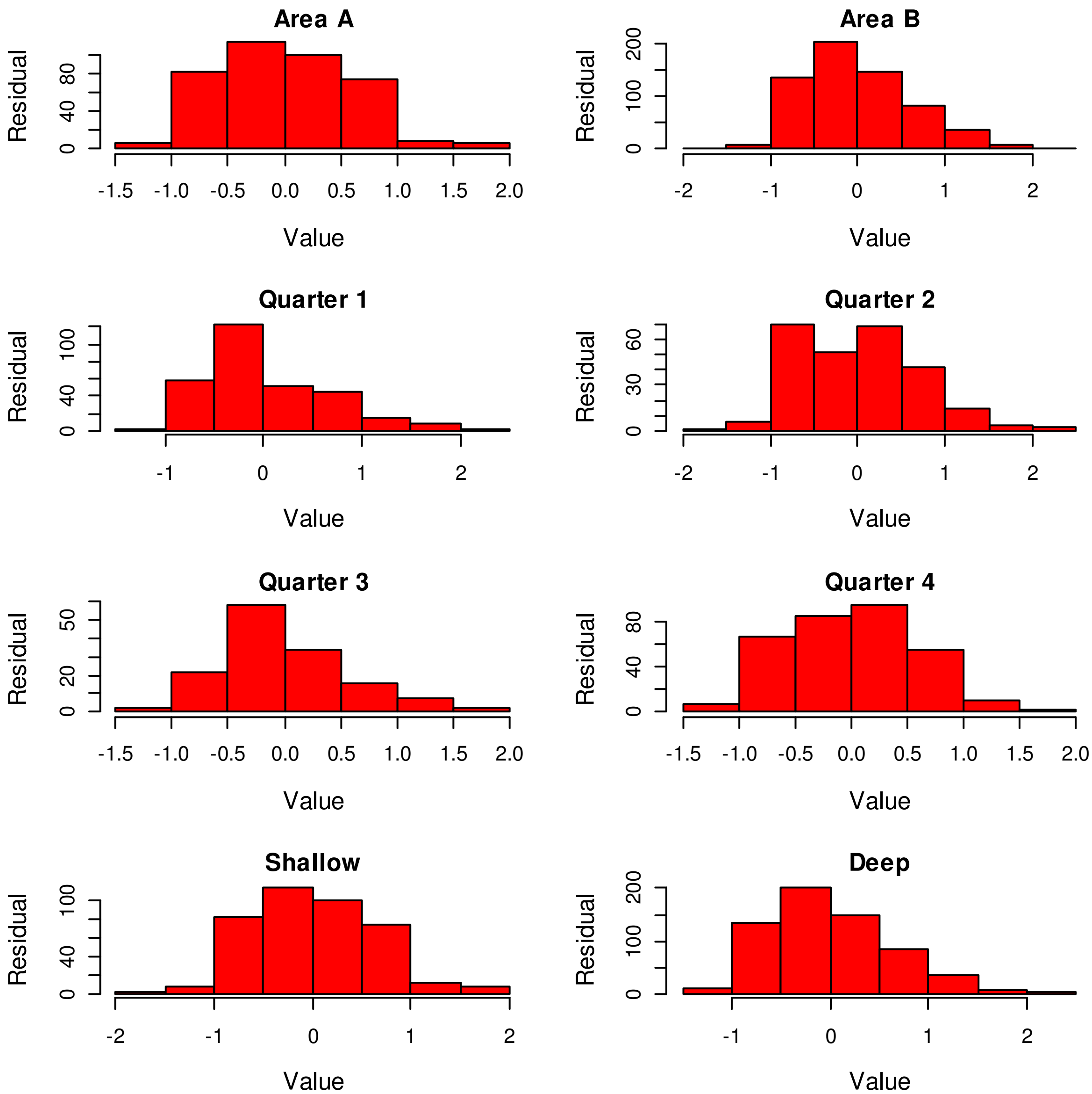
Appendix Fig. 2. Annual residual plots from the Delta model.



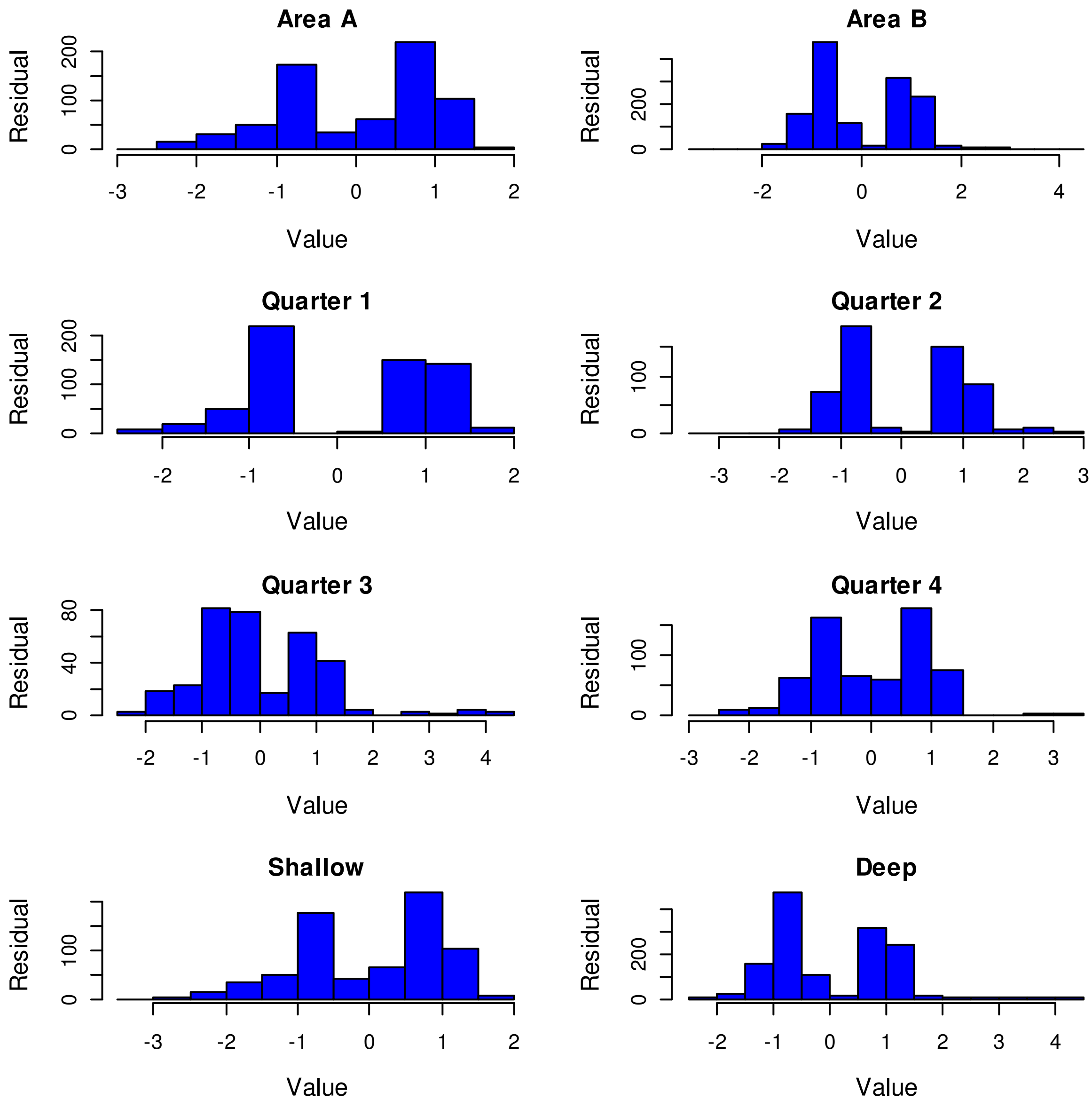
Appendix Fig. 3. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and HPB for GLM model.



Appendix Fig. 4. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and HPB for Delta model.



Appendix Fig. 5. Histogram residuals plots for the variables Year, Quarter, Area and HPB from GLM model.



Appendix Fig. 6. Histogram residuals plots for the variables Year, Quarter, Area and HPB from Delta model.

Appendix 2. Deviance tables for the Delta-lognormal GLM model.

```
glm(formula = log(DATA$CPUE) ~ yy + Q + A + HPB + LAT + Q * HPB,
    family = gaussian())

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.63763  -0.47403  -0.06797   0.39632   2.30306

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -2.18113    0.22292  -9.784  < 2e-16 ***
yy2005       0.59861    0.16402   3.650 0.000276 ***
yy2006       0.40395    0.13834   2.920 0.003579 **
yy2007       0.20124    0.14921   1.349 0.177734
yy2008       0.43488    0.13682   3.179 0.001525 **
yy2009       0.27877    0.15018   1.856 0.063711 .
yy2010       0.42256    0.14082   3.001 0.002761 **
yy2011       0.07513    0.14306   0.525 0.599603
yy2012       0.33433    0.14440   2.315 0.020794 *
Q2          -0.26489    0.12602  -2.102 0.035799 *
Q3          -1.22148    0.71219  -1.715 0.086635 .
Q4           0.02732    0.08460   0.323 0.746799
A2           2.09382    0.35289   5.933 4.08e-09 ***
HPB2        -0.87032    0.34982  -2.488 0.013011 *
LAT          0.03450    0.00574   6.011 2.58e-09 ***
Q2:HPB2      0.62547    0.14363   4.355 1.47e-05 ***
Q3:HPB2      1.22860    0.71682   1.714 0.086844 .
Q4:HPB2     -0.16172    0.11896  -1.359 0.174306
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.3903947)

    Null deviance: 500.70  on 1022  degrees of freedom
Residual deviance: 392.35  on 1005  degrees of freedom
```

```
Call:
glm(formula = DATA2$PA ~ yy + Q + A + HPB + LAT + LON + Q * HPB,
    family = binomial(), data = DATA2)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.2105  -1.0267  -0.3867   1.0235   2.4000

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept) -4.7725744  1.0824469  -4.409 1.04e-05 ***
yy2005       3.0361296  0.3874940   7.835 4.68e-15 ***
yy2006       2.6989349  0.2805342   9.621  < 2e-16 ***
yy2007       1.1360931  0.2708016   4.195 2.73e-05 ***
yy2008       1.6848615  0.2700046   6.240 4.37e-10 ***
yy2009       0.7815033  0.2913823   2.682 0.007317 **
yy2010       1.0881092  0.2903802   3.747 0.000179 ***
yy2011       0.9402615  0.3025971   3.107 0.001888 **
yy2012       1.1853866  0.2765317   4.287 1.81e-05 ***
Q2          -1.9130424  1.0026083  -1.908 0.056383 .
Q3           2.4878300  1.9557203   1.272 0.203345
Q4           0.9053235  0.6977964   1.297 0.194492
A2           4.2349711  0.5701440   7.428 1.10e-13 ***
HPB         -0.0793378  0.0754145  -1.052 0.292789
LAT          0.1439417  0.0140730  10.228  < 2e-16 ***
LON          0.0013414  0.0003914   3.427 0.000610 ***
Q2:HPB       0.1104476  0.0624255   1.769 0.076849 .
Q3:HPB      -0.1863538  0.1135493  -1.641 0.100762
Q4:HPB      -0.1408603  0.0488248  -2.885 0.003914 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 2931.1  on 2115  degrees of freedom
Residual deviance: 2584.2  on 2097  degrees of freedom
AIC: 2622.2
```

```
Model: gaussian, link: identity

Response: log(DATA$CPUE)

Terms added sequentially (first to last)


       Df Deviance Resid. Df Resid. Dev        F    Pr(>F)
NULL                    1022     500.70
yy      8   59.133      1014     441.57 18.9339 < 2.2e-16 ***
Q       3   17.180      1011     424.39 14.6691 2.352e-09 ***
A       1    6.185      1010     418.21 15.8421 7.380e-05 ***
HPB     1    1.458      1009     416.75  3.7359   0.05354 .
LAT     1   13.430      1008     403.32 34.4002 6.084e-09 ***
Q:HPB   3   10.971      1005     392.35  9.3671 4.140e-06 ***
---
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                    2115     2931.1
yy      8  177.646      2107     2753.4 22.2057 < 2.2e-16 ***
Q       3   10.115      2104     2743.3  3.3717 0.0176127 *
A       1   28.503      2103     2714.8 28.5028 9.356e-08 ***
HPB     1    4.062      2102     2710.8  4.0624 0.0438481 *
LAT     1   98.149      2101     2612.6 98.1487 < 2.2e-16 ***
LON     1    8.565      2100     2604.0  8.5649 0.0034270 **
Q:HPB   3   19.868      2097     2584.2  6.6228 0.0001808 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```