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Updated standardized CPUE and catch estimation of the blue shark caught by the Taiwanese large scale tuna longline fishery in the North Pacific Ocean[1]

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Abstract

In the present study, the blue shark catch and effort data from observers' records of the Taiwanese large-scale longline fishing vessels operating in the North Pacific Ocean during the period of 2004-2022 were analyzed. 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 standardized CPUE of blue shark showed a stable increasing trend. 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 nominal 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 1,200 tons in 2022.

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. Materials and Methods

2.1 Source of data

The logbook data of Taiwanese large-scale longline fishery from 1971 to 2022, provided by the Overseas Fisheries Development Council, Taiwan 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 2004-2020 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 2004-2020.

It should be noted that the fishing effort of the Taiwanese LTLL fleet before 2014 was overestimated because the observers could not observe the whole process of handling catch. 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

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

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). The area strata used for the analysis were shown in Figure 2. To estimate the proportion of positive blue shark catch (PA), we used a model assuming a binomial error distribution (ε_2):

Part 2: Binomial model

$$PA = \mu + Y + Q + A + HPB + LON + LAT + Q*A + Q*HPB + A*HPB + \varepsilon_2 \quad (2)$$

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

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

Part 2: Binomial model

$$PA = \mu + Y + Q + HPB + LON + LAT + Q*HPB + \varepsilon_4 \quad (4)$$

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*PA (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).

2.3 Estimate of historical blue shark catch

Annual blue shark by-catch in number (C_y) from 2004 to 2022 was estimated by

$$C_y = \sum_1^2 \frac{Standarized\ CPUE_{i,y} \times Logbook\ effort_{i,y}}{Coverage\ rate_y} \tag{6}$$

While the blue by-catch for 1970-2003 was estimated by

$$C_y = \sum_1^2 \frac{Nominal\ CPUE_{i,y} \times Logbook\ effort_{i,y}}{Coverage\ rate_y} \tag{7}$$

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: $W = 5.009 \times 10^{-6} FL^{3.054}$ (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 44.45% 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 + LON + LAT + Q*A + Q*HPB + A*HPB (AIC= 7,675)" and "PA = μ + Y + Q + A + LON + LAT + Q*A (AIC= 7,570)", 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+ Q + LON + LAT (AIC= 3,472)" and "PA = μ + Y + LON + LAT (AIC= 2,489)"and for Area B: "ln(CPUE) = μ + Y + Q + HPB + LAT + Q*HPB (AIC= 3,894)" and "PA = μ + Y + Q + HPB + LAT + Q*HPB (AIC= 4,808)"

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, 1,186 MT, 1,298MT, 1,087MT, and 1,200MT in 2002 2004, 2015, 2019, 2020, and 2022, 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 2004-2018. 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.

Cook, R. D. and Weisberg, S., 1982. Residuals and Influence in Regression, Chapman and Hall, New York.

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

Kohin, S. and Wraith, J. 2010. NMFS SWFSC Juvenile Shark Abundance Survey Results. NOAA/NMFS/SWFC Admin. Rep.

Lo, N. C. H., Jacobson, L. D., Squire, J. L., 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.

Venables, W. N. and Ripley, B. D., 2002. Modern Applied Statistics with S. Fourth edition, Springer.
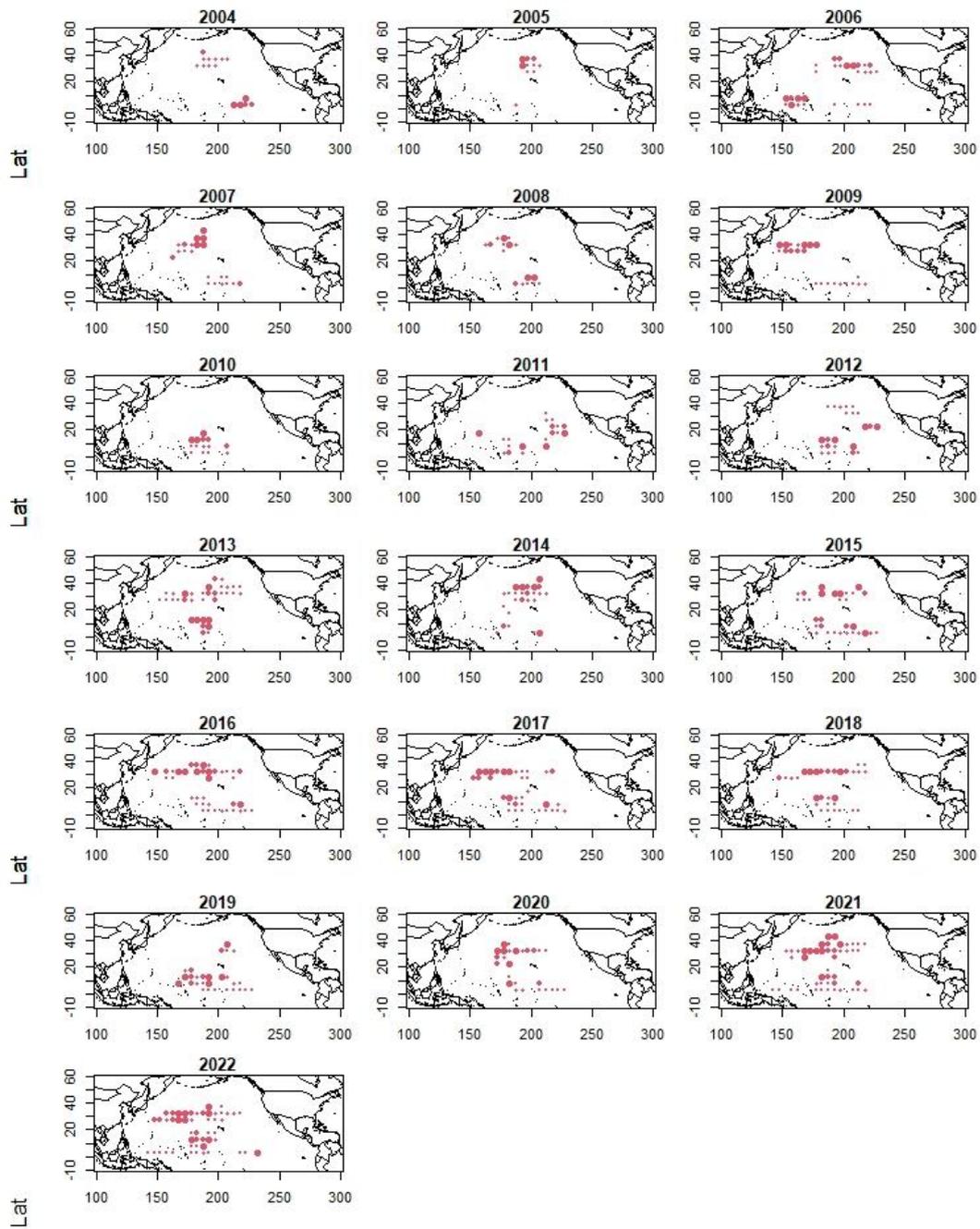
Figure 1. Distribution of nominal CPUE of the blue shark caught by the Taiwanese large-scale tuna longline fishery from 2004 to 2022.
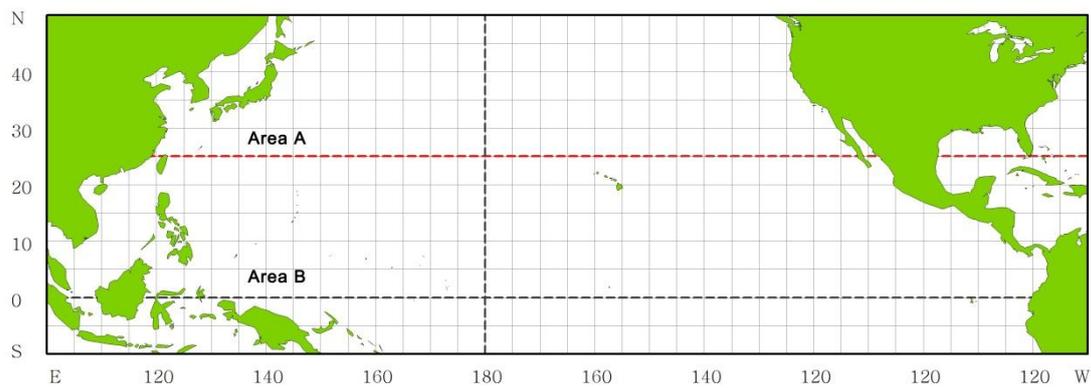
Figure 2. Area stratification used for the estimation of blue shark by-catch of the Taiwanese large-scale longline fishery in the North Pacific Ocean.
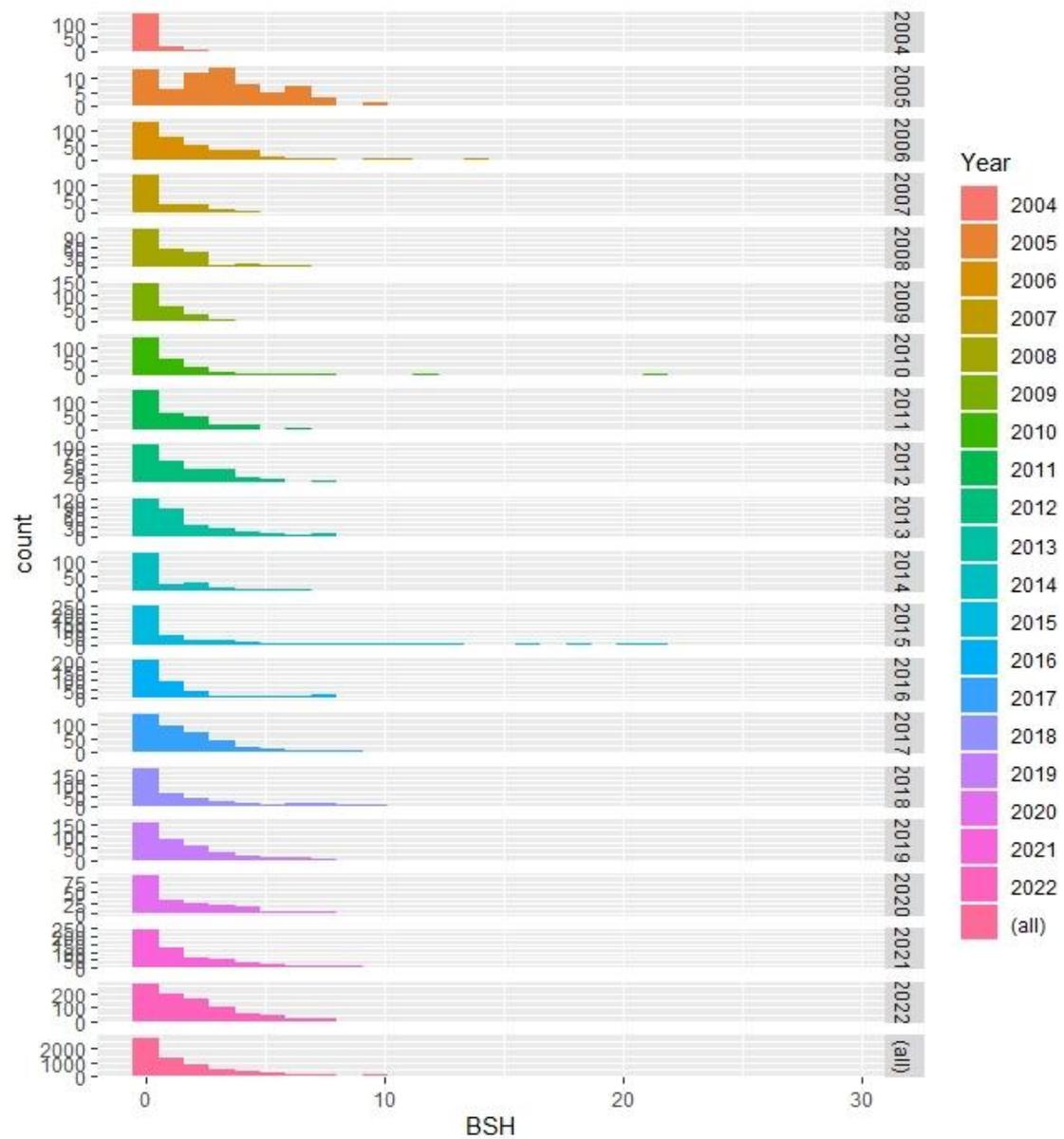
Figure 3. Frequency distribution of the blue shark (number) per set caught by the Taiwanese large-scale longline fishery from 2004-2022.

North Pacific Ocean
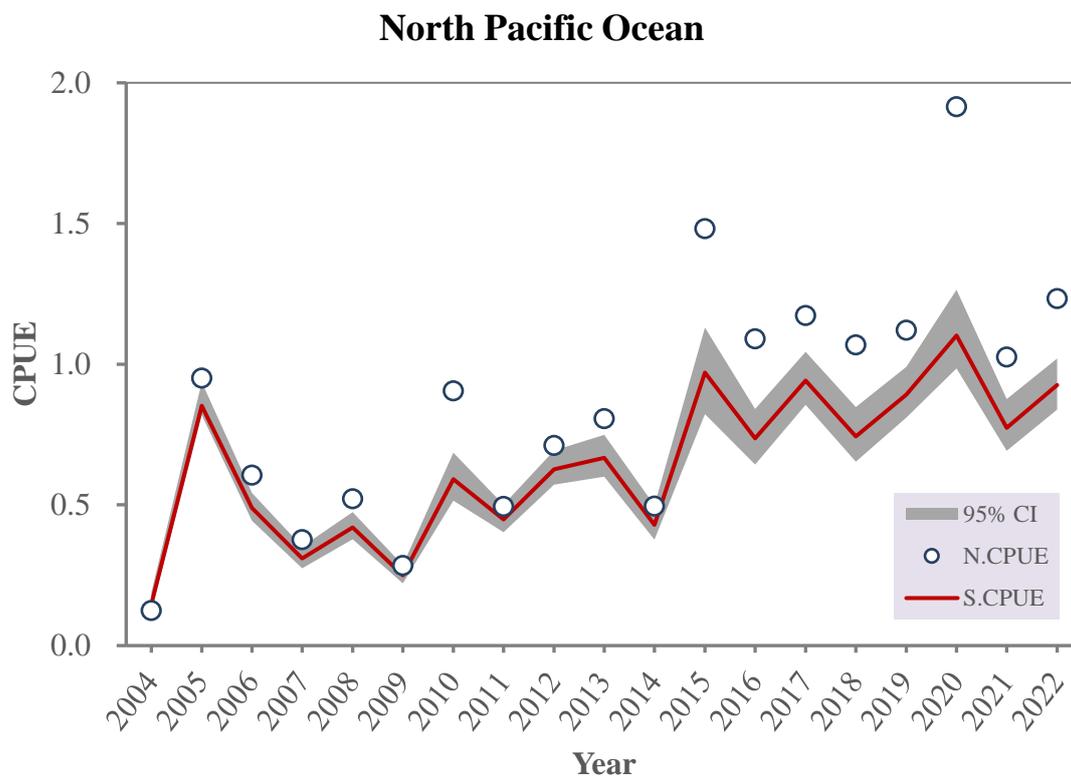
Figure 4. Nominal and standardized CPUE with 95% confidence interval of the blue shark caught by the Taiwanese large-scale longline fishery from 2004 to 2022.
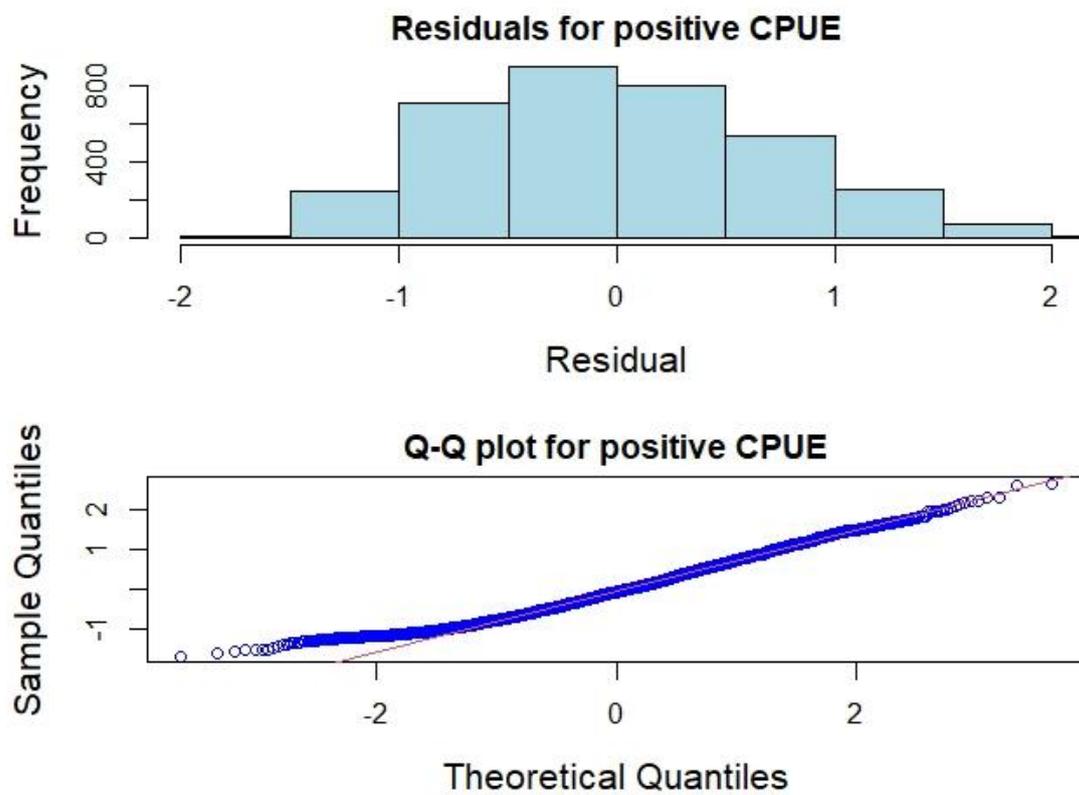
Figure 5. Diagnostic results from the lognormal model fit to the Taiwanese large-scale longline blue shark bycatch data.
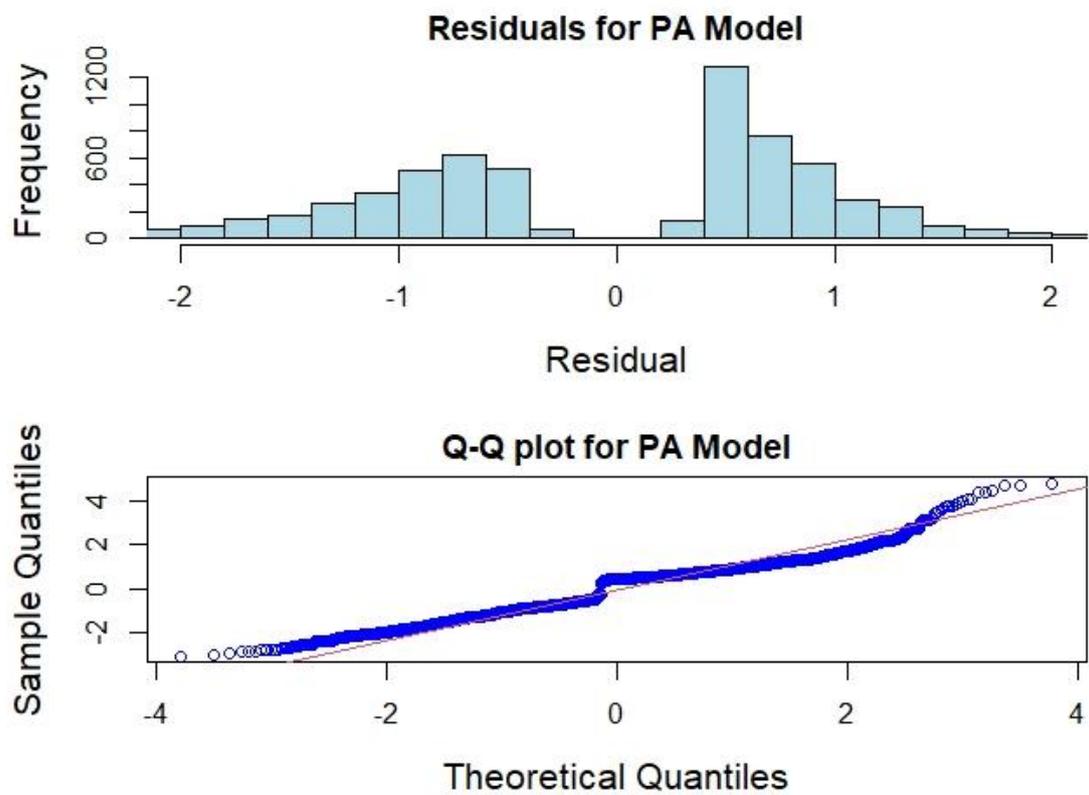
Figure 6. Diagnostic results from the binomial model fit to the Taiwanese large-scale longline blue shark bycatch data.
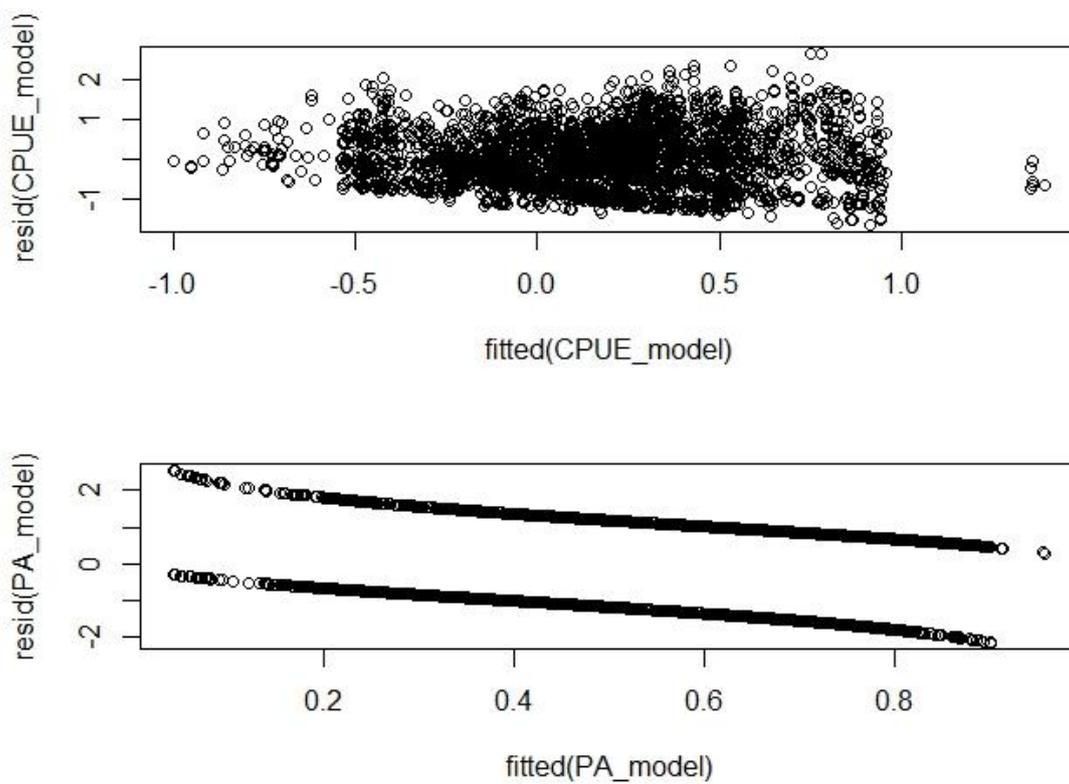
Figure 7. Residual plots for the DLN model fit to the Taiwanese large-scale longline blue shark bycatch data.
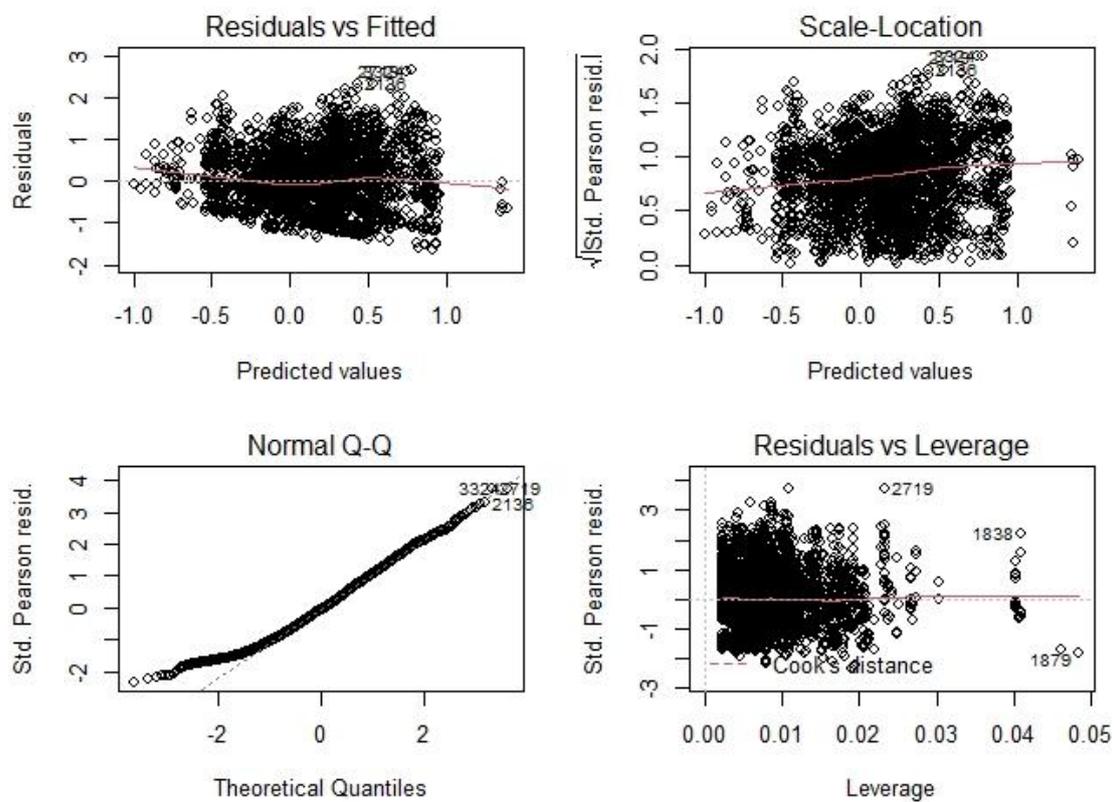
Figure 8. Residual plots for the lognormal model fit to the Taiwanese large-scale longline blue shark bycatch data.
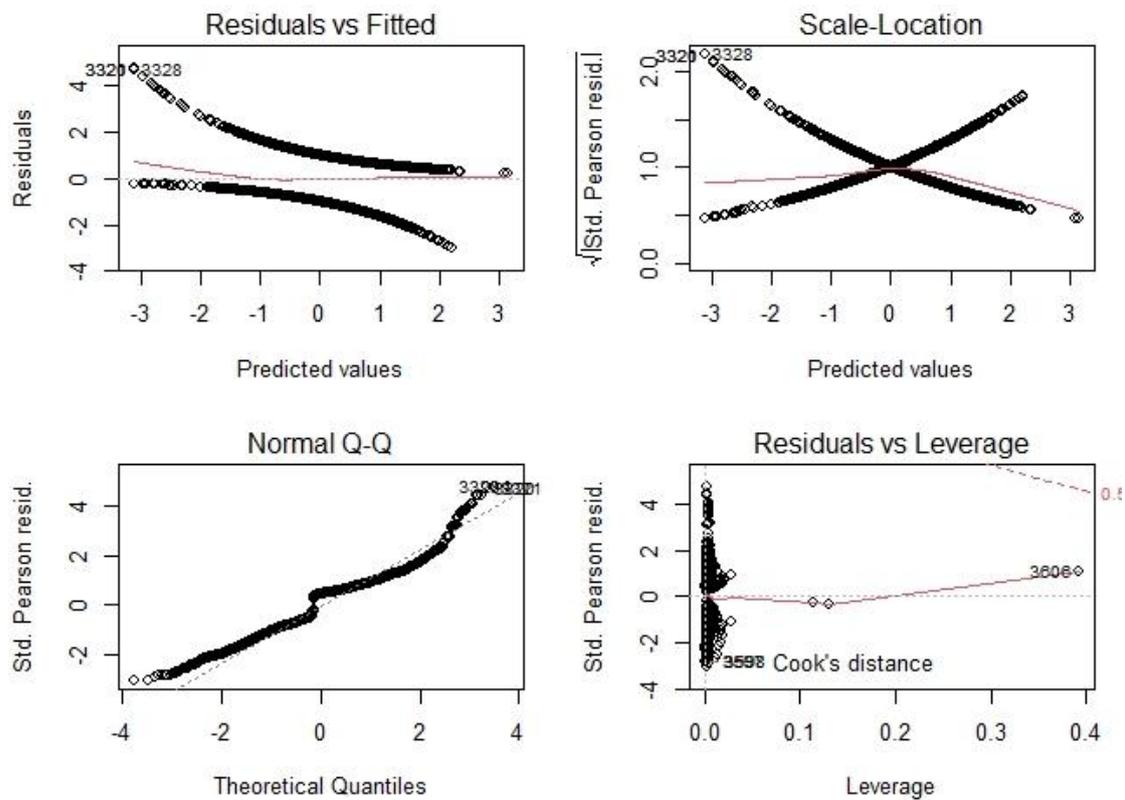
Figure 9. Residual plots for the binomial model fit to the Taiwanese large-scale longline blue shark bycatch data.

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

Year	North Pacific	
	No. of Hooks	No. of Sets
2004	392,682	49
2005	213,504	203
2006	923,483	560
2007	578,008	218
2008	574,550	300
2009	533,061	152
2010	489,556	443
2011	491,471	243
2012	557,652	397
2013	589,828	476
2014	387,352	192
2015	603,353	894
2016	692,524	755
2017	611,036	717
2018	612,760	655
2019	560,822	629
2020	335,176	642
2021	1,126,304	1,155
2022	1,767,361	2,179
Average	207,877	321

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	82.61
2005	18.84
2006	37.93
2007	59.13
2008	46.72
2009	60.85
2010	51.71
2011	51.52
2012	38.15
2013	38.44
2014	63.41
2015	57.85
2016	48.28
2017	34.09
2018	49.87
2019	40.10
2020	41.63
2021	40.37
2022	28.82
Average	44.45

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

Year	Hook	BSH	N.CPUE	S.CPUE	Lower95	Upper95
2004	392,682	49	0.1248	0.1474	0.1203	0.1885
2005	213,504	203	0.9508	0.8517	0.8192	0.9363
2006	923,483	560	0.6064	0.4885	0.4436	0.5429
2007	578,008	218	0.3772	0.3096	0.2750	0.3518
2008	574,550	300	0.5221	0.4199	0.3776	0.4747
2009	533,061	152	0.2851	0.2499	0.2213	0.2861
2010	489,556	443	0.9049	0.5911	0.5148	0.6852
2011	491,471	243	0.4944	0.4482	0.4031	0.5007
2012	557,652	397	0.7119	0.6258	0.5721	0.6935
2013	589,828	476	0.8070	0.6668	0.6003	0.7492
2014	387,352	192	0.4957	0.4294	0.3763	0.4984
2015	603,353	894	1.4817	0.9700	0.8225	1.1302
2016	692,524	755	1.0902	0.7359	0.6438	0.8404
2017	611,036	717	1.1734	0.9419	0.8555	1.0442
2018	612,760	655	1.0689	0.7434	0.6532	0.8477
2019	560,822	629	1.1216	0.8918	0.8107	0.9908
2020	335,176	642	1.9154	1.1017	0.9854	1.2643
2021	1,126,304	1,155	1.0255	0.7742	0.6920	0.8760
2022	1,767,361	2,179	1.2329	0.9262	0.8390	1.0203

Table 4. Nominal and standardized CPUE values of the blue shark by area.

Year	Area A		AreaB	
	N.CPUE	S.CPUE	N.CPUE	S.CPUE
2004	0.0077	0.0099	0.3523	0.3018
2005	0.9523	0.8507	0.8945	1.1254
2006	0.5962	0.4994	0.6326	0.5126
2007	0.4815	0.4326	0.1736	0.1695
2008	0.6173	0.5209	0.4563	0.3770
2009	0.4894	0.4289	0.1582	0.1588
2010	—	—	0.9049	0.5895
2011	0.5175	0.4940	0.4934	0.4492
2012	0.0438	0.0490	0.8428	0.7365
2013	0.3944	0.3385	1.2619	1.0663
2014	0.5146	0.4524	0.3527	0.3959
2015	2.7198	2.3363	0.9699	0.7281
2016	1.5870	1.1866	0.4683	0.4045
2017	1.3826	1.0572	1.0452	0.9108
2018	1.3454	0.9705	0.7350	0.5780
2019	1.4768	1.2485	1.0608	0.8543
2020	3.1242	1.9712	0.7093	0.5926
2021	1.4413	1.0682	0.4883	0.4708
2022	1.7471	1.2727	0.8036	0.7064

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

Year	Estimated catch	
	Number (n)	Weight (ton)
2001	14,896	953
2002	20,547	1,315
2003	11,762	753
2004	18,006	1,152
2005	13,857	887
2006	13,387	857
2007	12,392	793
2008	10,528	674
2009	7,328	469
2010	10,051	643
2011	14,054	899
2012	10,375	664
2013	8,602	551
2014	10,930	700
2015	18,532	1,186
2016	7,027	430
2017	10,606	367
2018	9,872	402
2019	20,873	1,298
2020	17,049	1,087
2021	11,567	737
2022	18,821	1,200

Appendix A. Additional residual plots for the Delta-lognormal GLM model.
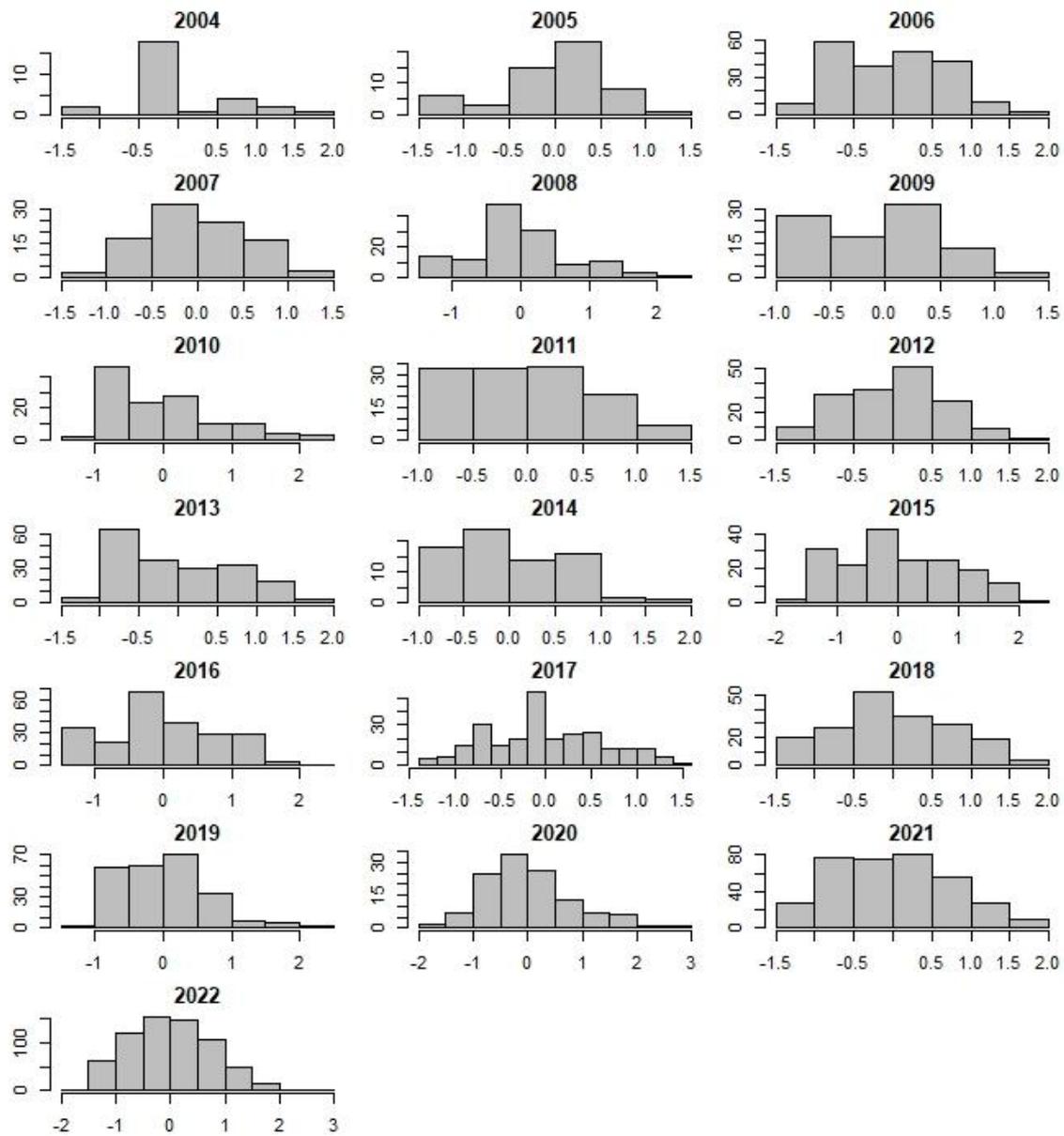
Appendix A. Figure 1. Annual residual plots from the lognormal model.
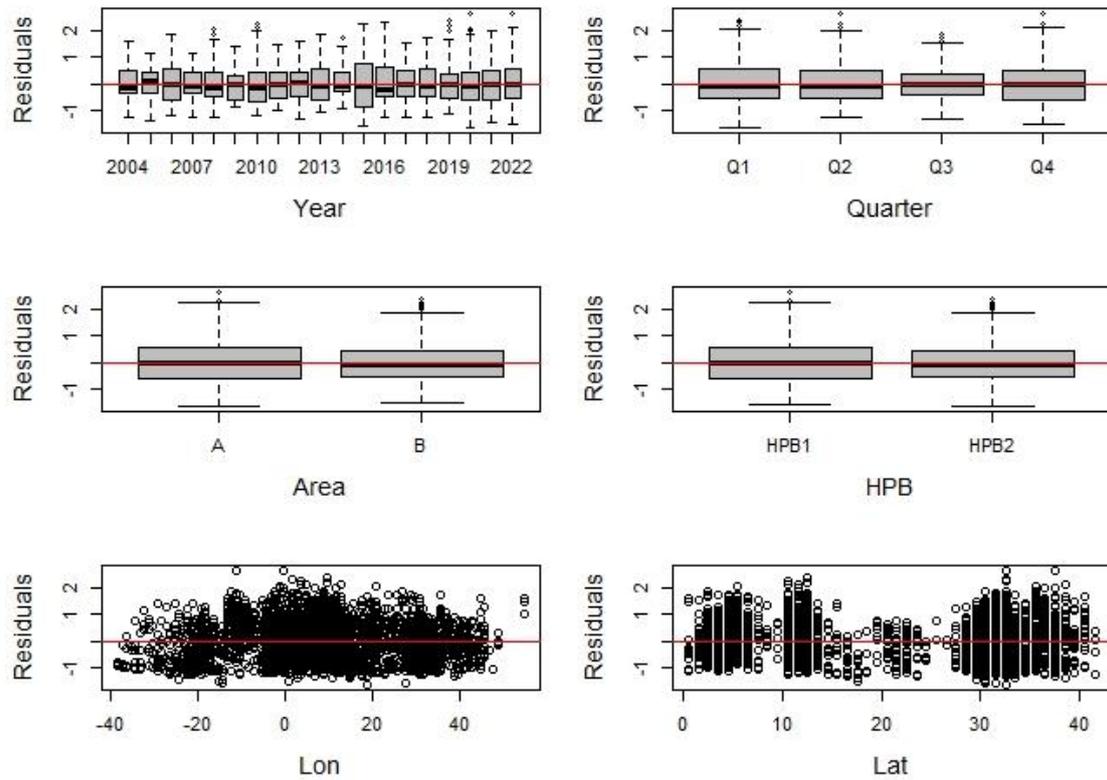
Appendix A. Figure 2. Plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area, HPB, Longitude (Lon) and Latitude (Lat) for lognormal model.
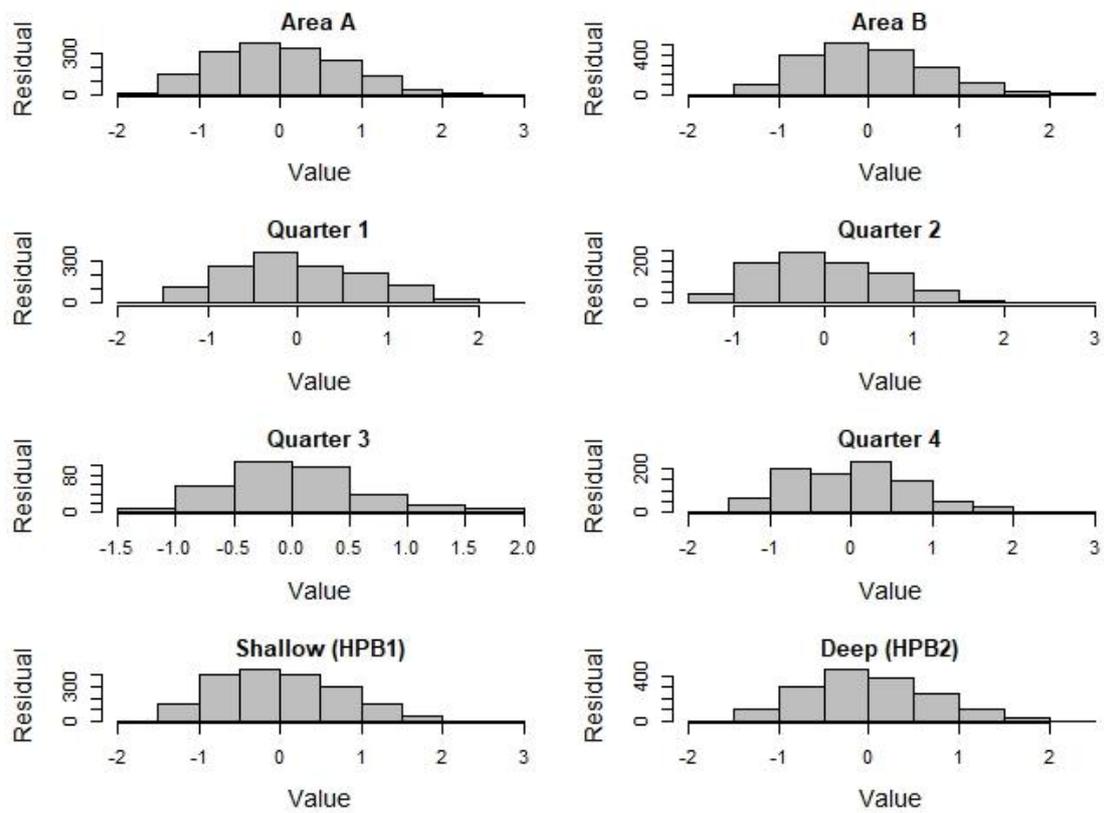
Appendix A. Figure 3. Histogram residuals plots for the variables Year, Quarter, Area and HPB from lognormal model.

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

Lognormal model (positive catch):

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			3529	2216.9			
Year	18	283.193	3511	1933.8	30.8536	< 2.2e-16	***
Quarter	3	0.941	3508	1932.8	0.6153	0.605032	
Area	1	4.075	3507	1928.7	7.9914	0.004727	**
HPB	1	9.155	3506	1919.6	17.9533	2.32E-05	***
LON	1	12.796	3505	1906.8	25.0934	5.73E-07	***
LAT	1	94.775	3504	1812	185.8612	< 2.2e-16	***
Q:A	3	10.599	3501	1801.4	6.9288	0.00012	***
Q:HPB	3	7.287	3498	1794.1	4.7637	0.002567	**
A:HPB	1	10.914	3497	1783.2	21.4029	3.86E-06	***

Binomial model:

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			6354	8731.5			
Year	18	380.74	6336	8350.8	21.152	< 2.2e-16	***
Quarter	3	44.22	6333	8306.6	14.739	1.36E-09	***
Area	1	260	6332	8046.6	259.996	< 2.2e-16	***
LON	1	18.79	6331	8027.8	18.787	1.46E-05	***
LAT	1	467.62	6330	7560.2	467.622	< 2.2e-16	***
Q:A	3	46.64	6327	7513.5	15.547	4.14E-10	***

Appendix C. Diagnostic of area-specific standardization modeling.

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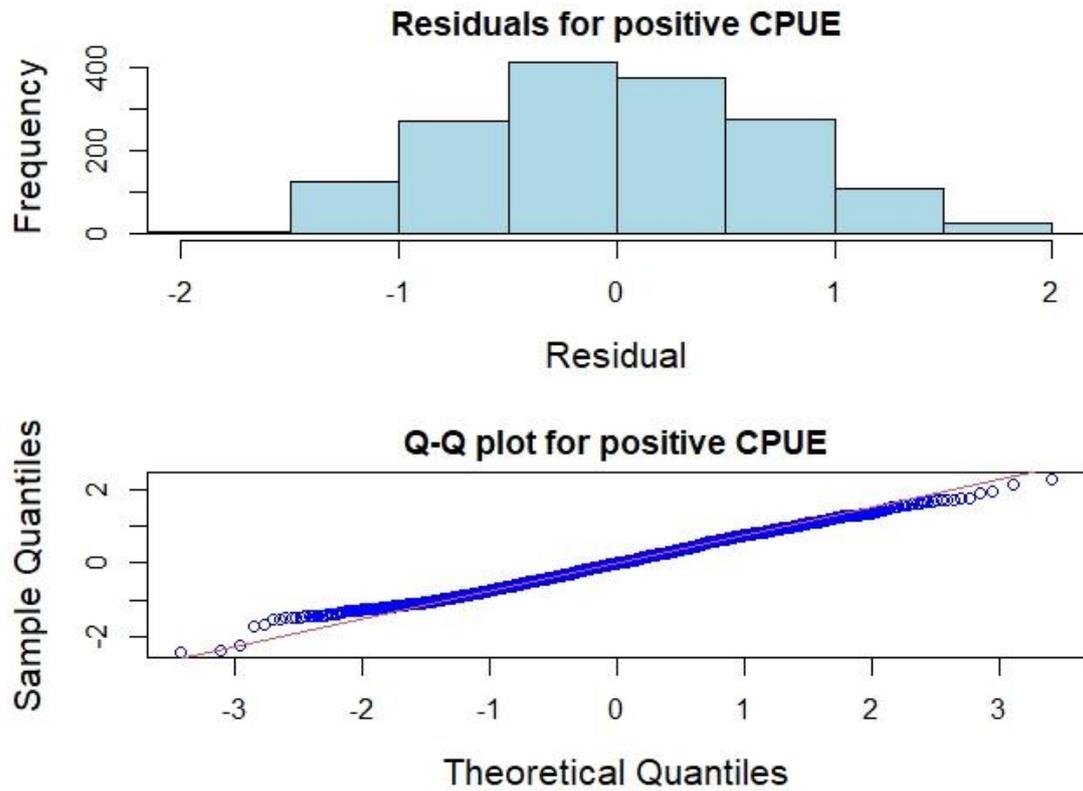
Appendix C. Figure 1. Diagnostic results from the lognormal model fit to the Taiwanese large-scale longline blue shark bycatch data in area A.

Area A:

Residuals for PA Model

Q-Q plot for PA Model
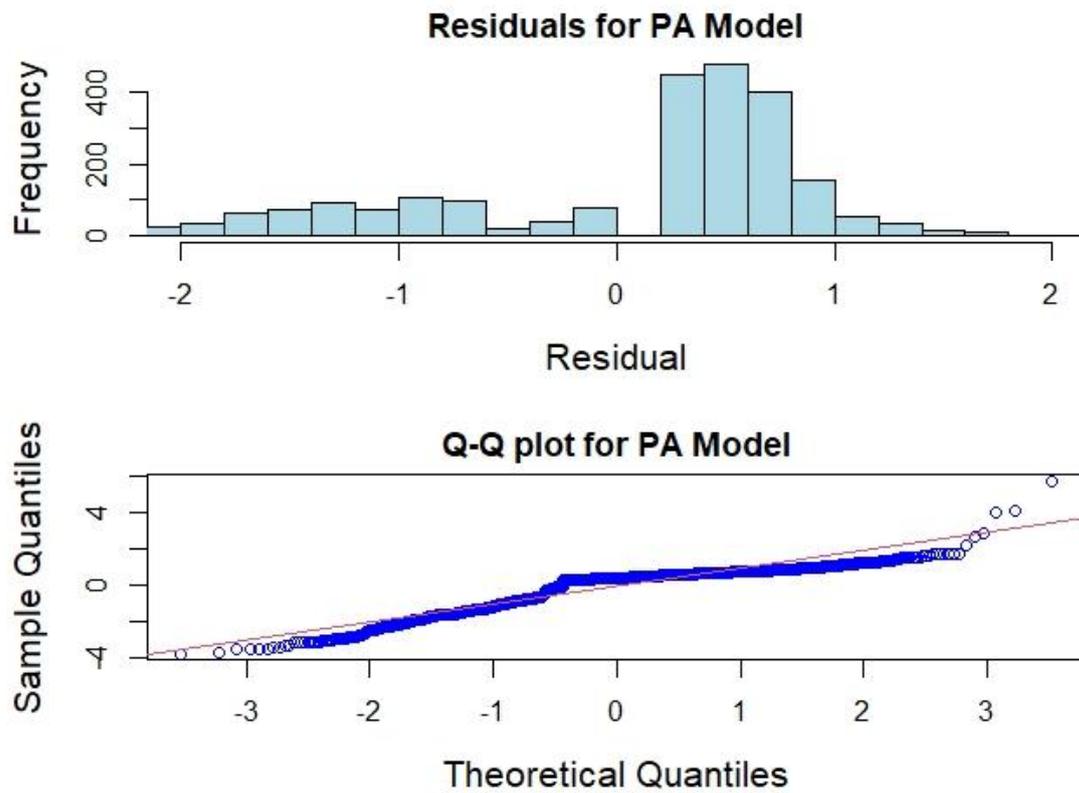
Appendix C. Figure 2. Diagnostic results from the binomial model fit to the Taiwanese large-scale longline blue shark bycatch data in area A.
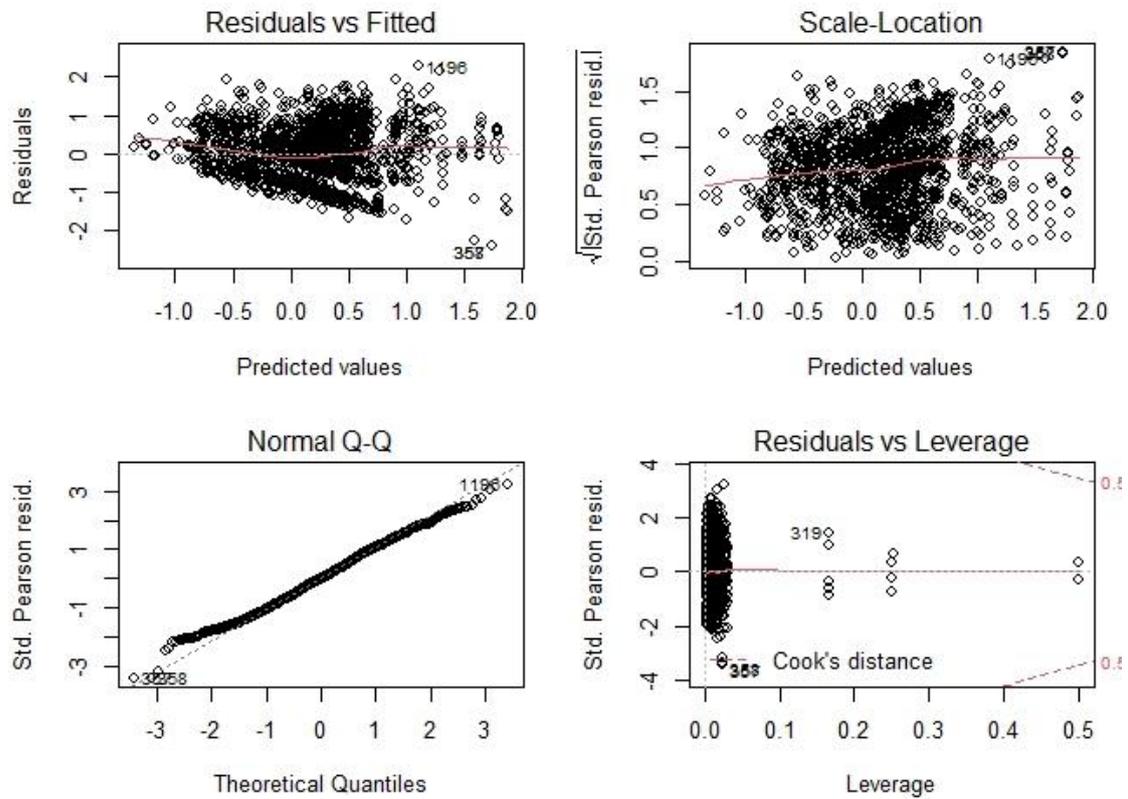
Area A:

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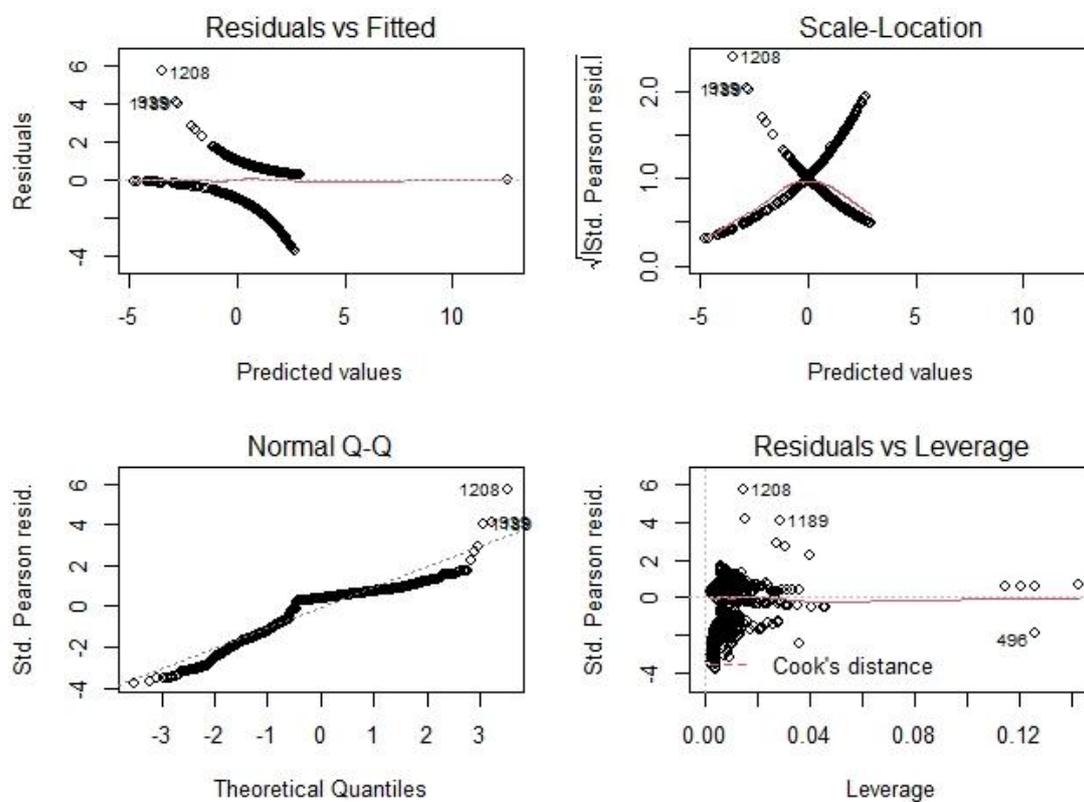
Area A:

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

Area B:

Residuals for positive CPUE

Q-Q plot for positive CPUE
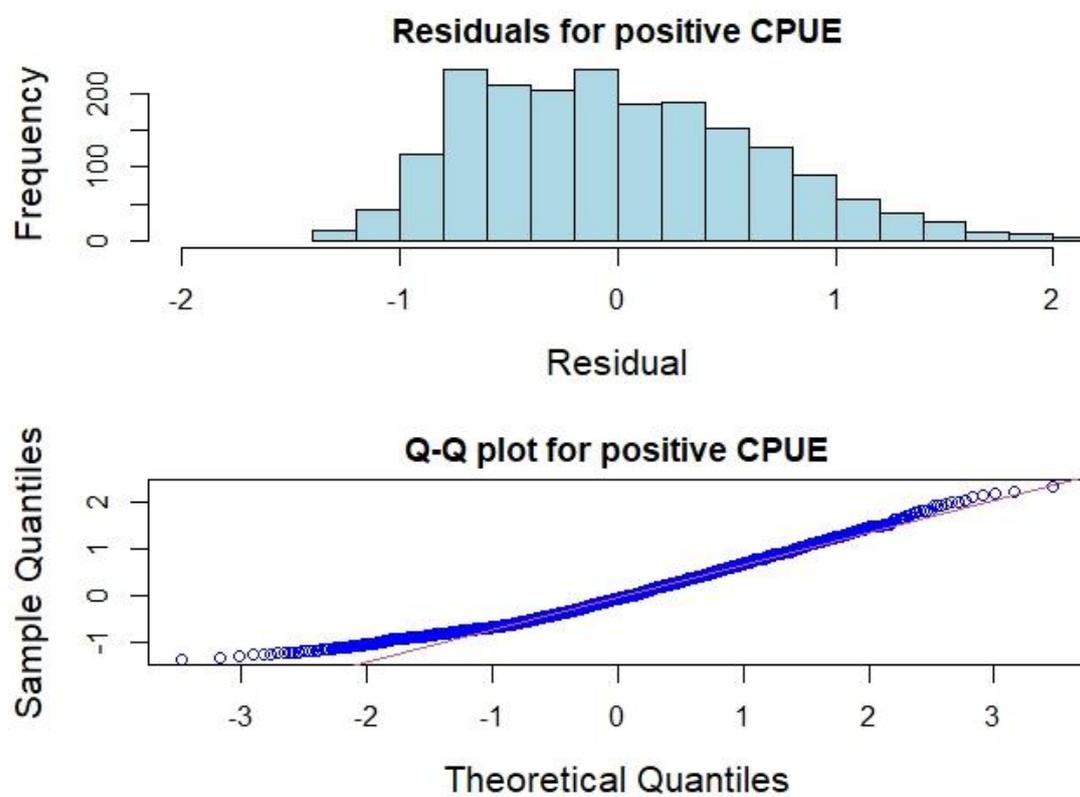
Appendix C. Figure 5. Diagnostic results from the lognormal model fit to the Taiwanese large-scale longline blue shark bycatch data in area B.
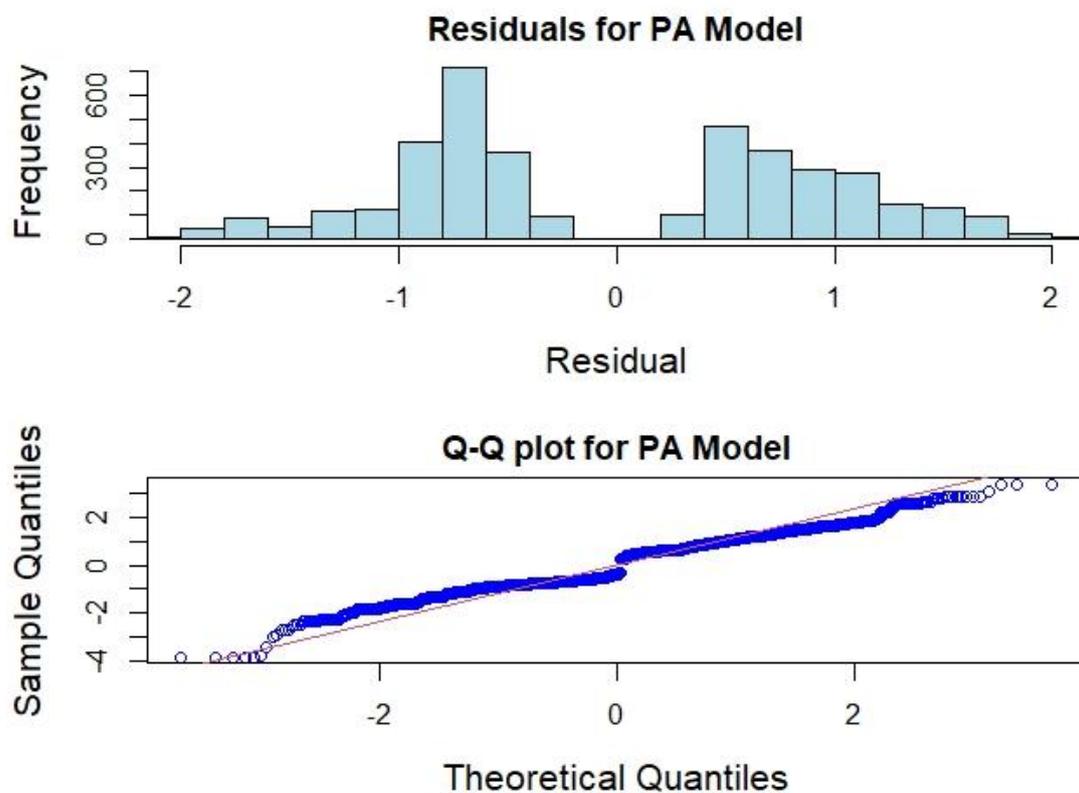
Area B:

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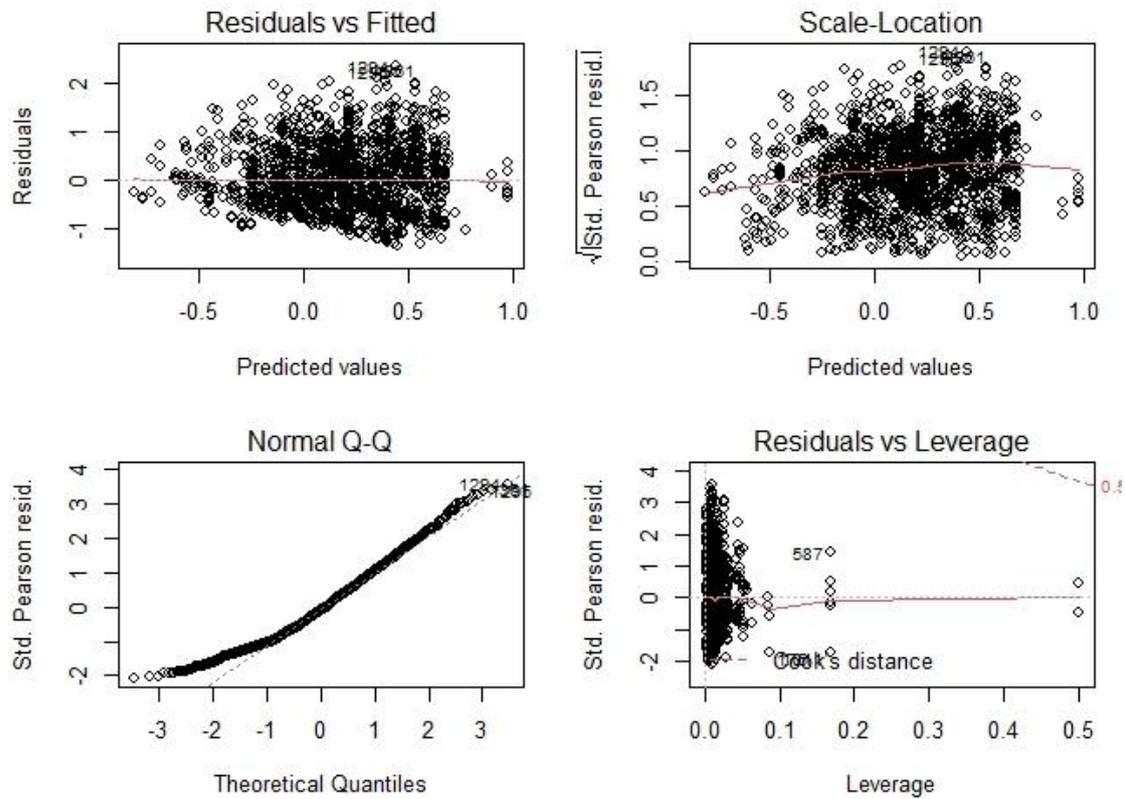
Area B:

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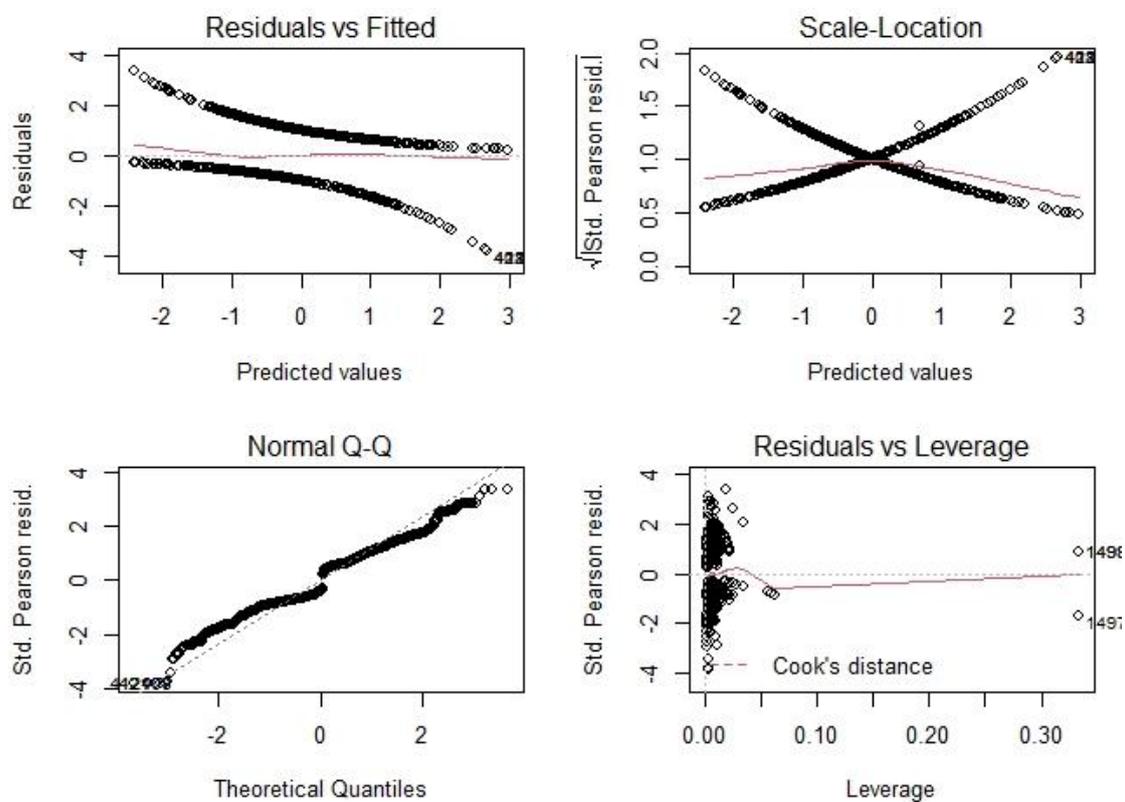
Area B:

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