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STANDARDIZED CATCH RATES OF BLUE SHARKS CAUGHT BY THE TAIWANESE LONGLINE FISHERY IN THE ATLANTIC OCEAN

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SUMMARY

In this document, the blue shark catch and effort data from observers' records of Taiwanese large longline fishing vessels operating in the Atlantic Ocean from 2004-2012 were analyzed. Based on the shark by-catch rate, five areas, namely, A (north of 20ºN), B (5ºN-20ºN), C (5ºN-15ºS), D (15ºS-50ºS, west to 20ºW) and E (15ºS-50ºS, 20ºW-20ºE), were categorized. To cope with 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 a two-step delta-lognormal approach that treats the proportion of positive sets and the CPUE of positive catches separately. Standardized indices with 95% bootstrapping confidence intervals are reported. The standardized CPUE showed a stable trend for blue sharks with a peak in 2006 for the South Atlantic and two peaks (2005 and 2006) for the North Atlantic. The results suggested that the blue shark stock in the North and South Atlantic Ocean were likely at the level of optimum utilization in recent years. The results obtained in this study can be improved if longer time series observers' data are available.

RÉSUMÉ

Ce document analyse les données de prise et d'effort du requin peau bleue provenant des registres des observateurs déployés à bord des grands palangriers du Taipei chinois réalisant des opérations de pêche dans l'océan Atlantique entre 2004 et 2012. Sur la base du taux de prise accessoire de requins, cinq zones ont été délimitées, à savoir la zone A (Nord de 20ºN), B (5ºN-20ºN), C (5ºN-15ºS), D (15ºS-50ºS, Ouest de 20ºW) et E (15ºS-50ºS, 20ºW-20ºE). Pour s'adapter au pourcentage élevé de captures nulles de requins, la capture par unité d'effort (CPUE) du requin peau bleue (nombre de spécimens capturés par 1.000 hameçons) a été standardisée au moyen d'une approche delta-lognormale en deux étapes qui traite séparément la proportion d'opérations positives et la CPUE de captures positives. Des indices standardisés avec des intervalles de confiance de 95 % par bootstrap sont déclarés. Les CPUE standardisées ont affiché une tendance stable pour le requin peau bleue avec un chiffre record en 2006 pour l'Atlantique Sud et deux chiffres record (2005 et 2006) dans le cas de l'Atlantique Nord. Les résultats donnent à penser que les stocks de requin peau bleue du Nord et du Sud se situaient probablement à un niveau d'utilisation optimale ces dernières années. Les résultats obtenus dans cette étude pourraient être améliorés si des séries temporelles plus longues de données d'observateurs étaient fournies.

RESUMEN

En este documento, se analizan los datos de captura y esfuerzo de tintorera procedentes de los registros de observadores embarcados en grandes palangreros de Taipei Chino que operaron en el Atlántico entre 2004 y 2012. Basándose en la tasa de captura fortuita de tiburones, se establecieron cinco áreas, a saber, A (al norte de 20ºN), B (5ºN-20ºN), C (5ºN-15ºS), D (15ºS-50ºS, al oeste de 20ºW) y E (15ºS-50ºS, 20ºW-20ºE). Para tratar el gran porcentaje de captura cero de tiburones, la captura por unidad de esfuerzo (CPUE) de la tintorera, el número de ejemplares capturados por 1000 anzuelos, fue estandarizado utilizando un enfoque delta-lognormal de dos etapas que trata la proporción de lances positivos y la CPUE de las capturas positivas por separado. Se comunican los índices estandarizados con intervalos de confianza de bootstrapp del 95%. Las CPUE estandarizadas presentaban una tendencia estable para la tintorera con un pico en 2006 para el Atlántico sur y dos picos (2005 y 2006) para el Atlántico norte. Los resultados sugerían que el stock de tintorera en el Atlántico norte y sur se encontraba probablemente en años recientes en el nivel de utilización óptima. Los resultados obtenidos en este estudio pueden mejorarse si se dispone de series temporales de datos de observadores más largas.

KEYWORDS

Blue sharks, Taiwanese longline fishery,
Standardized CPUE, By-catch, Observer programs, Delta-lognormal approach

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1. Introduction

The Taiwanese longline fishery has operated in the Atlantic Ocean since the late 1960s. However, 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 2002, 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, *Prionace glauca*, mako shark, *Isurus spp*., silky shark, *Carcharihnus falciformis*, and others since 2003. As the Taiwanese longline fishery has widely covered the Atlantic Ocean especially the tropical waters and the South Atlantic, our fishery statistics must be one of the most valuable information that can be used to describe the population status of pelagic sharks.

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 logbook data have been confounded with many factors, such as under-reporting, no-recording of sharks and target-shifting effects. Therefore, the observer program for the large longline fishery was conducted to obtain detailed and reliable data for more comprehensive stock assessment and management studies. Relative abundance series for blue sharks from these sources were previously analyzed by Liu et al. (2005; 2009). Recently, the increase of coverage rate of observations enabled us to get a better estimation of shark by-catch. In present study, the CPUE series are therefore updated to examine recent trends in relative abundance of the blue sharks in the Atlantic Ocean.

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) should be conducted in CPUE standardization to address these excessive zero catch of sharks. However, our previous studies (Liu et al., 2005; 2009) did not consider this issue because the blue shark catch was estimated based on the ratio between blue sharks and target species. In addition, CPUE standardization was solely based on general linear model (GLM). In this study, updated CPUEs of blue sharks in the North and South Atlantic were standardized using delta-lognormal model based on observers' records data and hopefully these CPUE series can be used in the blue shark stock assessment in 2015.

2. Material and methods

2.1 Source of data

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 longline fishery in the Atlantic Ocean. The summary of these data were shown in **Table 1**. In the Atlantic, Taiwanese tuna longline fishery targets different tuna species depending on the area; targeting albacore tuna (ALB) in the mid-high latitude of the North Atlantic, targeting tropical bigeye tuna (BET) in the low latitude of the North and South Atlantic, and targeting ALB in the mid-high latitude of the South Atlantic.

Blue sharks (BSH) caught by Taiwanese longline fishery in the Atlantic Ocean were mainly observed in the equatorial waters (**Figure 1**). Based on the shark by-catch rate, five areas, namely, A (north of 20ºN), B (5ºN-20ºN) (North Atlantic), C (5ºN-15ºS), D (15ºS-50ºS, west to 20ºW) and E (15ºS-50ºS, 20ºW-20ºE) (South Atlantic), were categorized. 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 sharks (about 40% and 30 % for North and South Atlantic) was found in observers' records. Hence, to address these excessive zero catches, 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), group (targeting on albacore or bigeye tunas, GRP) and bycatch rate (the proportion of blue sharks to the total catch in number of albacore and bigeye tunas, TGE). 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:

$\ln(CPUE) = \mu + Y + Q + A + GRP + TGE + LAT + LON + Q*A + Q*GRP + A*GRP + Q*TGE + A*TGE + \varepsilon_1$
where μ is the mean, Q*A, Q*GRP, A*GRP, Q*TGE and A*TGE 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):

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

The different group effect (GRP) is defined by targeting on ALB or BET. The effect of bycatch rate was categorized into the two classes of percentage for blue shark "BSH/(ALB+BET)" < 0.8 (bycatch), and > 0.8 (targeting), and quarter into the 4 classes of Jan-Mar (1st quarter), Apr-Jun (2nd quarter), Jul-Sep (3rd quarter) and Oct-Dec (4th 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 the stepwise AIC method (Venables and Ripley, 2002). 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).

3. Results and discussion

The blue shark bycatch data are characterized by many zero values and a long right tail (**Figures 3 and 4**). Overall, there were 37.97% of sets in North Atlantic and 31.40% in South Atlantic had zero bycatch of blue sharks (**Table 2**).

The best models for GLM and Delta models chosen by AIC values in North Atlantic were " ln(CPUE) =μ + Y + Q + A + GRP + TGE + LON + Q*A + Q*GRP + Q*TGE + A*TGE " and " PA=μ + Y + Q + A + GRP + TGE + LAT + LON + Q*A + A*GRP ", respectively. And in South Atlantic were " ln(CPUE) =μ + Y +Q + A + GRP + TGE + LAT + Q*A + Q*GRP + A*GRP + Q*TGE + A*TGE " and " PA=μ + Y + Q + A + GRP + TGE + LAT + LON + Q*A + Q*GRP + A*GRP ". The best models for North and South Atlantic were then used in the later analyses.

The standardized CPUE series of the blue shark for North and South Atlantic using the DLN model were shown in **Figures 5 and 6**. 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 in both North and South Atlantic showed a strong inter-annual oscillation, particularly in year 2006. This higher CPUE might be due to some vessels seasonally changed targeting species to sharks in this year. The obvious lower zero percentage of blue shark catch (**Table 1)** and higher CPUE in certain area **(Appendix 1**) can be found in this year. This high variability was slightly smoothed 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 (**Figures 5 and 6**). These stable trends suggested that the blue shark stock in the Atlantic Ocean seems at the level of optimum utilization during the period of 2004-2012.

The diagnostic results from the DLN model do not indicate severe departure from model assumptions (**Figures 7-10**). The ANOVA tables for each models are given in **Appendix 2**. Most main effects and interaction terms tested were significant (mostly $P < 0.01$) and included in the final model. 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 of observers' data are available and environmental factors were included in the model.

References

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Table 1. Summary of information of the observers' data used in this study.

Year	North Atlantic		South Atlantic	
	No. of Hooks	No. of Sets	No. of Hooks	No. of Sets
2004	712,041	222	1,718,711	438
2005	188,120	57	1,194,271	341
2006	4,092,408	1,246	6,370,980	2,044
2007	411,960	107	5,461,379	1,694
2008	278,433	111	4,054,708	1,471
2009	558,831	207	4,619,567	1,719
2010	673,683	224	5,418,263	1,688
2011	1,002,452	326	7,876,639	2,295
2012	659,233	236	4,668,047	1,432
Average	953,018	304	4,598,063	1,458

Table 2. The observed percentage of zero-catch of blue shark for Taiwanese tuna longline vessels in the Atlantic Ocean from 2004 to 2012.

Year	North Atlantic	South Atlantic
2004	38.29%	69.18%
2005	7.02%	32.26%
2006	12.84%	5.28%
2007	60.75%	30.22%
2008	54.95%	32.49%
2009	47.83%	36.88%
2010	31.25%	19.96%
2011	39.26%	32.68%
2012	49.58%	23.60%
Average	37.97%	31.40%

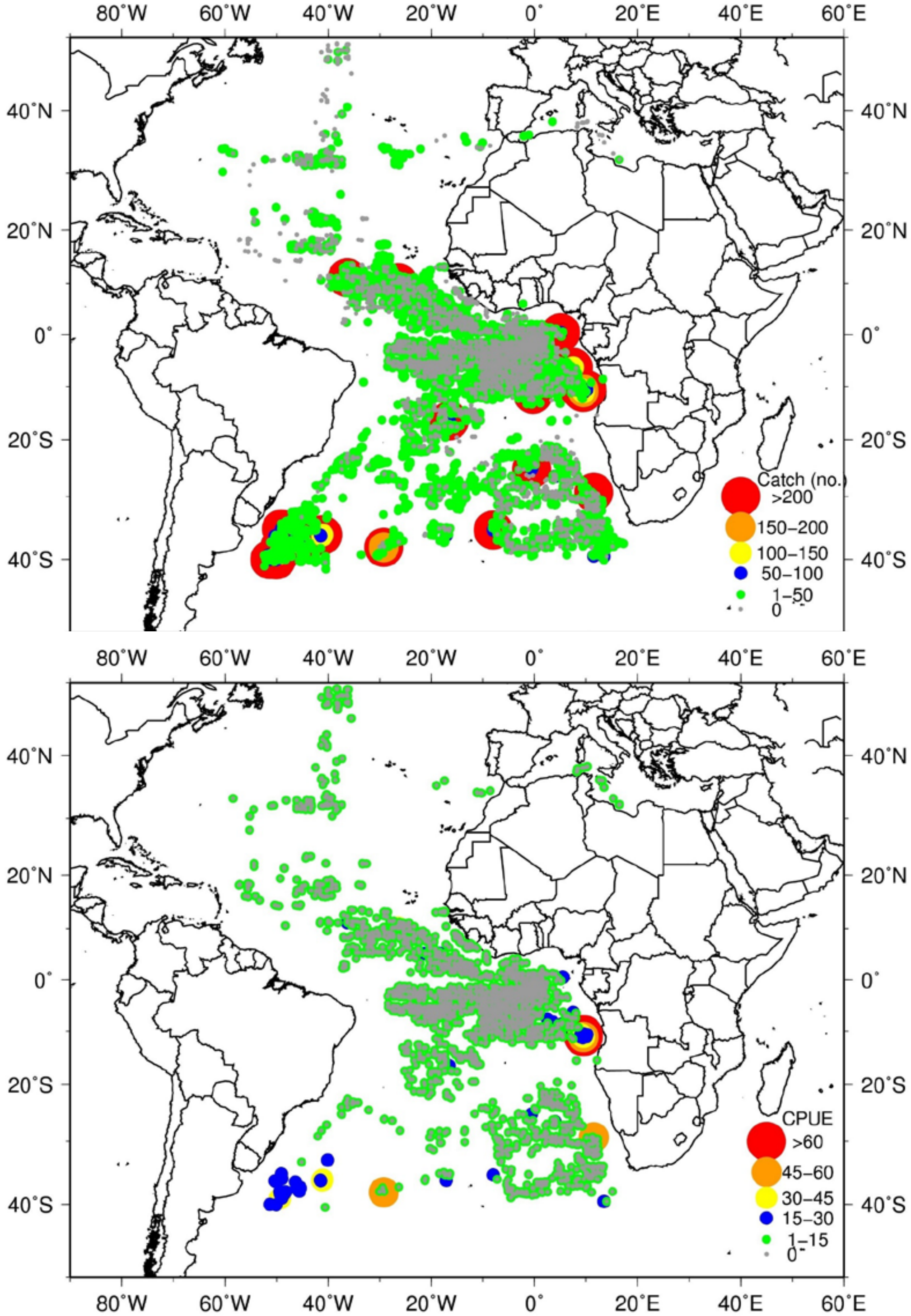


Figure 1. Observed distribution of blue shark catch and CPUE of Taiwanese tuna longline vessels in the Atlantic Ocean from 2004 to 2012.

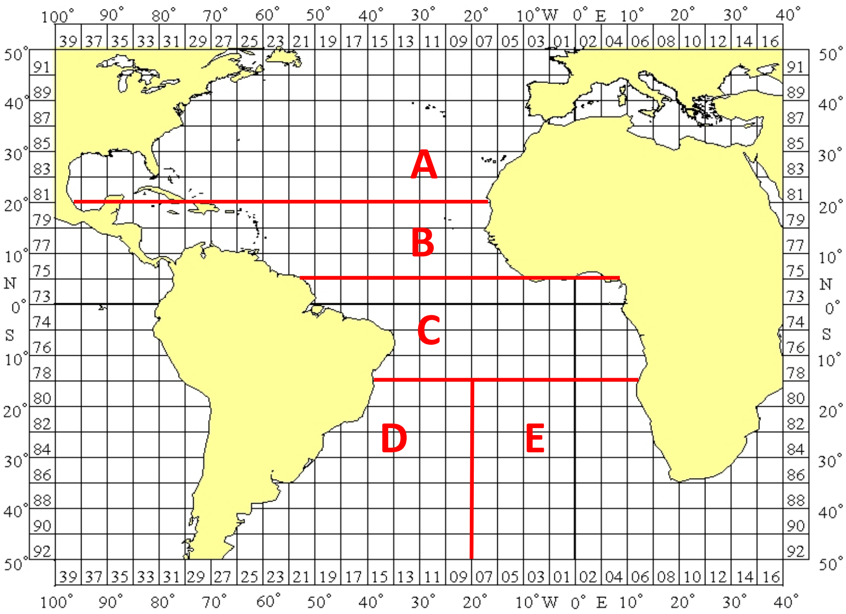


Figure 2. Area stratification in this study.

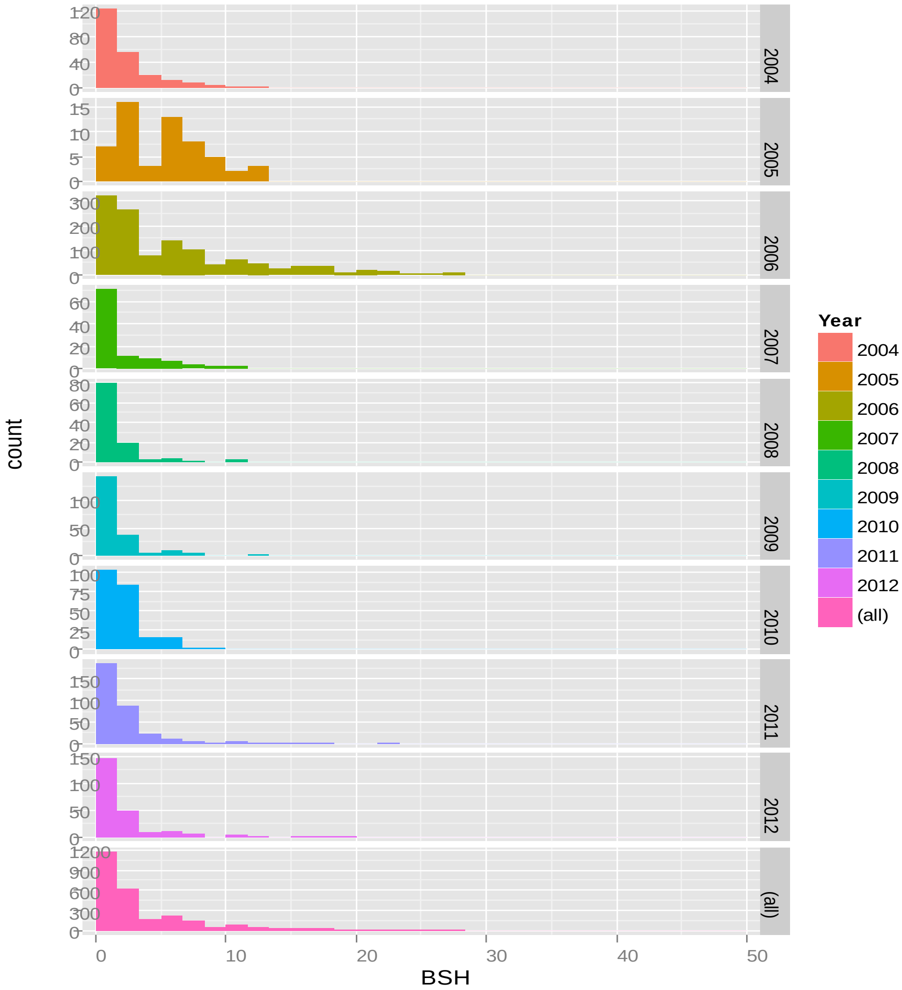


Figure 3. Annual frequency distribution of blue shark bycatch per set in the North Atlantic, 2004–2012.

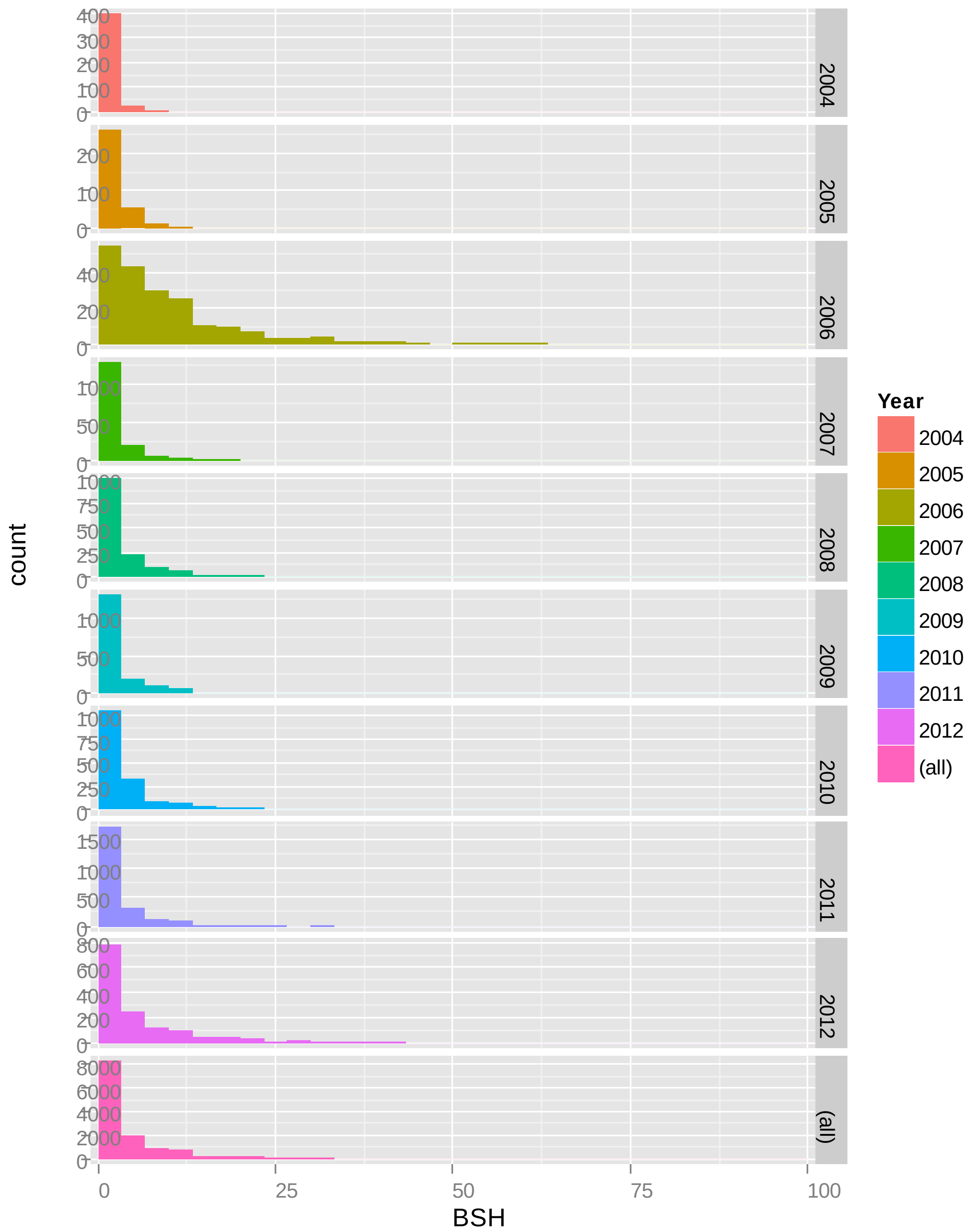


Figure 4. Annual frequency distribution of blue shark bycatch per set in the South Atlantic, 2004–2012.

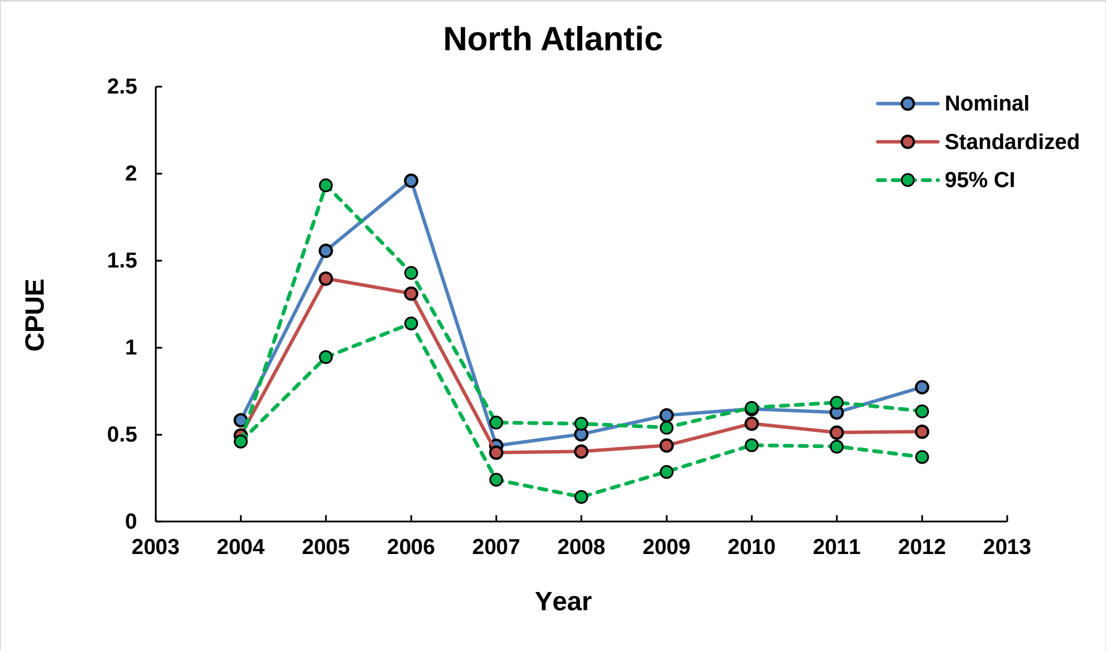


Figure 5. Observed nominal and standardized CPUE with 95% CI of blue shark by Taiwanese longline vessels in the North Atlantic from 2004 to 2012.

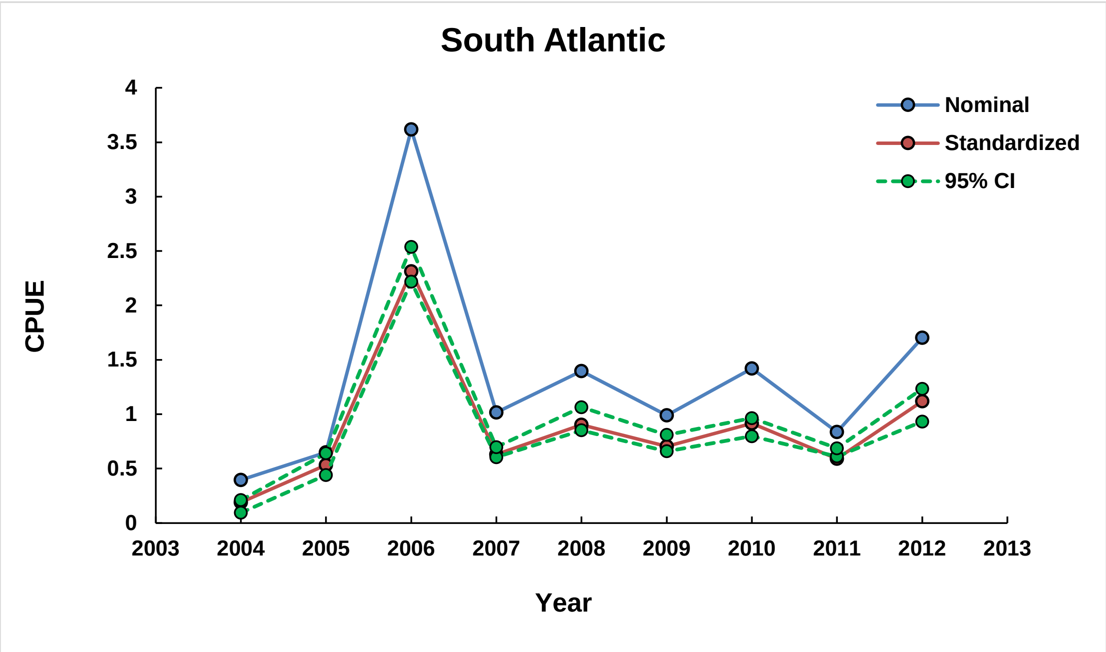


Figure 6. Observed nominal and standardized CPUE with 95% CI of blue shark by Taiwanese longline vessels in the South Atlantic from 2004 to 2012.

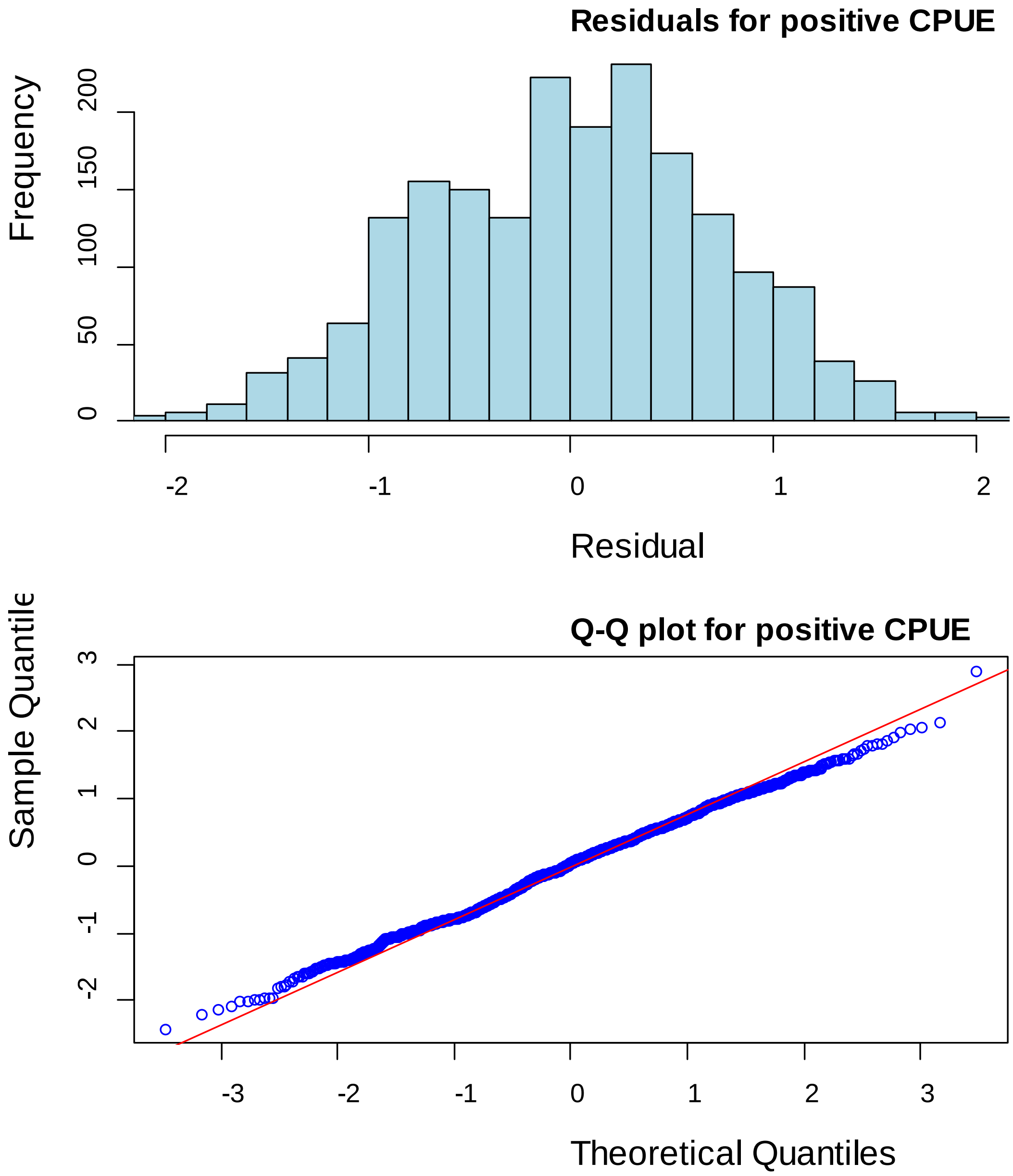


Figure 7. Diagnostic results from the GLM model fit to the North Atlantic longline blue shark bycatch data.

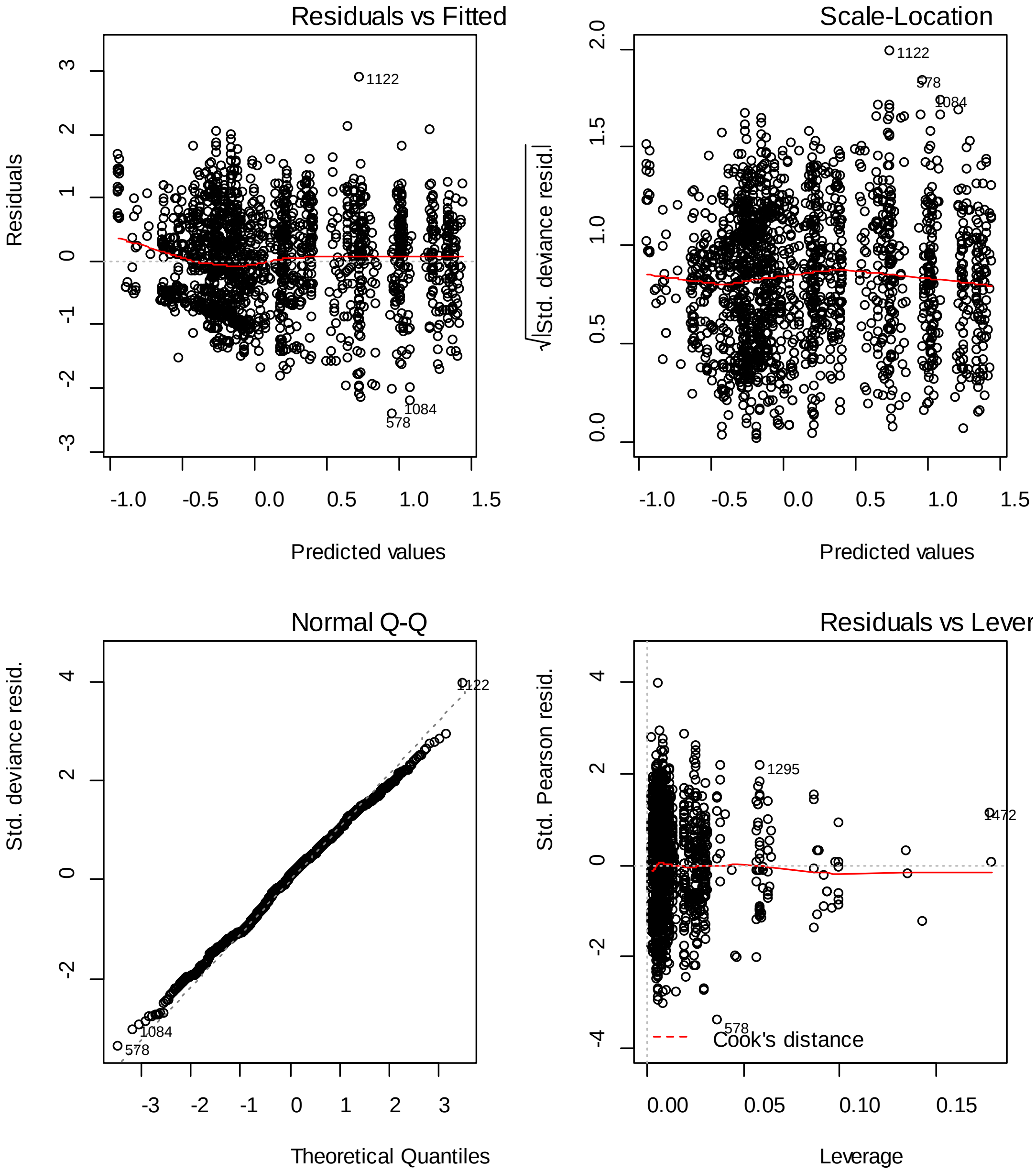


Figure 8. Residual plots for the GLM model fit to the North Atlantic longline blue shark bycatch data.

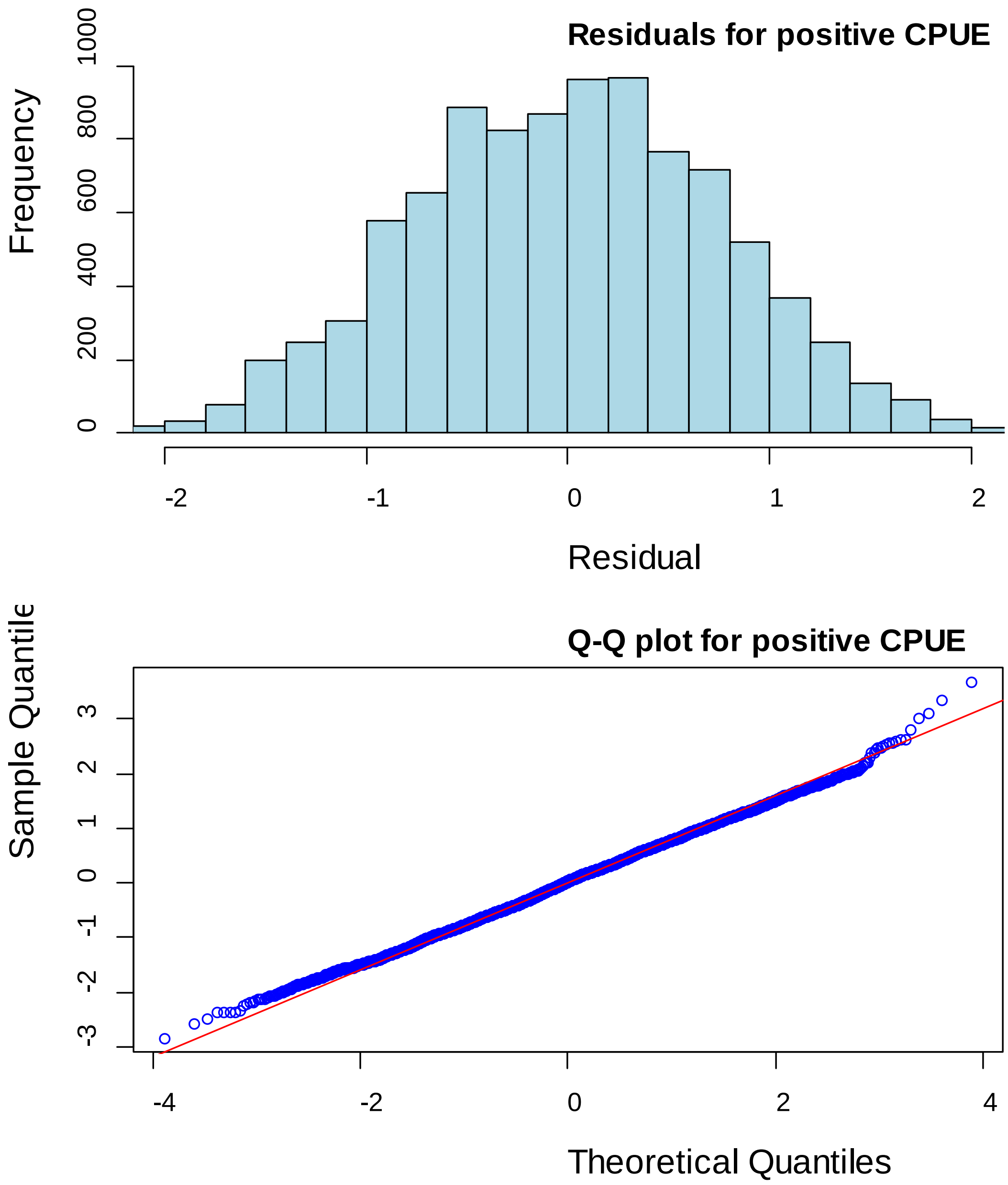


Figure 9. Diagnostic results from the GLM model fit to the South Atlantic longline blue shark bycatch data.

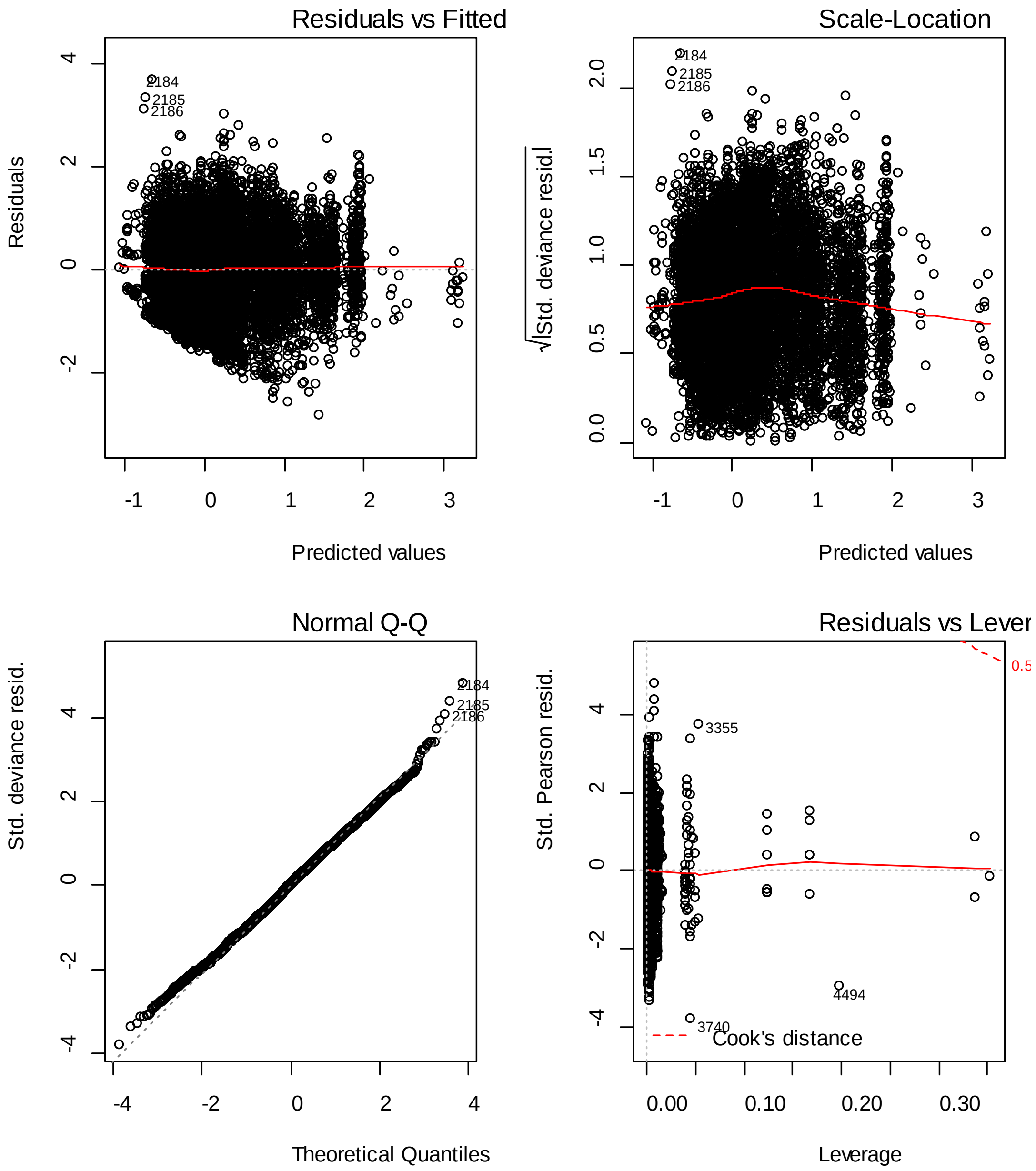
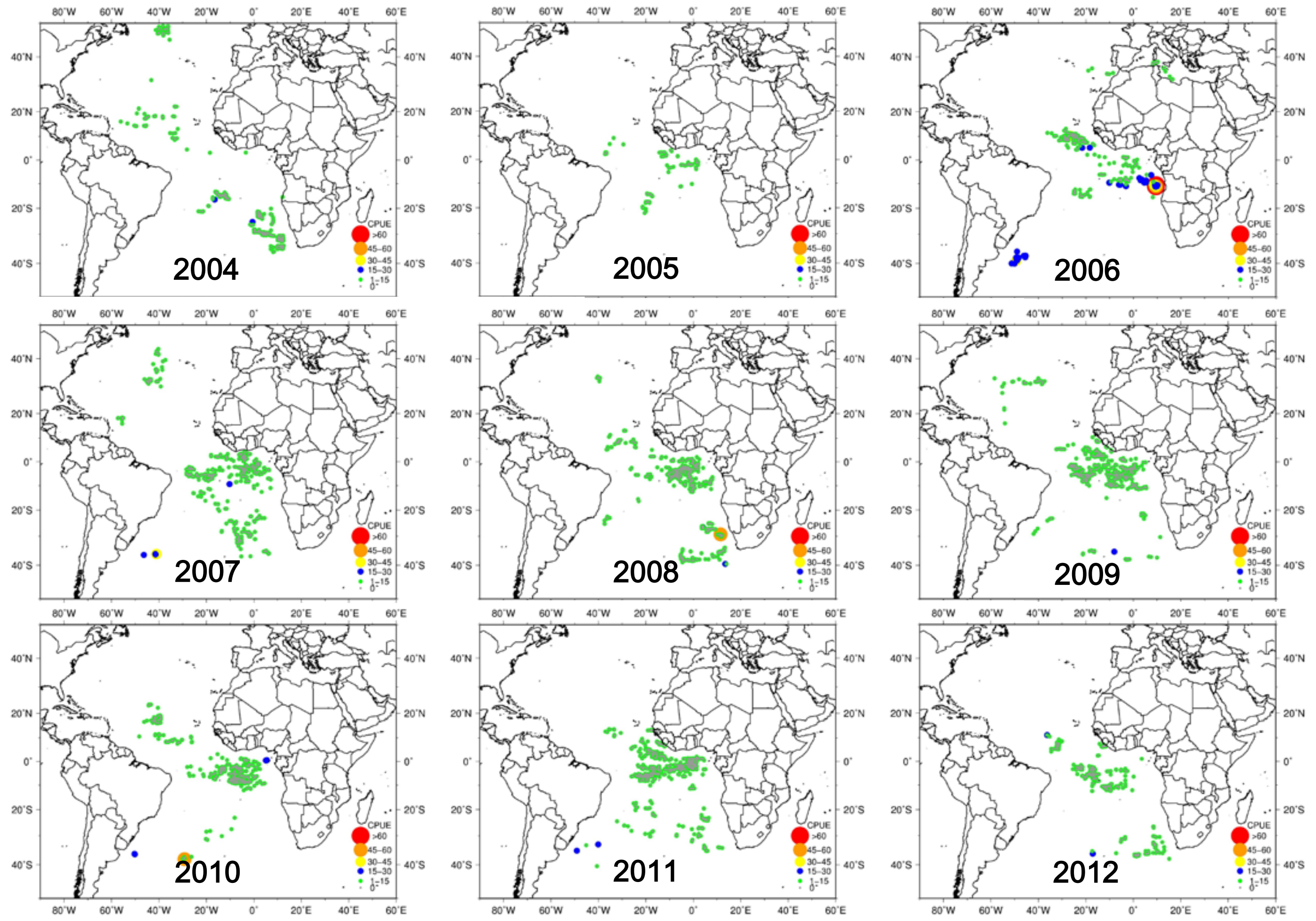


Figure 10. Residual plots for the GLM model fit to the South Atlantic longline blue shark bycatch data.

Appendix 1

Observed nominal CPUE of blue sharks by Taiwanese tuna longline vessels in the Atlantic Ocean from 2004-2012



Appendix 2

Deviance tables for the Delta-lognormal GLM model

North Atlantic

```
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                   1946     1665.0
yy     8  158.170      1938     1506.8  36.8708 < 2.2e-16 ***
Q      3  149.064      1935     1357.8  92.6618 < 2.2e-16 ***
A      1    2.120      1934     1355.7   3.9531  0.046927 *
GRP    1   34.514      1933     1321.1  64.3647 1.780e-15 ***
TGE    1  231.925      1932     1089.2 432.5103 < 2.2e-16 ***
LON    1   10.246      1931     1079.0  19.1082 1.301e-05 ***
Q:A    3   12.212      1928     1066.8   7.5911 4.787e-05 ***
Q:GRP  2   11.691      1926     1055.1  10.9007 1.961e-05 ***
Q:TGE  3   19.814      1923     1035.2  12.3171 5.564e-08 ***
A:TGE  1    4.618      1922     1030.6   8.6122  0.003379 **
---
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                   2735     3287.0
yy     8   382.35      2727     2904.6  47.7938 < 2.2e-16 ***
Q      3    41.29      2724     2863.3  13.7640 5.670e-09 ***
A      1     4.62      2723     2858.7   4.6208   0.03159 *
GRP    1    25.97      2722     2832.8  25.9719 3.464e-07 ***
TGE    1   309.27      2721     2523.5 309.2683 < 2.2e-16 ***
LAT    1    28.01      2720     2495.5  28.0120 1.206e-07 ***
LON    1   210.70      2719     2284.8 210.6950 < 2.2e-16 ***
Q:A    3    30.43      2716     2254.3  10.1445 1.119e-06 ***
A:GRP  1    39.04      2715     2215.3  39.0389 4.154e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

South Atlantic

```
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                    9551     9453.9
yy      8  1372.12      9543     8081.7  290.6658 < 2.2e-16 ***
Q       3   591.05      9540     7490.7  333.8826 < 2.2e-16 ***
A       2   118.56      9538     7372.1  100.4592 < 2.2e-16 ***
GRP     1     5.75      9537     7366.4    9.7378 0.0018106 **
TGE     1  1555.71      9536     5810.7 2636.4628 < 2.2e-16 ***
LAT     1   103.69      9535     5707.0  175.7152 < 2.2e-16 ***
Q:A     6    35.89      9529     5671.1   10.1382 3.323e-11 ***
Q:GRP   3     5.57      9526     5665.5    3.1457 0.0240570 *
A:GRP   2     3.31      9524     5662.2    2.8079 0.0603806 .
Q:TGE   3    36.45      9521     5625.8   20.5917 2.703e-13 ***
A:TGE   2     8.83      9519     5616.9    7.4833 0.0005657 ***
---
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                   13121      15361
yy      8  1197.81     13113      14163  149.7263 < 2.2e-16 ***
Q       3   270.11     13110      13893   90.0382 < 2.2e-16 ***
A       2   175.03     13108      13718   87.5168 < 2.2e-16 ***
GRP     1     9.05     13107      13709    9.0510  0.002625 **
TGE     1  1174.24     13106      12534 1174.2390 < 2.2e-16 ***
LAT     1    28.70     13105      12506   28.7014 8.444e-08 ***
LON     1    15.57     13104      12490   15.5665 7.965e-05 ***
Q:A     6    44.72     13098      12445    7.4527 5.329e-08 ***
Q:GRP   3    13.15     13095      12432    4.3831  0.004324 **
A:GRP   2     4.36     13093      12428    2.1797  0.113074
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```