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UPDATED STANDARDIZED CPUE, SIZE AND SPATIAL DISTRIBUTION OF BLUE SHARK (*PRIONACE GLAUCA*) CAUGHT BY THE CHINESE TAIPEI LONGLINE FISHERY IN THE ATLANTIC OCEAN

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SUMMARY

The blue shark Prionace glauca *catch and effort data from observers' records of Chinese Taipei large longline fishing vessels operating in the Atlantic Ocean from 2007-2022 were analyzed. To cope with the large percentage of zero shark catch, the catch per unit effort (CPUE) of blue sharks, 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 of blue sharks in the North Atlantic had a lowest value in 2015, peaked in 2016, and decreased thereafter. The standardized CPUE of blue sharks in the South Atlantic was relatively stable from 2007-2019 but peaked in 2020 and decreased thereafter. The mean sizes of females were significantly smaller than those of males (P < 0.05) in the North and South Atlantic Ocean. The mean sizes of both sexes in the tropical waters were larger than those in the temporate waters.*

RÉSUMÉ

Les données de prise et d'effort du requin peau bleue (Prionace glauca) *provenant des registres des observateurs déployés à bord des grands palangriers du Taipei chinois réalisant des opérations de pêche dans l'océan Atlantique entre 2007 et 2022 ont été analysées. 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. La CPUE standardisée du requin peau bleue dans l'Atlantique Nord a connu sa valeur la plus faible en 2015, atteignant un sommet en 2016 et diminuant par la suite. La CPUE standardisée du requin peau bleue dans l'Atlantique Sud était relativement stable entre 2007 et 2019 mais a atteint un sommet en 2020, pour décroître par la suite. Les tailles moyennes des femelles étaient significativement plus petites que celles des mâles (P < 0,05) dans l'océan Atlantique Nord et Sud. Les tailles moyennes des deux sexes dans les eaux tropicales étaient plus grandes que celles des eaux tempérées.*

RESUMEN

*Se analizaron los datos de captura y esfuerzo del tiburón azul (*Prionace glauca*) procedentes de registros de observadores de los grandes palangreros de Taipei Chino que operaron en el océano Atlántico entre 2007 y 2022. Para tratar el gran porcentaje de captura cero de tiburones, la captura por unidad de esfuerzo (CPUE) del tiburón azul, como el número de ejemplares capturados por 1.000 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 %. La CPUE estandarizada del tiburón azul en el Atlántico norte tuvo su valor más bajo en 2015, alcanzó un máximo en 2016 y posteriormente descendió. La CPUE estandarizada del tiburón azul en el Atlántico sur fue relativamente estable de 2007 a 2019, pero alcanzó un máximo en 2020 y posteriormente descendió. Las tallas medias de las hembras fueron significativamente inferiores a las de los machos (P < 0,05) en el océano Atlántico norte y sur. Las tallas medias de ambos sexos en aguas tropicales fueron superiores a las de las aguas templadas.*

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KEYWORDS

Blue sharks, Chinese Taipei longline fishery, standardized CPUE, by-catch, observer programs, delta-lognormal approach

1. Introduction

The Chinese Taipei longline fishery has operated in the Atlantic Ocean since the late 1960s. However, the shark by-catch of Chinese Taipei 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 Chinese Taipei 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 Chinese Taipei 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 Chinese Taipei 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. (2004; 2008). 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., 2004; 2008) did not consider this issue because the blue shark catch was estimated based on the ratio between shortfin makos and target species. In addition, CPUE standardization was solely based on general linear model (GLM). Tsai and Liu (2015) proposed an updated standardized catch rate of blue shark by using delta log-normal model. However, there might be compounded effect for the factors used in the standardized model. In addition, the observing time of observers decreased from 10-12 hr to 8 hr since 2013 resulting in a decreased number of observed hooks. In this study, updated and revised CPUEs of blue sharks in the North and South Atlantic were standardized using delta-lognormal model based on observers' records data from 2007 to 2022.

2. Material and methods

2.1 Source of data

The species-specific catch data including tunas, billfishes, and sharks from observers' records in 2007-2022 were used to standardize CPUE of blue shark of Chinese Taipei longline fishery in the Atlantic Ocean. The summary of these data were shown in **Table 1**. In the Atlantic, Chinese Taipei 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 Chinese Taipei longline fishery in the Atlantic Ocean were mainly observed in the equatorial waters. Based on the shark by-catch rate, four 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. For standardization, CPUE was calculated by set of operations based on observers' records during the period of 2007-2022.

The fishing date, location, weight (in kg), and fork length (FL in cm) of the specimens were recorded, and the sex of each specimen was identified.

2.2 CPUE standardization

A large proportion of sets with zero catch of blue sharks (about 50% and 30% for both 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, 2020) 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), HPB (number of hooks per basket, HPB), group (targeting on albacore or bigeye tunas, GRP), latitude (LAT), longitude (LON) and interaction terms. 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

$$\ln(CPUE) = \mu + Y + Q+A+HPB+GRP+LON+LAT+ \text{interactions} + \varepsilon_1$$

where μ is the mean, and ε_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), 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 1**. The different group effect (GRP) is defined by targeting on ALB or BET.

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

$$PA=\mu + Y + Q+A+HPB+GRP+LON+LAT+ \text{interactions} + \varepsilon_2$$

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

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 Size data analysis

The mean sizes of specimens were compared between areas and sexes and among quarters using t-test or ANOVA on the assumption of a normal distribution because of the large sample size.

3. Results and discussion

The blue shark bycatch data are characterized by many zero values and a long right tail (**Figures 2** and **3**). Overall, there were 49.91% of sets in the North Atlantic and 32.73% in the South Atlantic had zero bycatch of blue sharks (**Table 2)**. Historical nominal CPUE of the blue shark in the North and South Atlantic are showed in **Figures 4** and **5**, respectively.

The best models for Lognormal and Binomial models chosen by AIC values in North Atlantic were " ln(CPUE) = μ + Y + A + GRP + LON + LAT + Q:A + Q:HPB (AIC=3,146) " and " PA = μ + Y + Q + A + HPB + GRP + LAT + Q:HPB + Q:GRP (AIC=3593) ", respectively. While the best models in South Atlantic were " ln(CPUE) = μ + Y + Q + A + HPB + GRP + LAT + Q:A + Q:HPB + A:GRP + HPB:GRP, (AIC= 39,700) " and " PA = μ + Y + Q + A + HPB + GRP + LAT + Q * A + Q * HPB + Q * GRP + A * HPB + A * GRP + HPB * GRP (AIC= 28,910) ". The standardized CPUE series with 95% CI of the blue shark for the North and South Atlantic using the DLN model are shown in **Figures 6** and **7**. The detail values for nominal and standardized CPUE are listed in **Tables 3** and **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 in both North and South Atlantic showed inter-annual oscillation, particularly in year 2015 and 2016 in the North Atlantic and 2014 and 2020 in the South Atlantic, respectively. The standardized CPUE had the historical low in 2015, peaked in 2016 and decreased thereafter for the North Atlantic blue sharks (**Figures 6**). The large variation of standardized CPUE in 2015 and 2016 may be due to the difference in observed areas between the two years. The standardized CPUE of blue sharks in the South Atlantic was relatively stable in 2007-2019 but peaked in 2020 and decreased thereafter (**Figure 7**). The variation was likely due to smaller sample size. Overall, the standardized CPUE trends of 2007-2014 and 2017-2019 were stable but large variation was found between 2015 and 2016. Different sampling locations between 2015 and 2016 (**Figure 4**) may be the factor resulted in the result. The CPUE trend of blue sharks in the South Atlantic was relatively stable from 2007 to 2019 and peaked in 2020 (**Figure 7**). The high CPUE in 2020 is likely because large number of juveniles was caught in the southwestern Atlantic. The fishing activities in the recent three years were affected by the COVID-19. As smaller sample sizes compared with the past years, the representativeness of these CPUE values need further investigation.

In general, the diagnostic results from the DLN model do not indicate severe departure from model assumptions (**Appendix Figures**). However, the residual distributions skewed on the right-hand side because some predicted values obtained from the model corresponding to the high CPUE observations became positive. The ANOVA tables for each models are given in **Appendix Tables**.

A total of 37,716 blue shark specimens, including 2,873 in the North and 34,843 in the South were caught by the Chinese Taipei LTLL vessels in the Atlantic Ocean and collected by the on-board scientific observers. The sizes of the 1,578 and 1,295 specimens in the North Atlantic Ocean ranged from 102 to 309 cm FL and 81 to 320 cm FL for females and males, respectively (**Table 5**). The sizes of the 14,211 and 20,722 specimens in the South Atlantic Ocean ranged from 56 to 388 cm FL and 57 to 371 cm FL for males and females, respectively (**Table 5**). Based on historical annual length-frequency distribution, the mean sizes of catch in the North Atlantic did not become smaller and the size range did not become narrower (**Figure 8**). However, although the mean size did not become smaller but the size range became narrower and two modes were found in 2020 in the South Atlantic (**Figure 9**). The mean sizes of females were significantly smaller than those of males ($P < 0.05$) in the North and South Atlantic Ocean. The mean size of males in Area B was larger than that in Area A ($P < 0.05$) but no significant difference was found for females ($P>0.05$) (Figure 10; Table 5). In the South Atlantic, the mean size of blue sharks Area C was larger than those in Areas D and E ($P < 0.05$), but no significant difference in mean size was found between Areas D and E ($P > 0.05$).

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

	North			*South*		
Year	*Set*	*Hooks*	*Catch*	*Set*	*Hooks*	*Catch*
2007	108	297,959	185	1,691	3,939,979	5,520
2008	111	241,500	140	1,458	3,214,870	5,657
2009	205	465,151	342	1,708	3,660,556	4,570
2010	222	422,034	433	1,673	3,629,562	7,688
2011	325	651,397	632	2,293	5,310,376	6,578
2012	366	753,763	722	1,944	4,106,318	8,826
2013	135	233,317	302	1,839	2,747,729	5,509
2014	153	253,256	289	1,897	2,944,692	8,602
2015	300	582,646	44	1,383	1,937,382	2,886
2016	97	167,552	320	1,638	2,375,376	4,998
2017	235	343,140	448	1,834	2,648,498	3,254
2018	150	211,983	204	1,574	2,297,780	3,417
2019	195	294,633	198	1,730	2,575,884	2,331
2020	313	403,257	305	535	954,026	2,976
2021	119	239,070	50	471	842,656	678
2022				240	361,943	378
Average	202	370,711	308	1,494	2,721,727	4,617

Table 2. The observed percentage of zero-catch of blue shark for the Chinese Taipei tuna longline vessels in the Atlantic Ocean from 2007 to 2022.

Year	*North Atlantic*	*South Atlantic*
2007	60.19	30.16
2008	54.95	31.89
2009	47.32	36.30
2010	31.08	19.49
2011	38.77	32.62
2012	42.08	29.89
2013	40.74	34.75
2014	62.09	26.73
2015	91.67	48.52
2016	11.34	31.81
2017	45.11	42.91
2018	44.00	26.18
2019	55.38	45.61
2020	49.20	8.97
2021	74.79	49.04
2022		28.75
Average	49.91	32.73

Table 3. Estimated nominal and standardized CPUE values for blue shark of the Chinese Taipei tuna longline fishery in the North Atlantic Ocean.

Year	*Hook*	*BSH*	*nom_CPUE*	*std_CPUE*	*Lower95*	*Upper95*	*CV*
2007	297,959	185	0.6209	0.5461	0.4883	0.6368	7.11%
2008	241,500	140	0.5797	0.4638	0.4172	0.5410	6.84%
2009	465,151	342	0.7352	0.5242	0.4671	0.6101	6.85%
2010	422,034	433	1.0260	0.8880	0.8283	0.9748	4.35%
2011	651,397	632	0.9702	0.7711	0.6975	0.8647	5.51%
2012	753,763	722	0.9579	0.6776	0.6075	0.7658	6.03%
2013	233,317	302	1.2944	0.9527	0.8735	1.0776	5.62%
2014	253,256	289	1.1411	0.8766	0.7685	1.0290	7.68%
2015	582,646	44	0.0755	0.0715	0.0498	0.0997	17.93%
2016	167,552	320	1.9099	1.6628	1.5874	1.8038	3.46%
2017	343,140	448	1.3056	0.9280	0.8365	1.0525	5.92%
2018	211,983	204	0.9623	0.8121	0.7403	0.9162	5.70%
2019	294,633	198	0.6720	0.7086	0.6359	0.8110	6.45%
2020	403,257	305	0.7563	0.6675	0.6015	0.7484	5.67%
2021	239,070	50	0.2091	0.2431	0.2096	0.3002	9.48%

Table 4. Estimated nominal and standardized CPUE values for blue shark of the Chinese Taipei tuna longline fishery in the South Atlantic Ocean.

Year	*Hook*	*BSH*	*nom_CPUE*	*std_CPUE*	*Lower95*	*Upper95*	*CV*
2007	3,939,979	5,520	1.4010	0.8508	0.7433	0.9356	5.70%
2008	3,214,870	5,657	1.7596	1.1258	0.9957	1.2447	5.77%
2009	3,660,556	4,570	1.2484	0.8778	0.7710	0.9708	5.84%
2010	3,629,562	7,688	2.1182	1.3578	1.2099	1.4818	5.11%
2011	5,310,376	6,578	1.2387	0.8700	0.7686	0.9557	5.54%
2012	4,106,318	8,826	2.1494	1.3818	1.2128	1.5249	5.85%
2013	2,747,729	5,509	2.0049	1.4260	1.2536	1.5732	5.70%
2014	2,944,692	8,602	2.9212	1.6680	1.4763	1.8420	5.67%
2015	1,937,382	2,886	1.4896	1.0955	0.9489	1.2327	6.65%
2016	2,375,376	4,998	2.1041	1.6964	1.4975	1.8651	5.48%
2017	2,648,498	3,254	1.2286	0.9272	0.8153	1.0282	5.90%
2018	2,297,780	3,417	1.4871	1.1571	1.0439	1.2577	4.89%
2019	2,575,884	2,331	0.9049	0.7238	0.6315	0.8048	6.18%
2020	954,026	2,976	3.1194	2.3502	2.1324	2.5575	4.58%
2021	842,656	678	0.8046	0.6024	0.5280	0.6791	6.24%
2022	361,943	378	1.0444	0.9601	0.8904	1.0382	3.95%

Table 5. The mean fork length (FL) of blue sharks caught by the Chinese Taipei tuna longline fishery in the Atlantic Ocean.

		Female			*Male*			*Total*		
		n	*mean ± sd FL (cm)*	*Range of FL (cm)*	*n*	*mean ± sd FL (cm)*	*Range of FL (cm)*	*n*	*mean ± sd FL (cm)*	*Range of FL (cm)*
North Atlantic	Area A	578	199 ± 21	118 - 309	399	206 ± 24	140 - 276	977	201 ± 23	118 - 309
	Area B	1,000	203 ± 23	102 - 287	896	208 ± 26	81 - 320	1,896	205 ± 25	81 - 320
	Total	1,578	201 ± 22	102 - 309	1,295	207 ± 25	81 - 320	2,873	204 ± 24	81 - 320
South Atlantic	Area C	9,158	206 ± 30	56 - 388	12,074	208 ± 29	90 - 371	21,232	207 ± 30	56 - 388
	Area D	1,938	178 ± 37	63 - 341	3,187	186 ± 38	73 - 343	5,125	183 ± 38	63 - 343
	Area E	3,025	185 ± 35	60 - 325	5,461	186 ± 37	57 - 346	8,486	186 ± 36	57 - 346
	Total	14,121	198 ± 34	56 - 388	20,722	199 ± 35	57 - 371	34,843	199 ± 34	56 - 388
	Total	15,699	198 ± 33	56 - 388	22,017	199 ± 34	57 - 371	37,716	199 ± 34	56 - 388

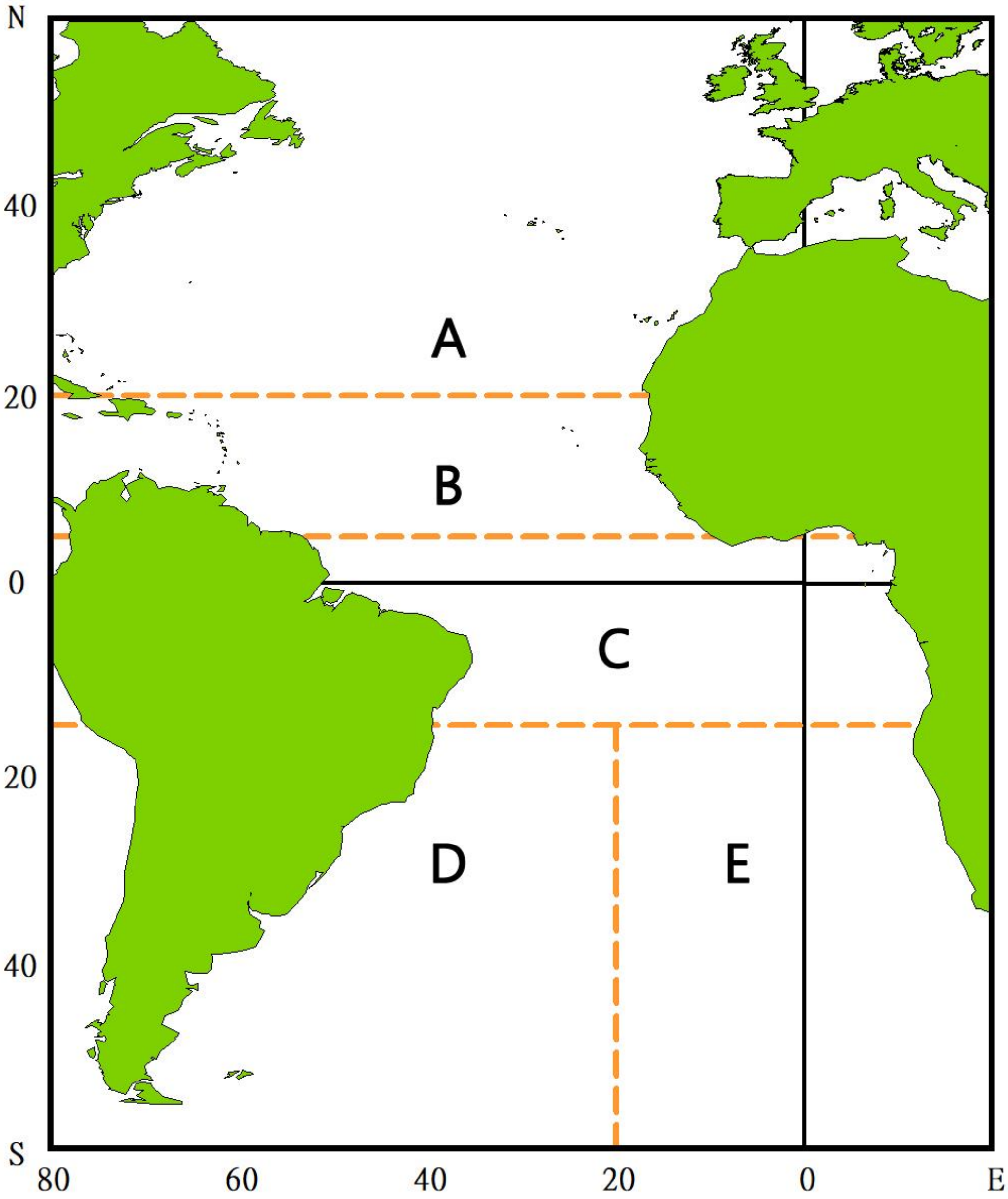

Figure 1. Area stratification in this study.

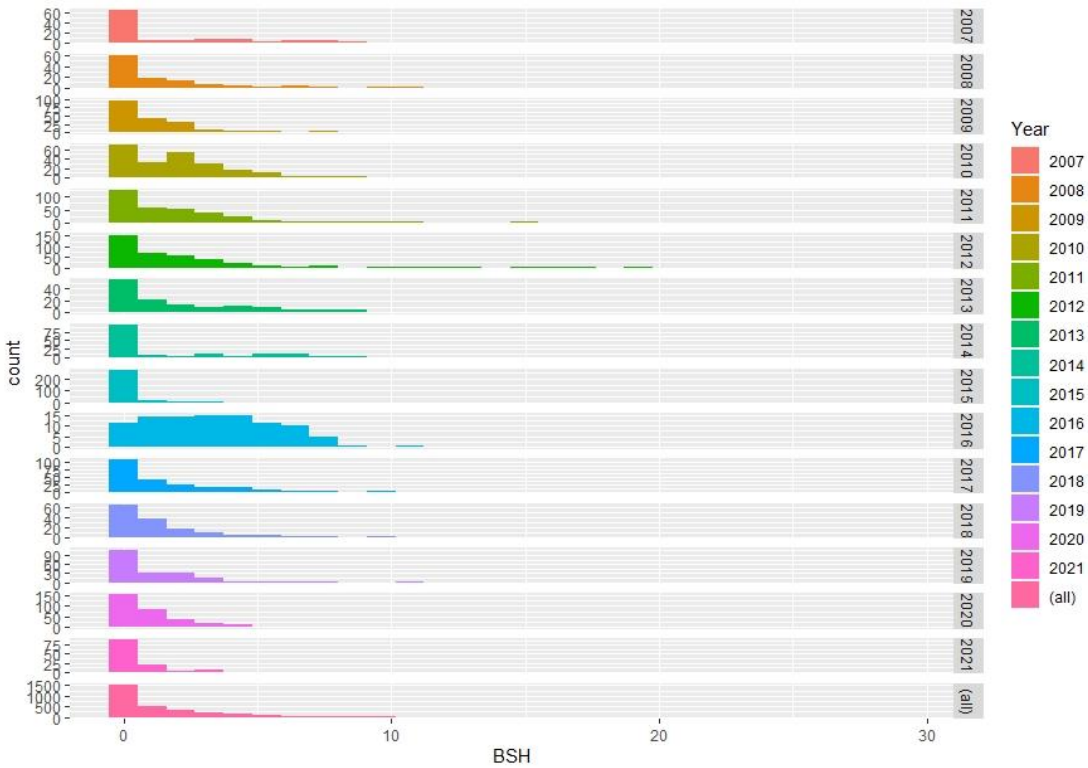

Figure 2. Frequency distribution of the blue shark catch in number per set for the Chinese Taipei large-scale tuna longline fishery in the North Atlantic Ocean 2007–2021.

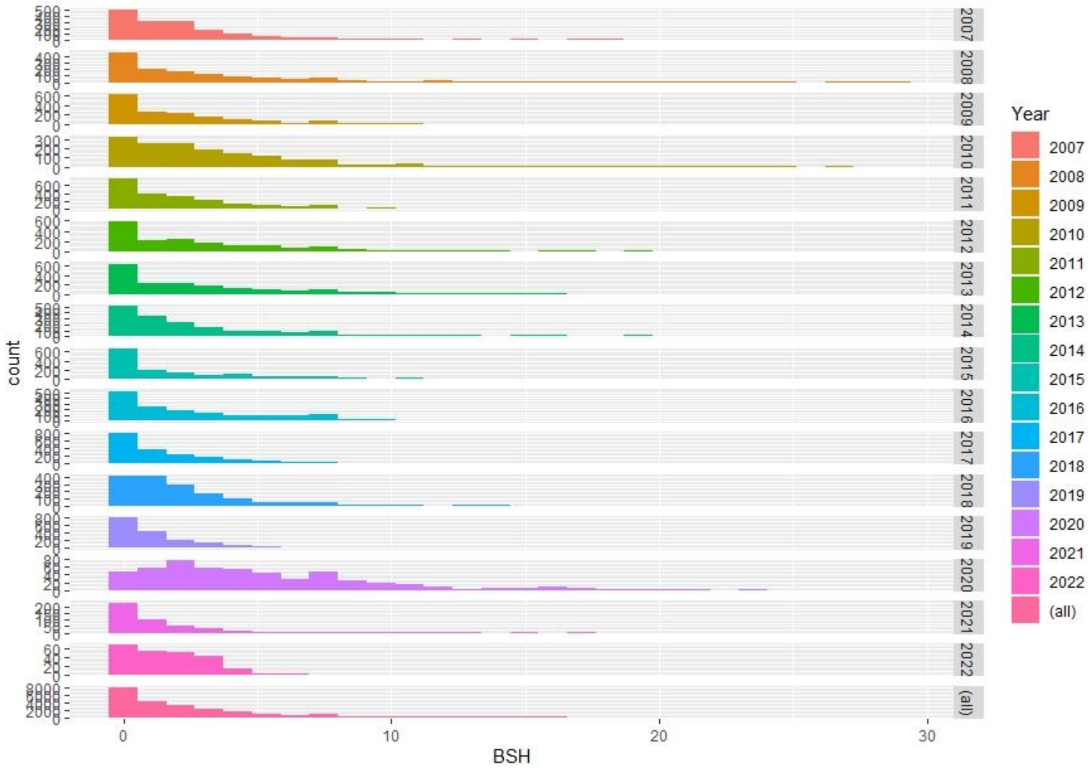

Figure 3. Frequency distribution of the blue shark (number) per set caught by the Chinese Taipei large-scale longline fishery in the South Atlantic Ocean from 2007-2022.

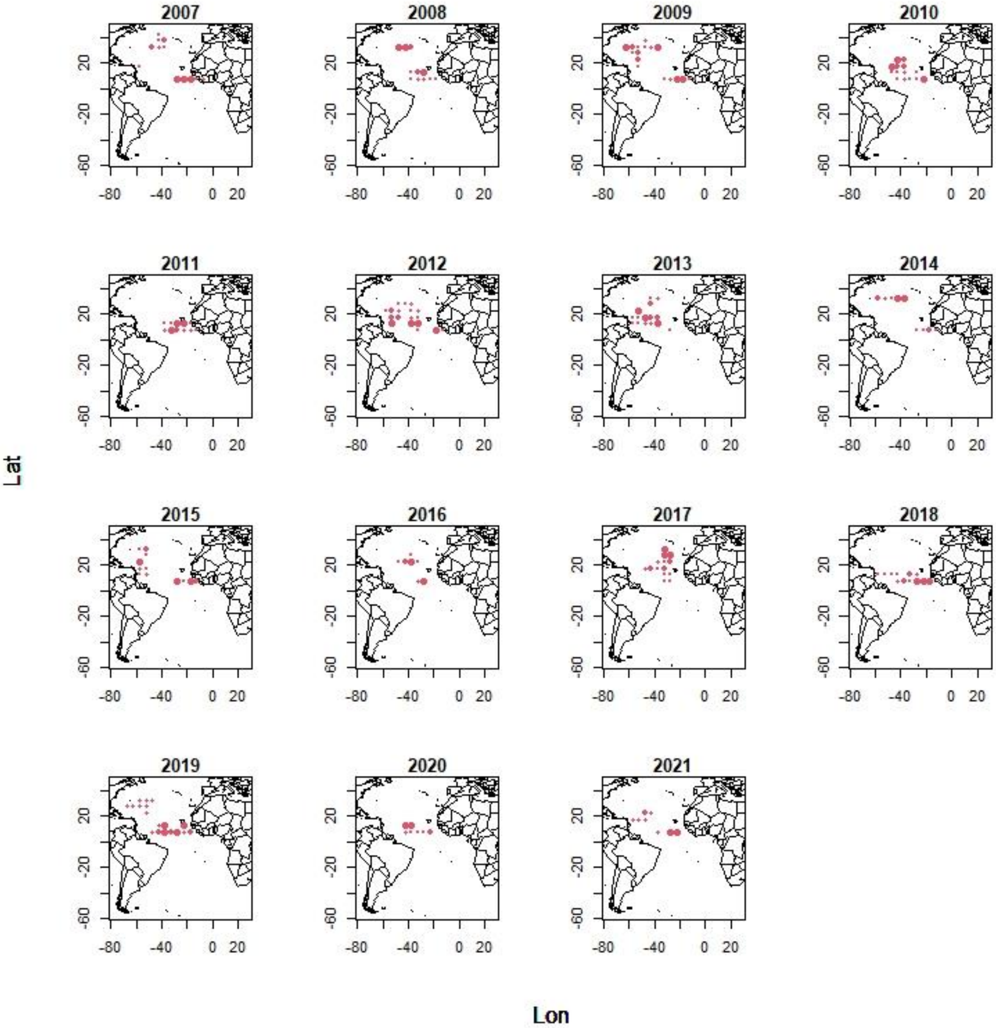

Figure 4. Nominal CPUE distribution of blue sharks caught by the Chinese Taipei large-scale tuna longline fishery in the North Atlantic Ocean from 2007-2021.

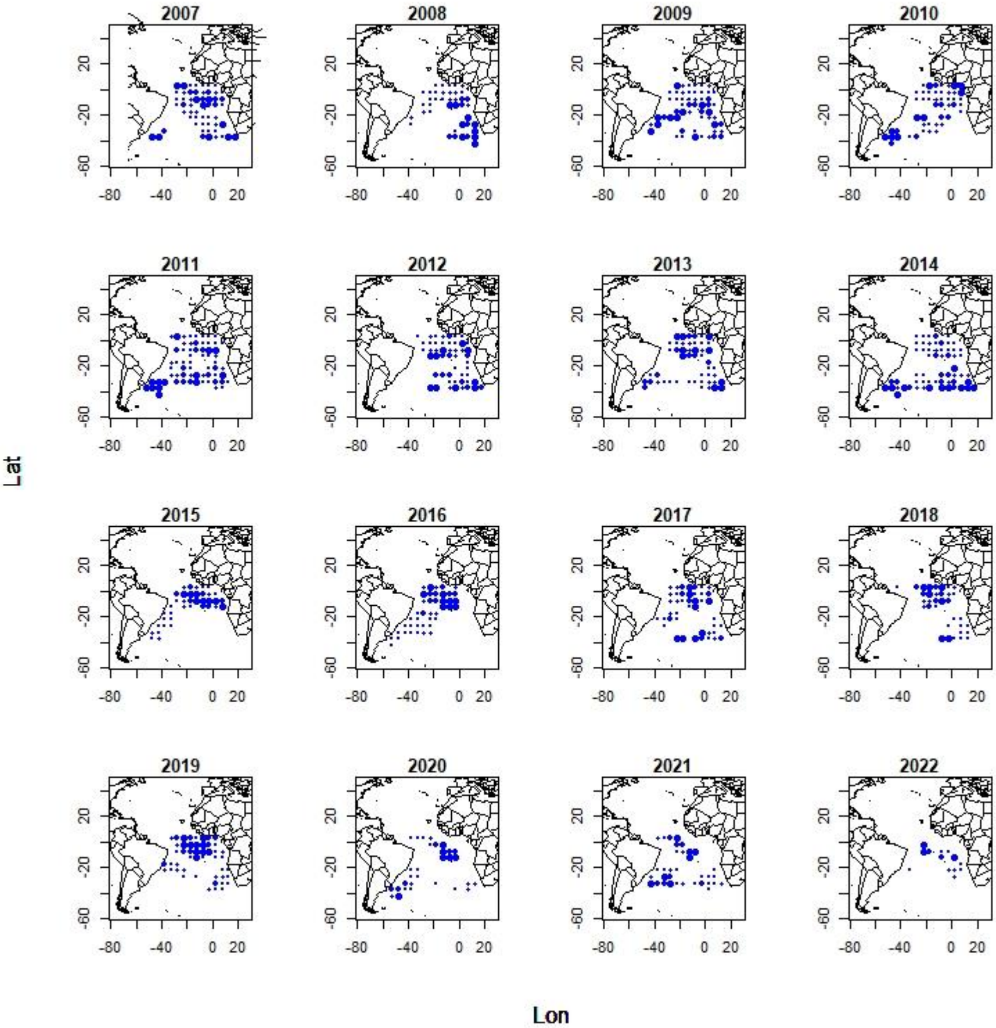

Figure 5. Nominal CPUE distribution of blue sharks caught by the Chinese Taipei large-scale tuna longline fishery in the South Atlantic Ocean from 2007-2022.

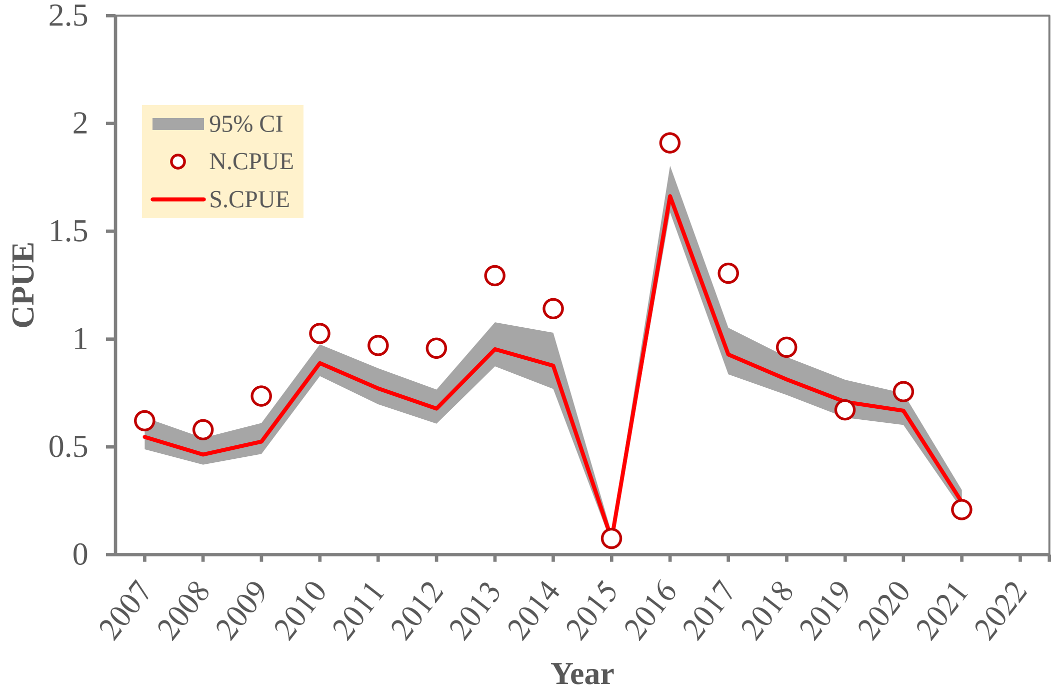

Figure 6. Nominal and standardized CPUE with 95% confidence interval of the blue shark caught by the Chinese Taipei large-scale longline fishery in the North Atlantic Ocean from 2007 to 2021.

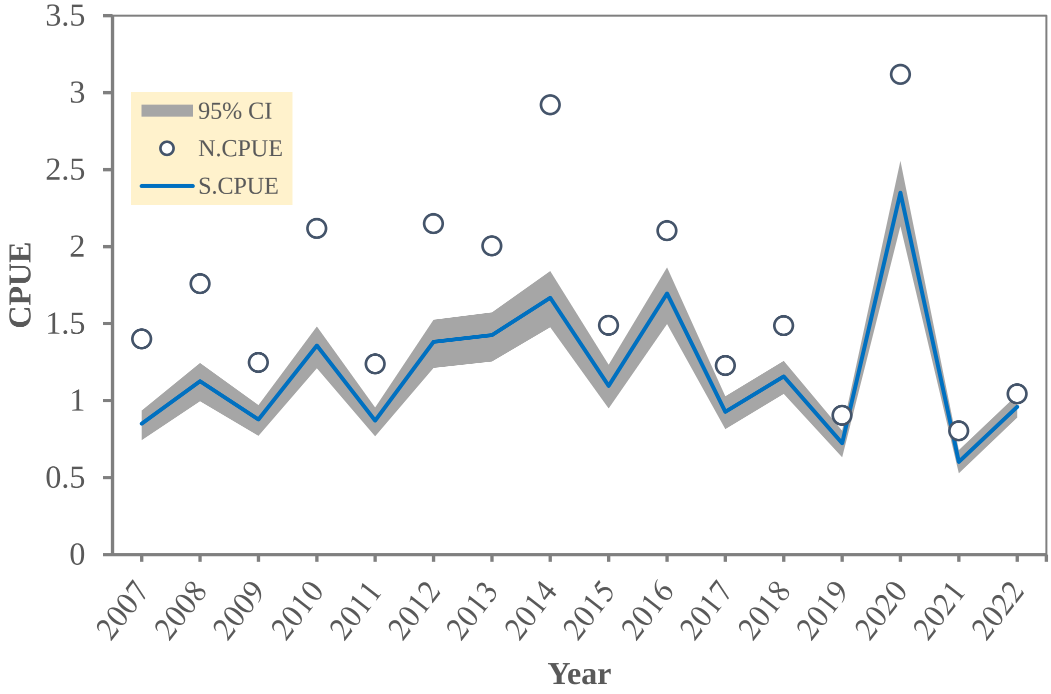

Figure 7. Nominal and standardized CPUE with 95% confidence interval of the blue shark caught by the Chinese Taipei large-scale longline fishery in the South Atlantic Ocean from 2007 to 2022.

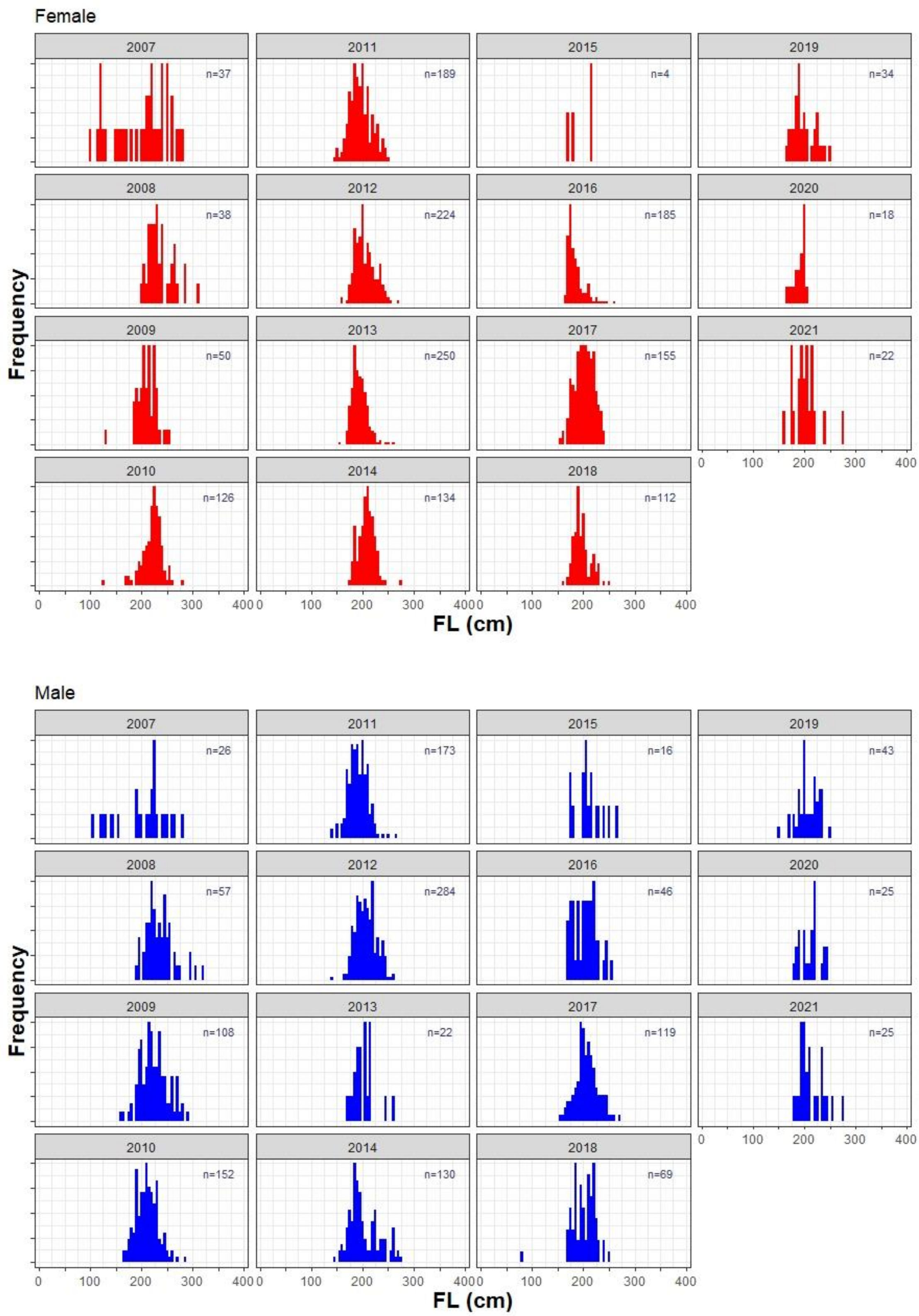

Figure 8. The fork length (FL) frequency distribution of blue sharks caught by the Chinese Taipei large-scale longline fishery in the North Atlantic Ocean from 2007-2021.

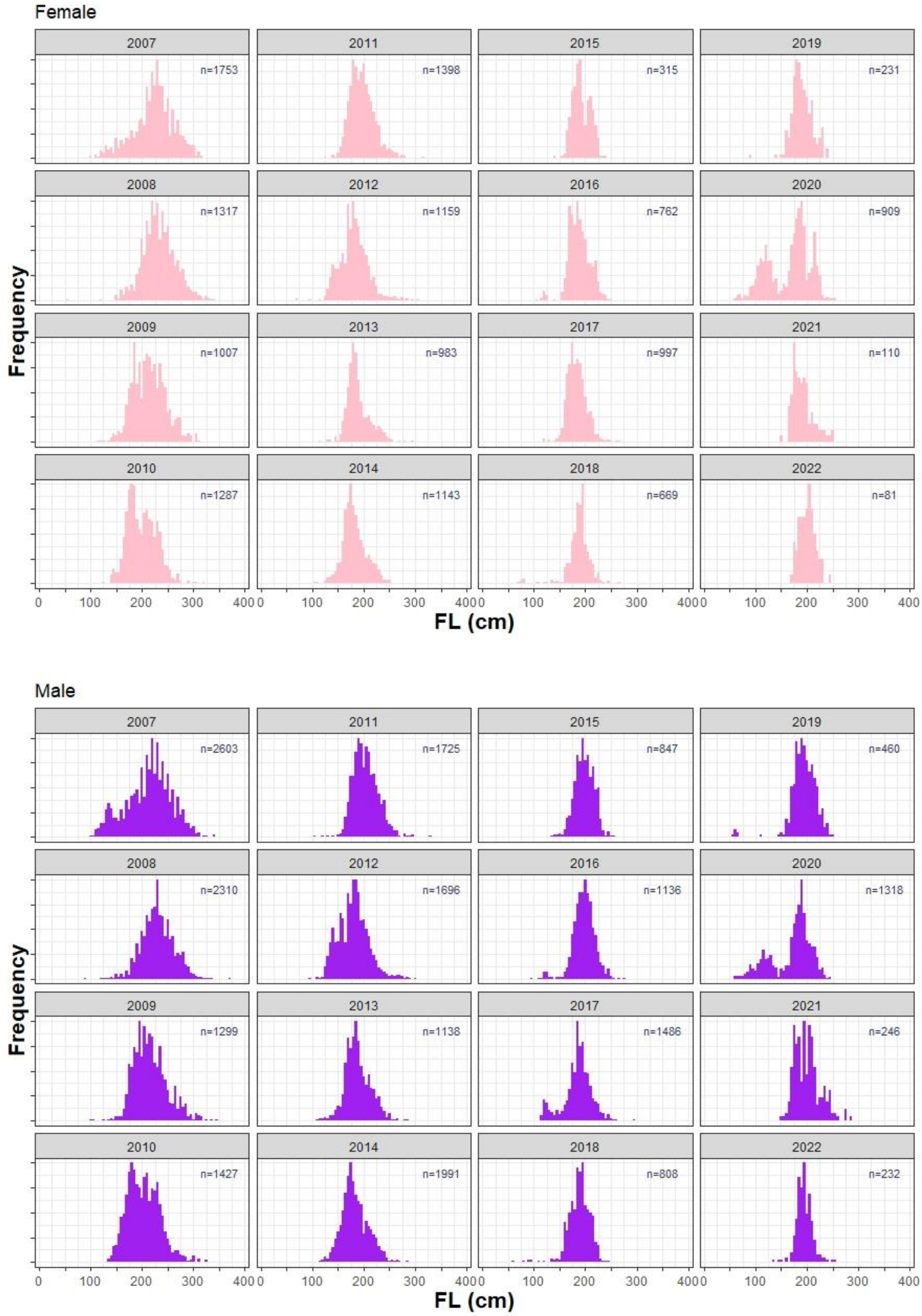

Figure 9. The fork length (FL) frequency distribution of blue sharks caught by the Chinese Taipei large-scale longline fishery in the South Atlantic Ocean from 2007-2022.

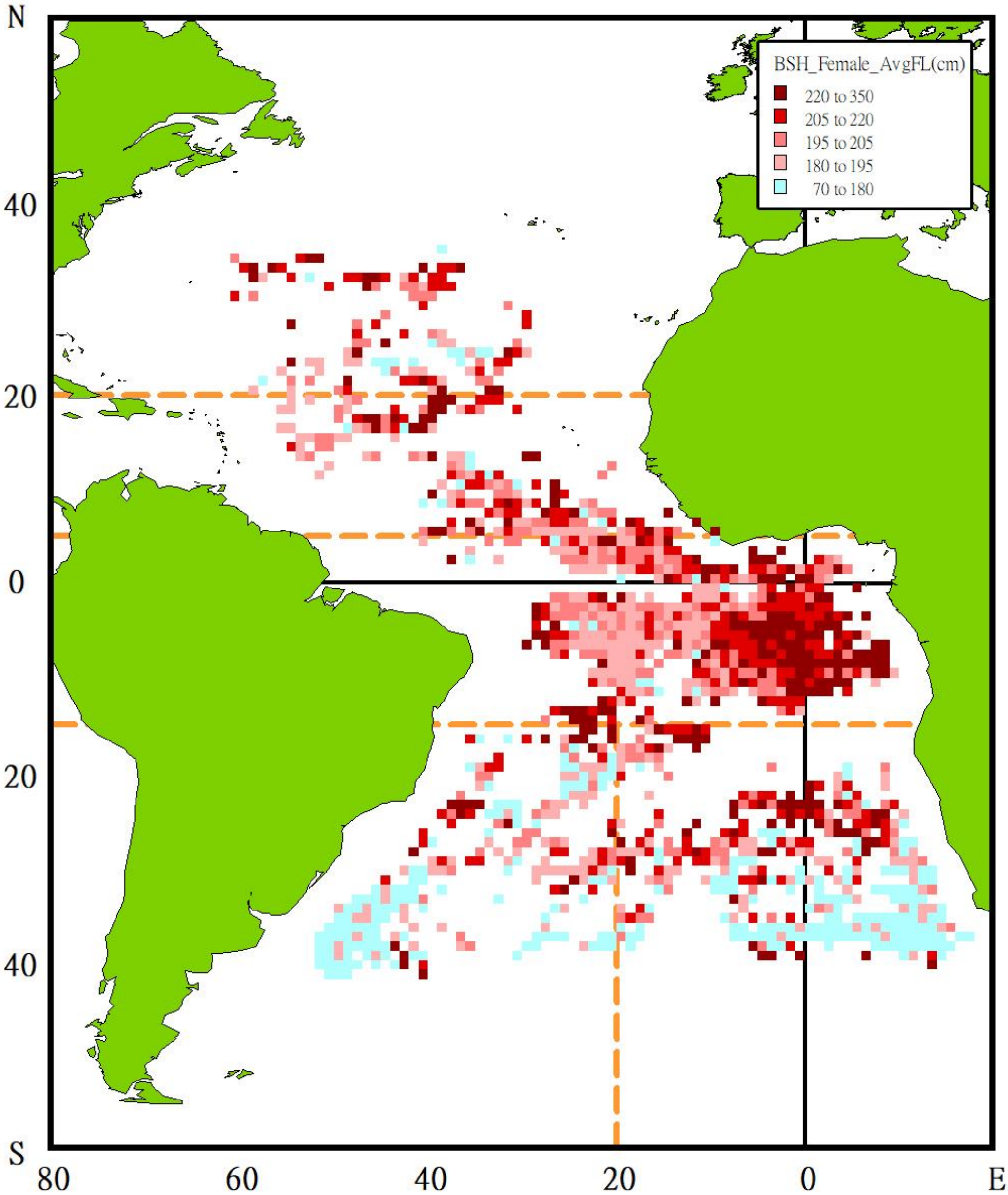

Figure 10. Sampling location and mean size (FL, cm) of female blue shark (*Prionace glauca*) recorded by observers onboard the Chinese Taipei large-scale longline fishing vessels in the Atlantic.

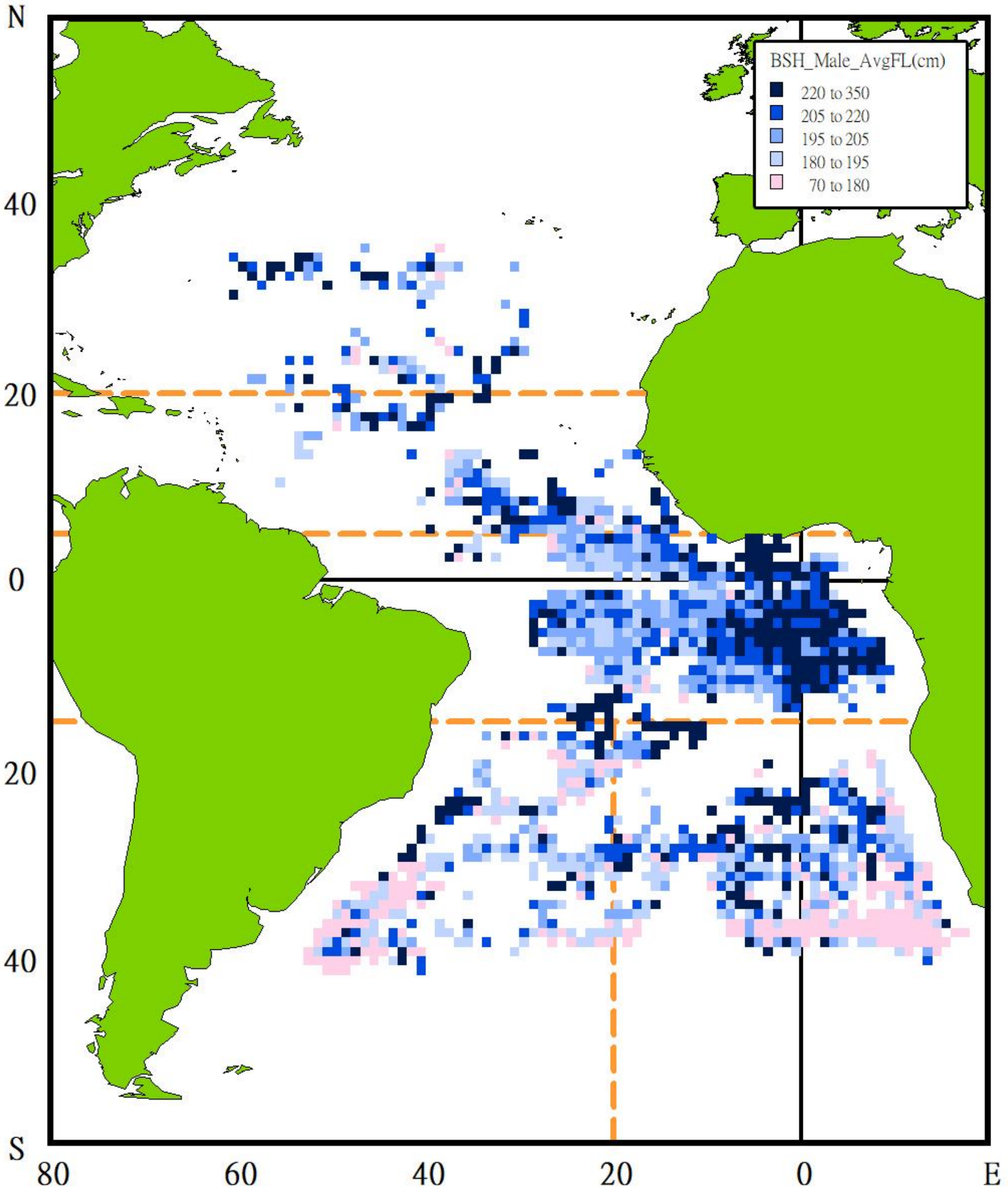

Figure 11. Sampling location and mean size (FL, cm) of male blue shark (*Prionace glauca*) recorded by observers onboard the Chinese Taipei large-scale longline fishing vessels in the Atlantic.

Table 1. Deviance tables for the Delta-lognormal GLM model of the blue shark in the North Atlantic Ocean

Lognormal model (positive catch):

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*F*	*Pr(>F)*	
NULL			1502	811.9			
yy	14	67.119	1488	744.78	10.3046	< 2.2e-16	***
A	1	7.457	1487	737.32	16.028	6.55E-05	***
GRP	1	9.1	1486	728.22	19.5585	1.05E-05	***
LON	1	6.101	1485	722.12	13.1134	0.0003031	***
LAT	1	8.859	1484	713.26	19.0423	1.37E-05	***
A:Q	6	16.41	1478	696.85	5.8785	4.50E-06	***
Q:HPB	4	11.074	1474	685.78	5.9504	9.49E-05	***

Binomial model:

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*F*	*Pr(>F)*	
NULL			3033	4205.8			
yy	14	425	3019	3780.8	30.3575	< 2.2e-16	***
Q	3	12.76	3016	3768	4.2539	0.005182	**
A	1	31.9	3015	3736.1	31.8951	1.63E-08	***
HPB	1	91.76	3014	3644.3	91.764	< 2.2e-16	***
GRP	1	5.54	3013	3638.8	5.5428	0.018557	*
LAT	1	7.08	3012	3631.7	7.0814	0.007789	**
Q:HPB	3	64.13	3009	3567.6	21.3776	7.69E-14	***
Q:GRP	3	30.11	3006	3537.5	10.0382	1.31E-06	***

Table 2. Deviance tables for the Delta-lognormal GLM model of the blue shark in the South Atlantic Ocean.

Lognormal model (positive catch):

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*F*	*Pr(>F)*	
NULL			15983	12776			
yy	15	916.31	15968	11859	87.2671	< 2.2e-16	***
Q	3	403.7	15965	11456	192.24	< 2.2e-16	***
A	2	10.82	15963	11445	7.731	0.0004407	***
HPB	1	3.89	15962	11441	5.5546	0.018444	*
GRP	1	55.61	15961	11385	79.4438	< 2.2e-16	***
LAT	1	74.82	15960	11310	106.8838	< 2.2e-16	***
Q:A	6	60.97	15954	11249	14.5166	< 2.2e-16	***
Q:HPB	3	14.25	15951	11235	6.7865	0.0001438	***
A:GRP	2	16.18	15949	11219	11.5575	9.65E-06	***
HPB:GRP	1	55.37	15948	11164	79.0966	< 2.2e-16	***

Binomial model：

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*F*	*Pr(>F)*	
NULL			23907	30372			
yy	15	814.2	23892	29558	54.2803	< 2.2e-16	***
Q	3	169.49	23889	29389	56.4957	< 2.2e-16	***
A	2	16.25	23887	29372	8.1273	0.0002954	***
HPB	1	59.79	23886	29313	59.7869	1.06E-14	***
GRP	1	185.46	23885	29127	185.4557	< 2.2e-16	***
LAT	1	22.82	23884	29104	22.8189	1.78E-06	***
Q:A	6	122.43	23878	28982	20.4058	< 2.2e-16	***
Q:HPB	3	65.31	23875	28917	21.7698	4.31E-14	***
Q:GRP	3	21.2	23872	28895	7.066	9.58E-05	***
A:HPB	2	46.59	23870	28849	23.2943	7.65E-11	***
A:GRP	2	7.88	23868	28841	3.9392	0.0194641	*
HPB:GRP	1	9.04	23867	28832	9.0411	0.0026397	**

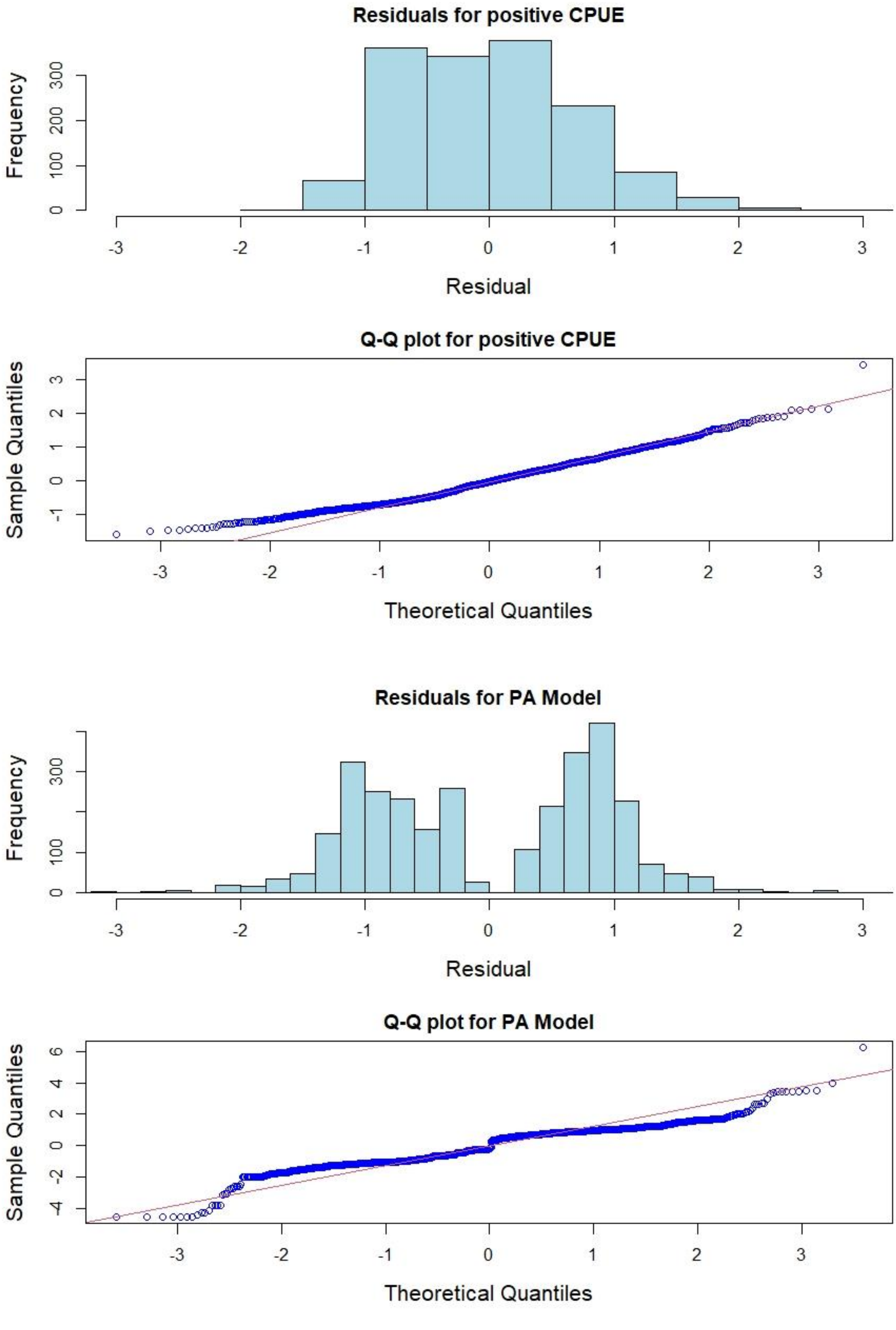

Figure 1. Diagnostic results from the lognormal model fit to the Chinese Taipei large-scale longline blue shark bycatch data in the North Atlantic Ocean.

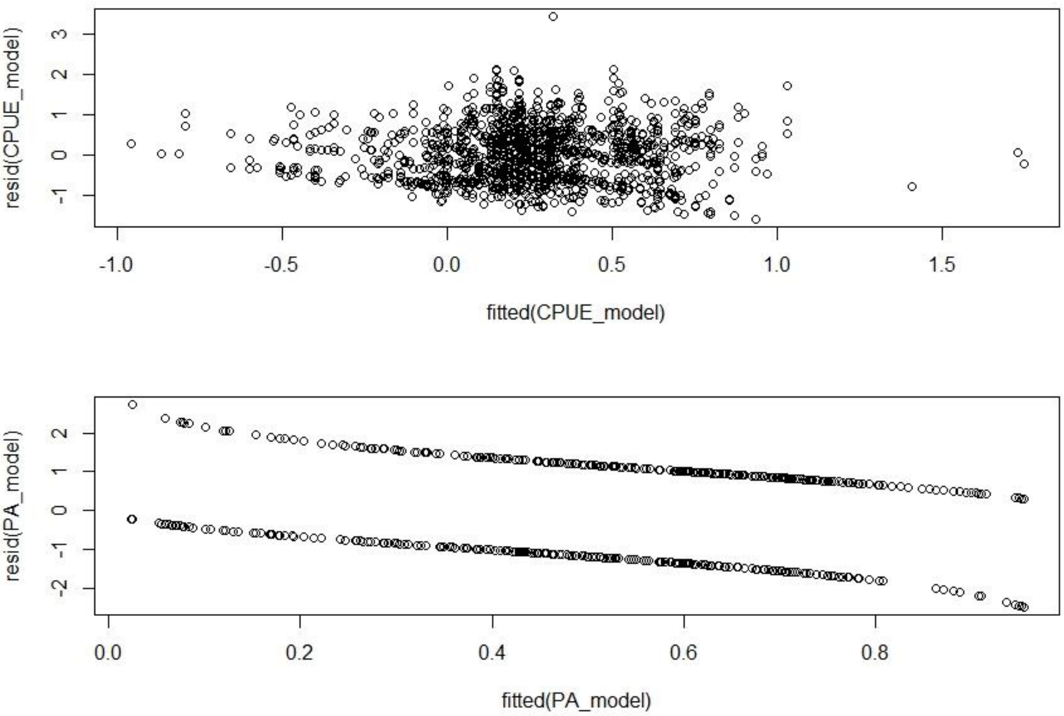

Figure 2. Residual plots for the DLN model fit to the Chinese Taipei large-scale longline blue shark bycatch data in the North Atlantic Ocean.

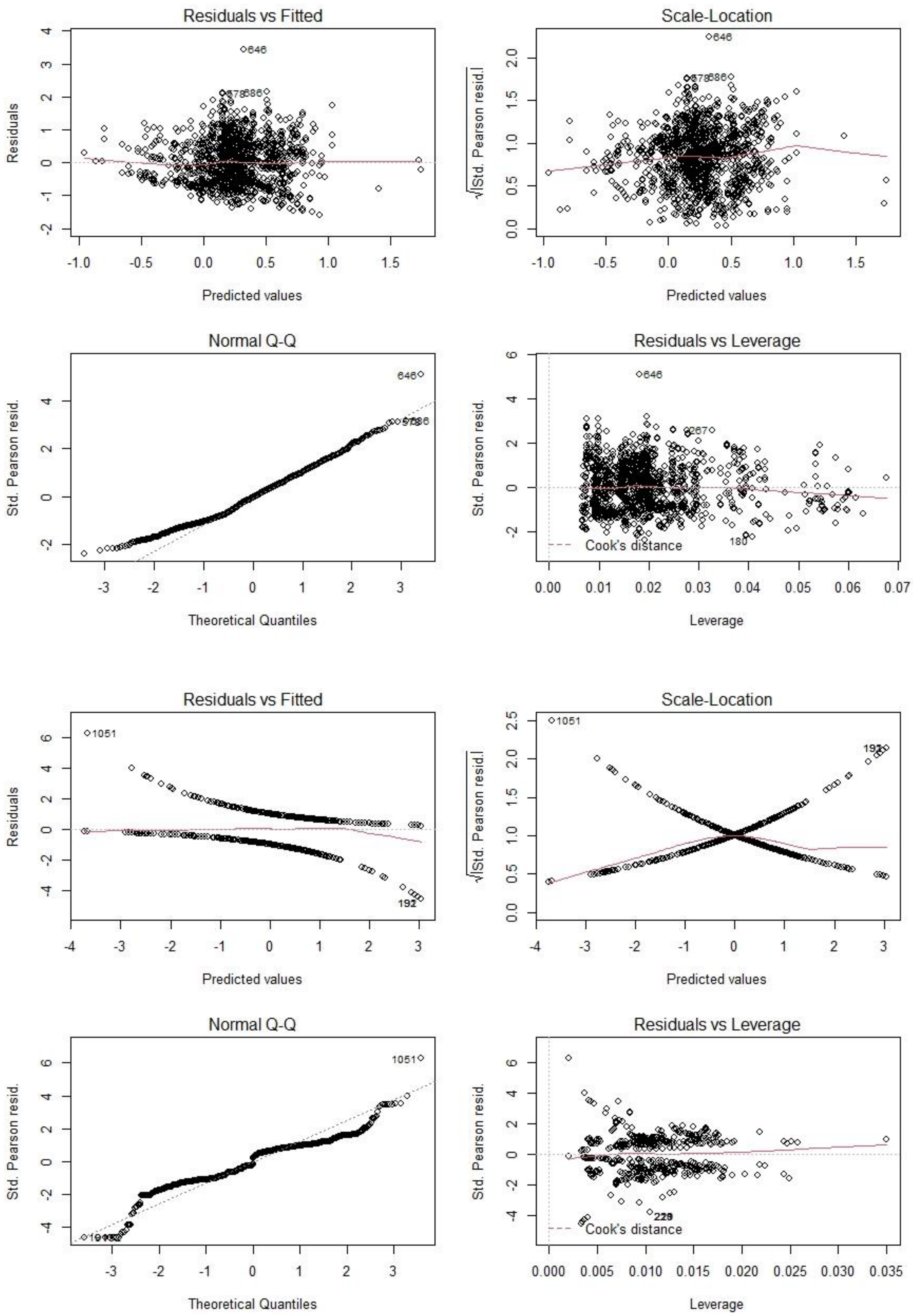

Figure 3. Residual plots for the GLM model fit to the Chinese Taipei large-scale longline blue shark bycatch data in the North Atlantic Ocean.

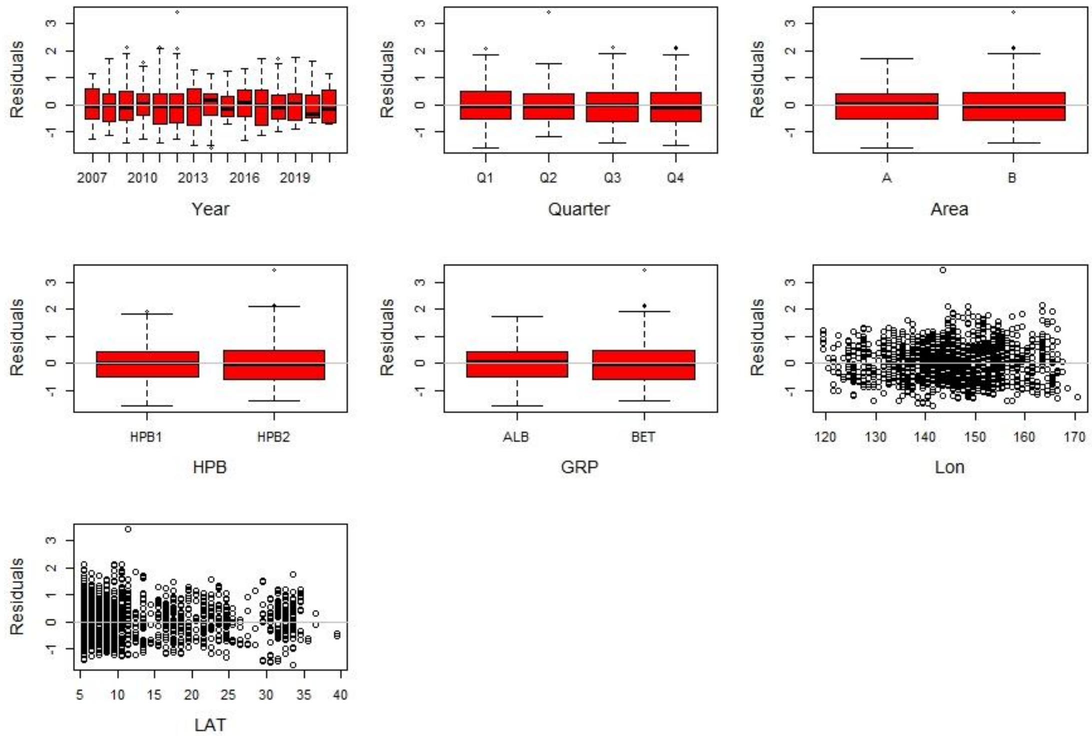

Figure 4. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area, HPB, GRP, Lon and Lat in the North Atlantic Ocean.

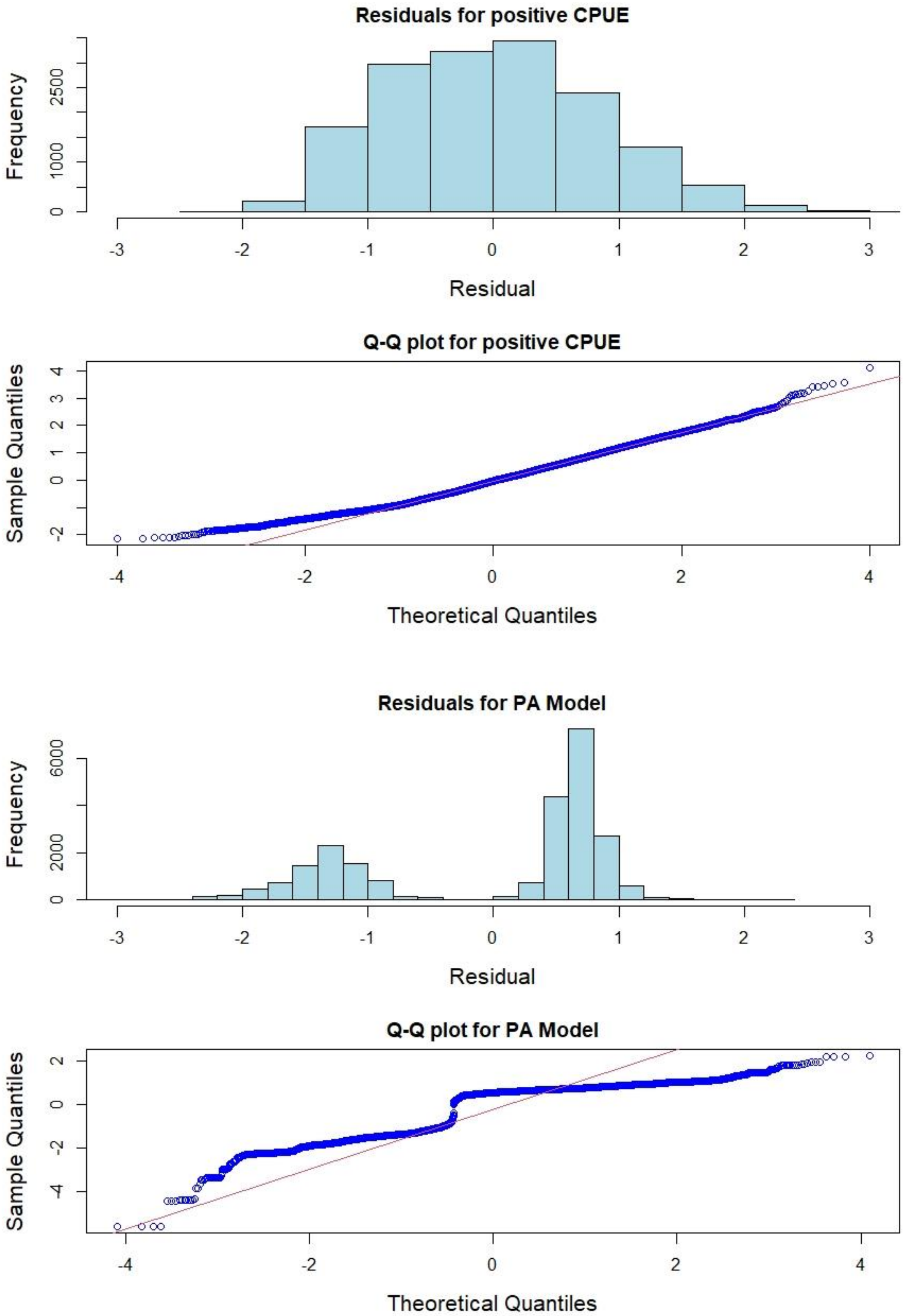

Figure 5. Diagnostic results from the lognormal model fit to the Chinese Taipei large-scale longline blue shark bycatch data in the South Atlantic Ocean.

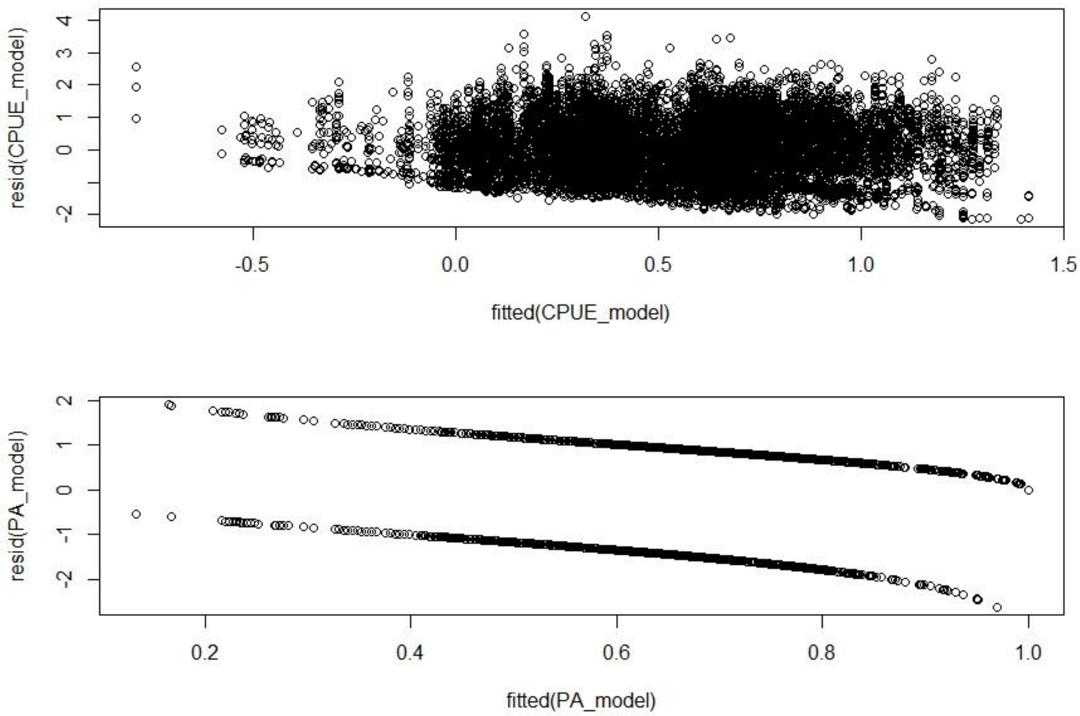

Figure 6. Residual plots for the DLN model fit to the Chinese Taipei large-scale longline blue shark bycatch data in the South Atlantic Ocean.

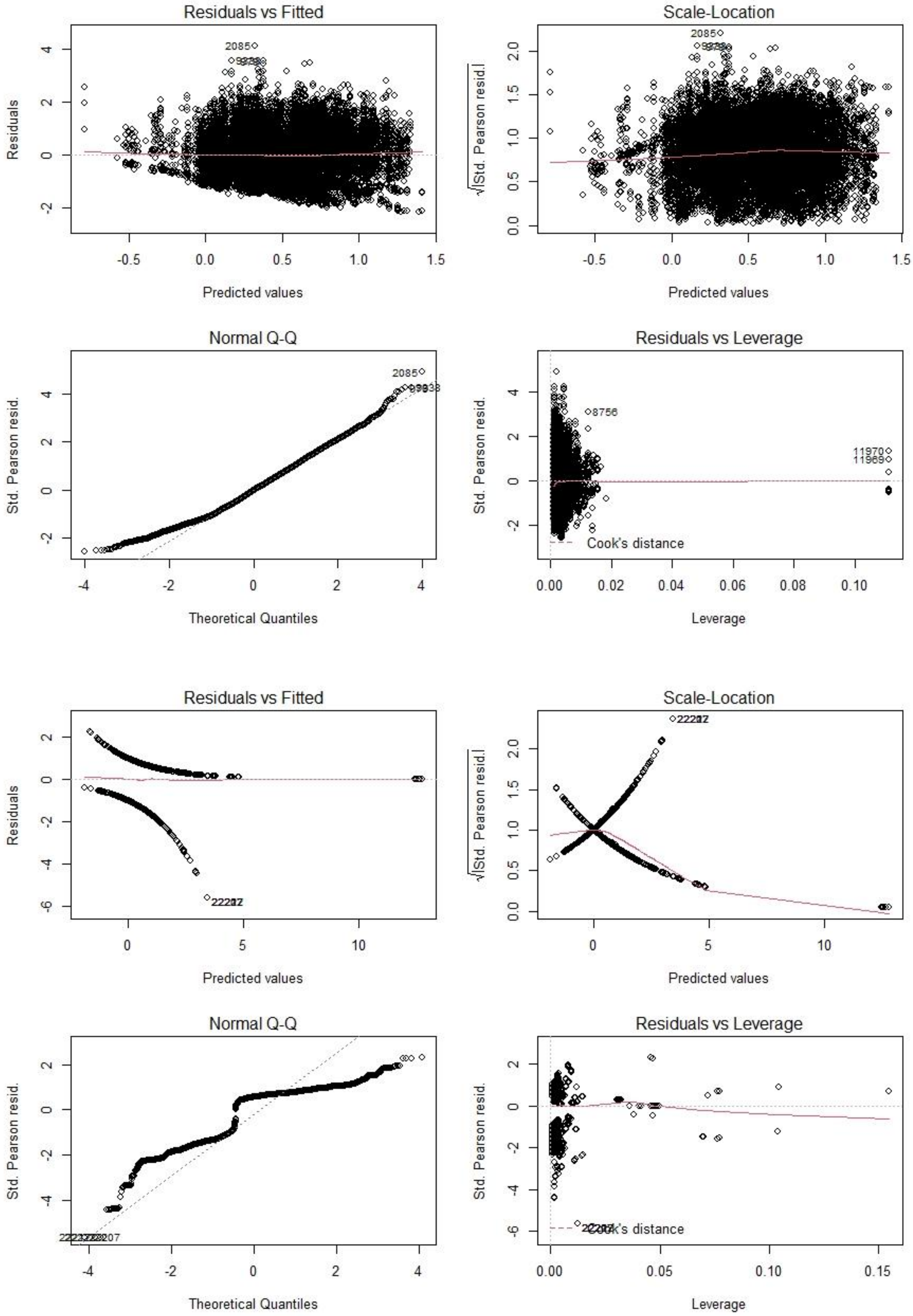

Figure 7. Residual plots for the GLM model fit to the Chinese Taipei large-scale longline blue shark bycatch data in the South Atlantic Ocean.

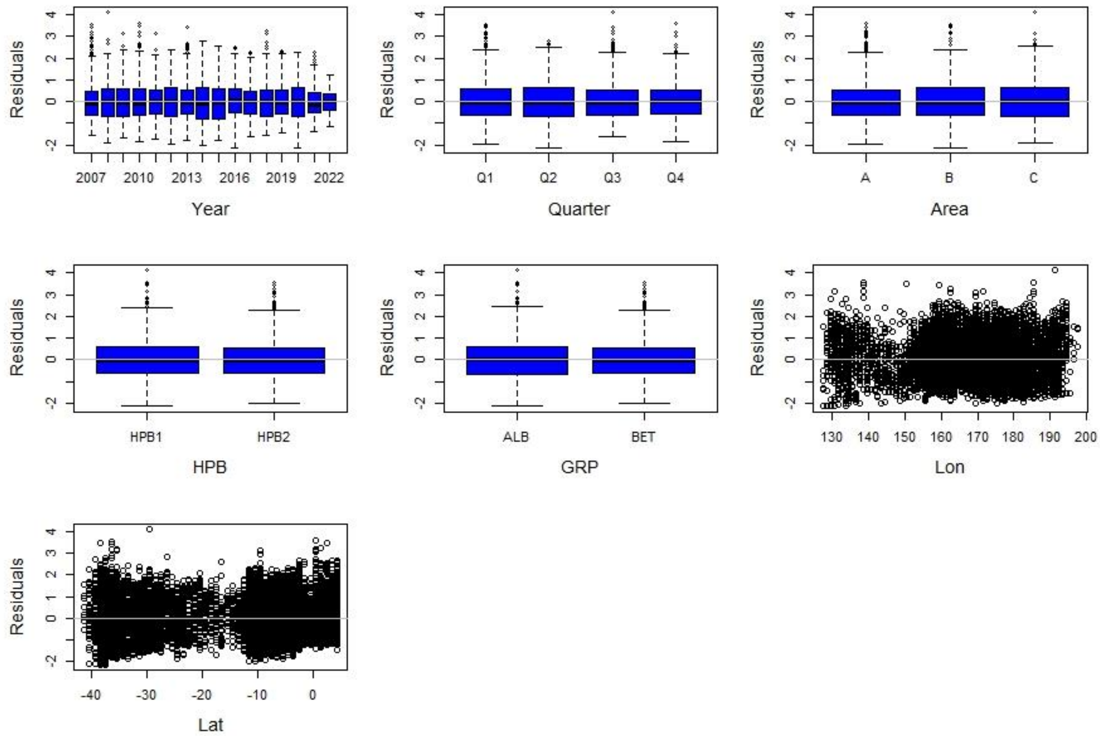

Figure 8. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area, HPB, GRP, Lon and Lat in the South Atlantic Ocean.