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UPDATE OF STANDARDIZED CPUE FOR BLUE SHARK CAUGHT BY THE JAPANESE TUNA LONGLINE FISHERY IN THE ATLANTIC OCEAN

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SUMMARY

The standardized CPUEs for blue shark caught by the Japanese tuna longline fishery in the Atlantic Ocean were updated using filtered logbook data during 1971-2012 whose reporting rates were more than 80%. Blue shark CPUE shows some fluctuations and relatively increasing trends since 1994 in the North, South and whole Atlantic stock hypotheses.

RÉSUMÉ

Les CPUE standardisées du requin peau bleue capturé par les palangriers japonais dans l'océan Atlantique ont été mises à jour en utilisant les données filtrées des carnets de pêche de 1971 à 2012 dont les taux de déclaration étaient supérieurs à 80 %. La CPUE du requin peau bleue affiche quelques fluctuations et des tendances relativement ascendantes depuis 1994 d'après les hypothèses concernant les stocks du Nord, du Sud et de l'ensemble de l'Atlantique.

RESUMEN

Las CPUE estandarizadas para la tintorera capturada por la pesquería atunera de palangre japonés en el Atlántico fueron actualizadas utilizando datos de los cuadernos de pesca filtrados durante 1971-2012 cuyas tasas de comunicación eran de más del 80%. La CPUE de la tintorera muestra algunas fluctuaciones y tendencias relativamente ascendentes desde 1994 en las hipótesis de stock del norte y del sur y de todo el Atlántico.

KEYWORDS

Atlantic Ocean, Blue shark, Prionace glauca, Japanese Longline, CPUE

1. Introduction

The standardized CPUEs of blue shark caught by the Japanese longline fishery in the Atlantic Ocean were reported in the previous document (Matsunaga 2009) using the filtering method which was introduced by Nakano and Honma (1997) and validated by Nakano and Clarke (2006). In this report, the standardized CPUEs for blue shark in the Atlantic Ocean during 1971 and 2012 were updated using the logbook data of the Japanese tuna longline fishery.

2. Material and methods

Log-normal model

Set-by-set logbook data from Japanese offshore and distant water longline fishery are used to standardize CPUEs for 1994-2012. The logbook data contain, for each set operation, information on latitude and longitude by 1×1 degree, day, month, year, catch in number of tunas, billfishes and sharks species, gear configurations such as a hooks per basket (HPB), ship name and the registered prefecture, fishery type such as offshore (Kinkai) longliner (vessel tonnage is 20-120 MT) and distant-water (Enyo) longliner (vessel tonnage is larger than 120 MT), and so on. The logbook data have been collected and compiled by the National Research Institute of Far Seas Fisheries since 1971. The logbook records in the early period from 1971 to 1993 contain only aggregated catch of shark species. The column of each species of sharks had been added to the data since 1994. Therefore, standardized CPUEs from 1971 through 1993 and from 1994 through 2012 were separately computed. The same filtering method of Nakano and Honma (1997) was adopted and data with reporting rates greater than 80% were used in this analysis. This reporting rate was recommended by Nakano and Clarke (2006). During 1971 through 1993, shark catches were not recorded by species, therefore all sharks are assumed to be blue sharks (Matsunaga 2009).

Standardized CPUEs (number of sharks caught per 1,000 hooks) were calculated using R to eliminate biases arising from differences in effort by fishing ground and fishing season etc. For standardization, CPUE was calculated for each operation. The area strata used for the analysis are shown in **Figure 1**. Numbers of branch line between floats were classified into three categories (< 9, 9-14, 14<). The CPUE value for blue shark was calculated for two geographical units, i.e. the north and south. The north unit includes Areas 1 to 4; the south unit includes Areas 5 to 7. The equations for standardizing CPUEs were as follows:

$$\ln(CPUE + const) = \mu + YR + QT + AR + BR + INTERA + \varepsilon$$

where ln: natural logarithm, CPUE: nominal CPUE (catch in number per 1,000 hooks), const :a constant value of 0.1 which is same as the value in Matsunaga (2009), μ: intercept, YR: year effect, QT: quarter effect, AR: area effect, BR: branch line effect, INTERA: any combination of two way interactions, and ε: normal error term.

The final model for the CPUE analysis was decided by the AIC values, and the selected model for each data set was;

1975-1993 for the northern stock (**Table 1**):

$$\ln(CPUE + const) = \mu + YR + QT + AR + BR + BR*QT + YR*QT + \varepsilon$$

1975 – 1993 for the southern stock:

$$\ln(CPUE + const) = \mu + YR + QT + AR + BR + BR*QT + YR*QT + \varepsilon$$

1994 – 2012 for the northern stock;

$$\ln(CPUE + const) = \mu + YR + QT + AR + BR + BR*QT + AR*BR + YR*BR + YR*QT + AR*QT + \varepsilon$$

1994 – 2012 for the southern stock;

$$\ln(CPUE + const) = \mu + YR + QT + AR + BR + BR*AR + YR*QT + AR*QT + \varepsilon$$

Some interactions for northern and southern stock are not available due to the shortage of the data.

Negative binominal model

Same data set as the log-normal model was used. Standardized CPUEs for 1971-2012 are computed using the logbook data after the data correction and filtering. Same classification of the number of branch line and same area stratification as the log-normal model were used (**Figure 1**). The generalized linear model (GLM) with negative binomial error distribution as follows;

$$Catch = YR + QT + AR + BR + INTERA + offset(\log(Effort)) + Error(NB),$$

where, Catch: expected catch in number of blue shark, YR: year effect, QT: season effect, AR: area effect, BR: branch line effect, Effort: number of 1000 hooks, Error (NB): negative binomial error distribution through a log link function.

For the CPUE standardization, the same interaction terms as the log-normal model were incorporated.

3. Results and Discussions

Catch and effort observation of Japanese longliners are widely covered the tropical to temperate area of the Atlantic (**Figure 2**), though its coverage largely shrunk in recent years due to the reduction of total effort (**Figure 3** bottom). Log-book reported catch of blue shark increased largely in recent years **(Figure 3** top) and this is primarily due to the fact that Japanese government promoted effective use of sharks (Fishery Agency, 2009). Especially in 2008, Japan demanded its longliners to land all the parts of sharks in possession in order to promote effective utilization of all the usable parts of sharks. Annual changes of coverage of filtered set by set data by reporting ratio (> 80%) of blue shark in the northern and southern Atlantic Ocean have increased since the mid 2000th (**Figure 4**). This indicates the coverage of reliable shark catch and effort data increased largely in recent years, and this seems at least partially complement recent decrease of the number of data caused by effort declining.

Figures 5 and 6 show the nominal CPUEs and the CPUEs standardized using the log-normal model with 95% confidence intervals of blue shark in the early (1971-1993) and late (1994-2012) periods, respectively. The values of CPUE ranged from 0.8 to 9.2 and were in the range of CPUE values reported by onboard observers in the longline fishery in the Atlantic Ocean (Senba and Nakano 2004). The results from the analysis using Japanese logbook data indicate relatively stable levels with slightly increasing trends both of the North and South unit, but the recent increasing trend of the standardized CPUEs were milder than those of the nominal ones. The standardized CPUEs from 1971 to 1993 in the North and South unit were 0.87-2.43 and 1.29-4.97, respectively. From 1994 to 2012, the ranges of the standardized CPUE in the North and South unit were 0.67-1.63 and 0.69-1.78, respectively.

In addition, the CPUEs standardized by the negative binominal model (**Figure 7 and 8**), and the comparison among the nominal and the standardized CPUEs by two different models are shown (**Figure 9**). Though the range of the estimated CPUE values of the negative binominal model are also within the range of CPUEs reported by the on-board observers (Senba and Nakano 2004), the general trends of the CPUEs standardized by the negative binominal model are bit different from the ones by the log-normal model, and they are closer to those of the nominal CPUEs. Shono (2008) reported that the log-normal model is rather ad-hoc method due to the weak statistical bases especially for the selection of the constant values added to each observation, and the data sets with higher than 20 % of zero catch ratios cannot be applied. The zero catch ratio of the data set used in this study is about 18 % in average. Though Matsunaga (2009) used the log-normal model with the constant value of 0.1 in the previous study, the negative binominal model in this study should have better statistical soundness. **Figure 10** shows the example of the effect of the addition of different constant values. The overall trends of standardized CPUEs seemed not largely changed by the constant values but the level of CPUE changed largely.

The detailed information of the CPUE standardization such as the numerical values of the estimates, ANOVA tables, and the diagnostics, is given in the Appendix tables and figures.

In the north Atlantic, high CPUE of blue shark obtained in the higher latitudinal areas (35N – 50N) along with the northern extension of the Gulf stream as well as the North Atlantic Drift where Japanese longliners historically targeting bluefin tuna and bigeye tuna (**Figure 2**). Distribution pattern of average weight (left bottom panel of **Figure 2**) show the lowest average weight (less than 10 kg) obtained in these area, especially northeastern part of them (10W – 30W). This suggests the fact that these areas are the nursery grounds of juvenile blue sharks. Because of the relatively shorter fishing seasons of these areas, the amount of effort of these areas has been limited historically, and the efforts (number of hooks) in the north Atlantic have decreased (**Figure 3**). This would allow some ranges of survivors of juvenile blue sharks in the north Atlantic. In addition, the amount of effort of these fishing grounds largely decreased in recent years mainly due to the worse stock conditions of some of major tuna and billfish species such as bluefin tuna and swordfish. This would cause the increase of the standardized CPUEs of blue sharks in the north Atlantic.

In the south Atlantic, standardized CPUEs of blue shark show gradual decreasing trend up to 2003 and then, reversed. The general trend of CPUE in the period of 1994 – 2012 was similar to that of the northern stock. This would be due to the decrease of the amount of effort in the high latitudinal areas where Japanese longliners targeting southern bluefin tuna as well as bigeye tuna. In the north Pacific, it was shown that the apparent habitat segregation of blue shark by sex and growth stage (Nakano and Seki, 2003), and thus the distribution and migration pattern of blue shark in the Atlantic should be reviewed with the extensive cooperative study of sexed size data in the future.

Figure 11 shows the annual trends of the reported average weight of blue shark caught by Japanese longliners in the period of 1994 and 2012. The observed apparent increasing trend seen in both stock would be reflected relative large decrease of the amount of catches in the higher latitudinal area in both the north and the south Atlantic where smaller fishes mainly caught than those in the tropical area. Also, rather lower values during earlier period supposed to be partially reflecting the historical change of the processing form of blue shark or reporting way of catch amount of blue shark (Okamoto, personal comm.). In addition, this catch does not include amount of the dead discard and amount of fish died after live release especially for the periods before 2008. These amounts should be estimated for the stock assessment. Also the total mortality in the past should be revisited.

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Table 1. Standardized CPUE and 95% confidence intervals for blue shark based on the logbook data of Japanese longline fishery in the North, South and whole Atlantic Ocean.

1-a Summary of the step-AIC for the northern stock from 1971 to 1993.

	Df	Deviance	AIC
None		28051	67685
-as.factor(area)	3	28178	67778
-as.factor(qt):as.factor(hpbc)	6	28317	67879
-as.factor(year.x):as.factor(qt)	66	29523	68671

1-b Summary of the step-AIC for the southern stock from 1971 to 1993.

	Df	Deviance	AIC
None		33875	86305
-as.factor(qt):as.factor(hpbc)	6	34099	86482
-as.factor(qt):as.factor(area)	6	34116	86497
-as.factor(year.x)	22	36503	88406

1-c Summary of the step-AIC for the northern stock from 1994 to 2012.

	Df	Deviance	AIC
None		119654	241572
-as.factor(qt):as.factor(hpb)	6	120096	241825
-as.factor(area):as.factor(hpb)	6	120150	241858
-as.factor(year):as.factor(hpb)	36	120487	242000
-as.factor(year):as.factor(qt)	54	121925	242820
-as.factor(year):as.factor(area)	54	122688	243270

1-d Summary of the step-AIC for the southern stock from 1994 to 2012.

	Df	Deviance	AIC
None		73467	146854
-as.factor(area):as.factor(hpb)	4	74005	147164
-as.factor(year):as.factor(qt)	54	76794	148681

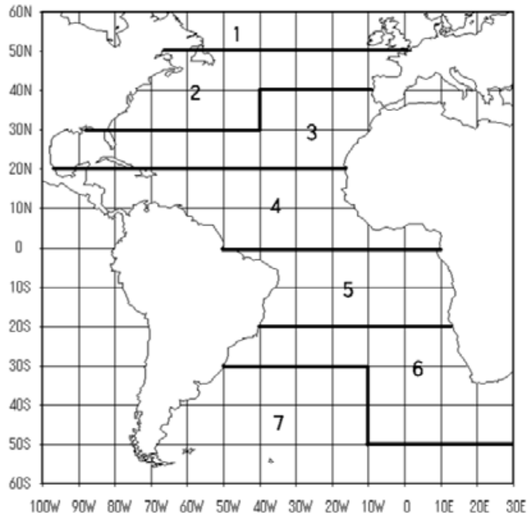

Figure 1. Area stratification of the Atlantic Ocean used for the analyses (Matsunaga 2009).

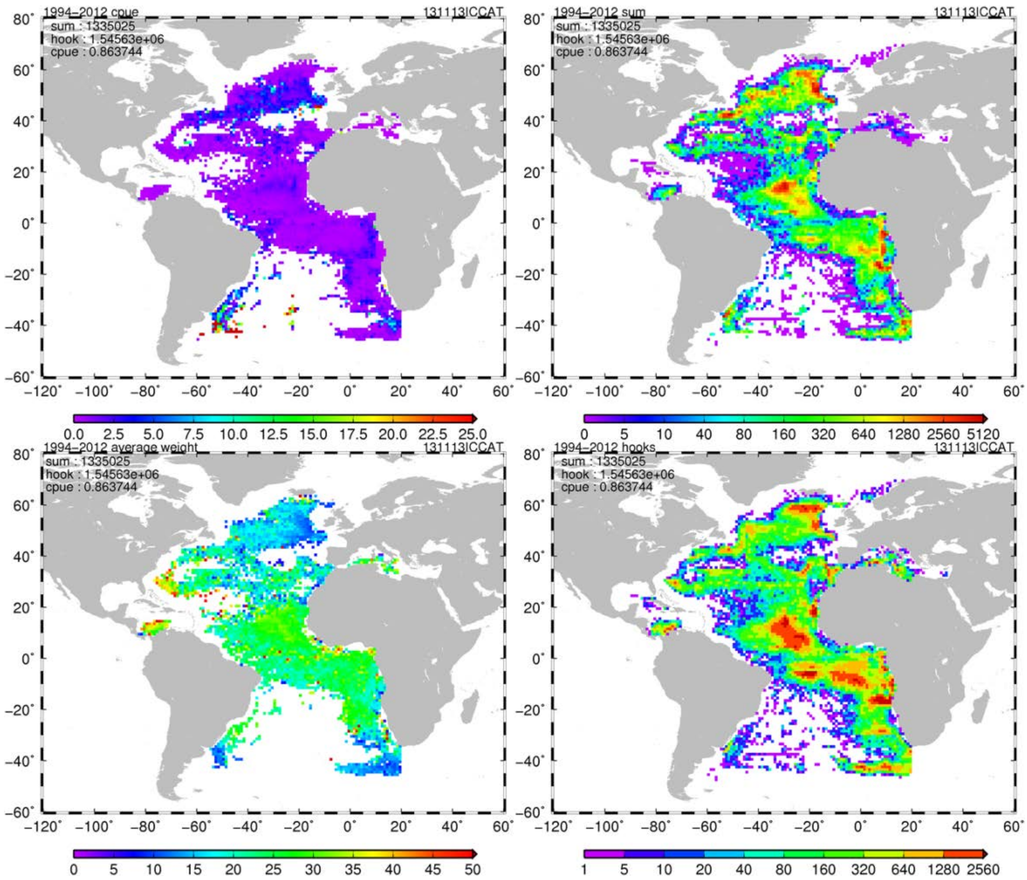

Figure 2. Average distribution pattern of reported CPUE (n / 1000 hooks) for blue shark (left top panel), sum of reported catch in number of blue shark (right top panel), average weight (kg, left bottom panel) and sum of hooks in number of Japanese longliners in the period between 1994 and 2012.

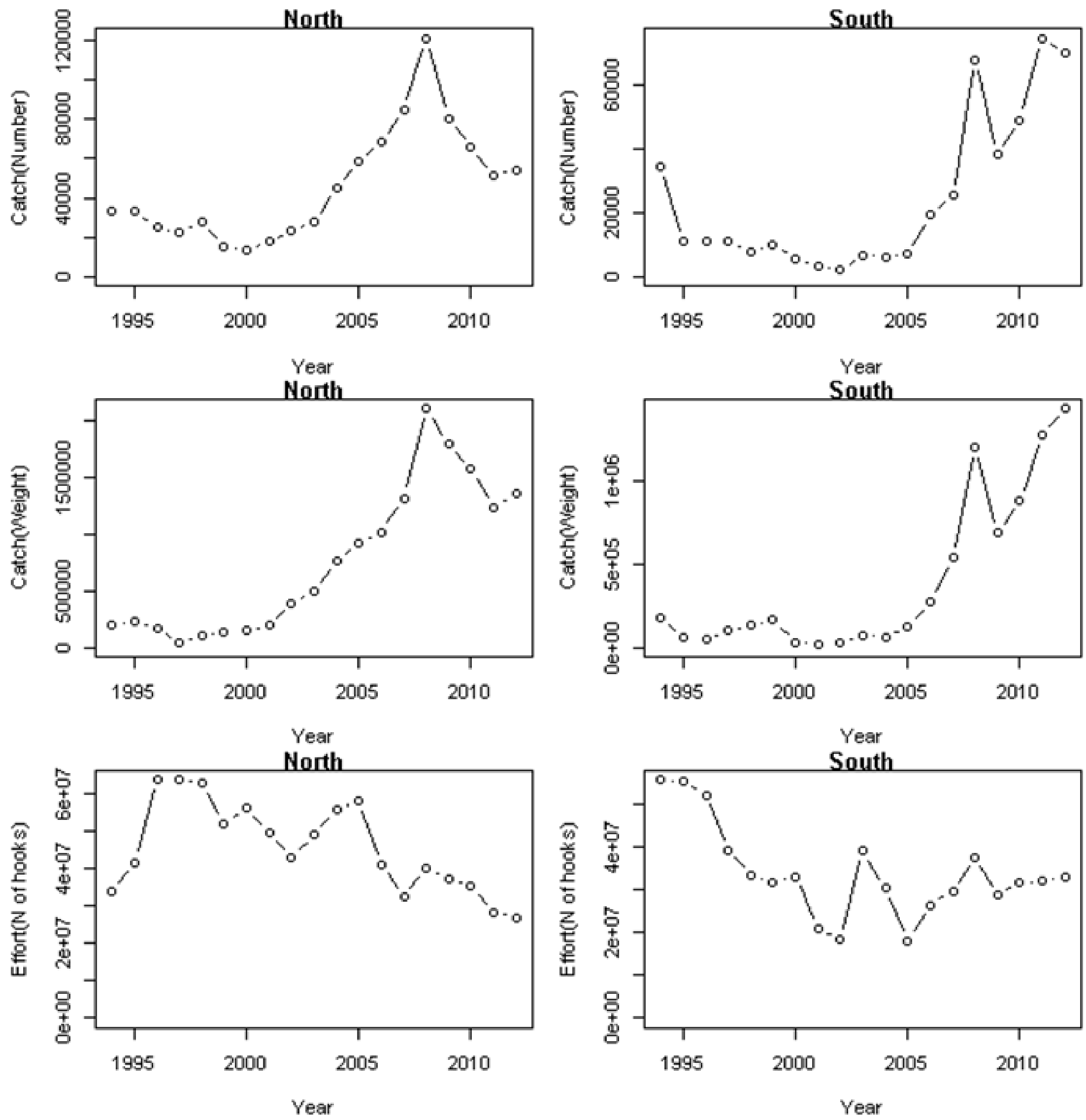

Figure 3. Annual changes of the reported catch in number of blue shark by Japanese longliners (top panels), reported catch in amount (kg, not filtered, middle panels) and nominal effort (not filtered, bottom panels) of Japanese longliners in the Atlantic by north and south stock during 1994 to 2012.

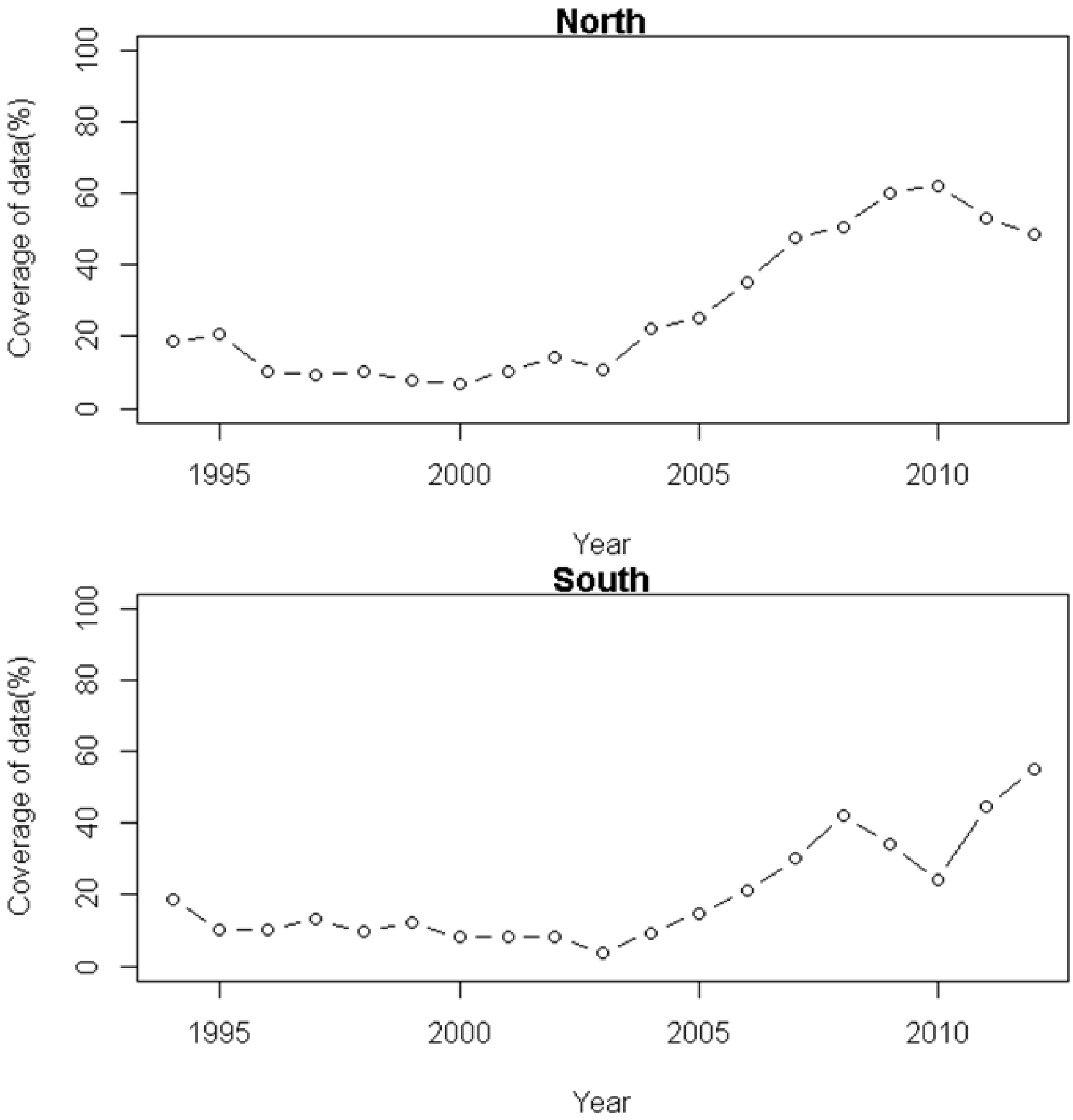

Figure 4. Annual changes of coverage (%) of filtered set by set data by reporting ratio of blue shark catch for the northern and southern stocks from 1994 to 2012.

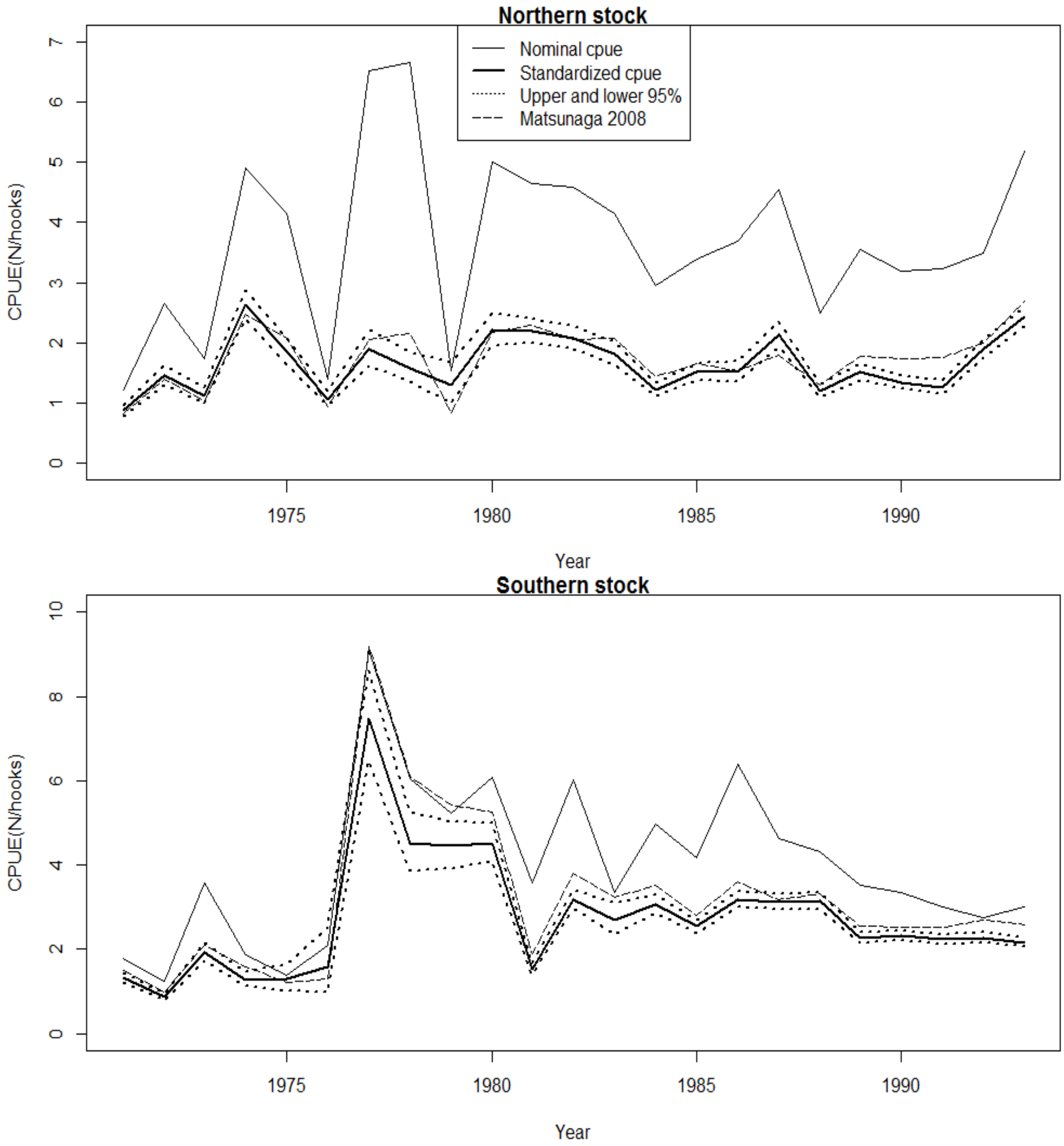

Figure 5. Nominal and standardized CPUE (Number of blueshark / 1000 hooks) estimated by lognormal model with 95% confidence intervals for the northern (upper figure) and southern (lower figure) stocks from 1971 to 1993.

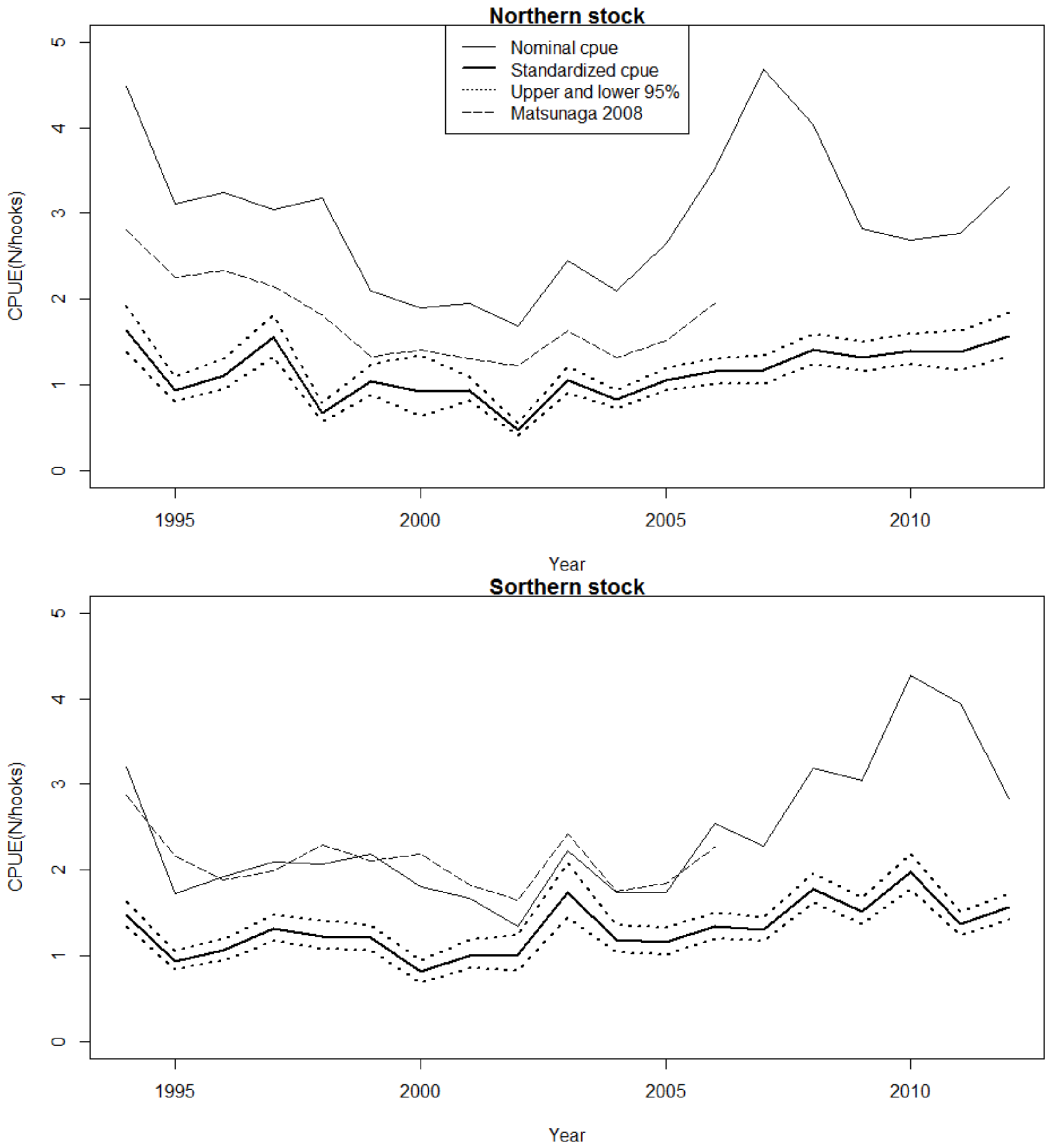

Figure 6. Nominal and standardized CPUE (Number of blueshark / 1000 hooks) estimated by lognormal model with 95% confidence intervals for the northern (upper figure) and southern (lower figure) stocks from 1994 to 2012.

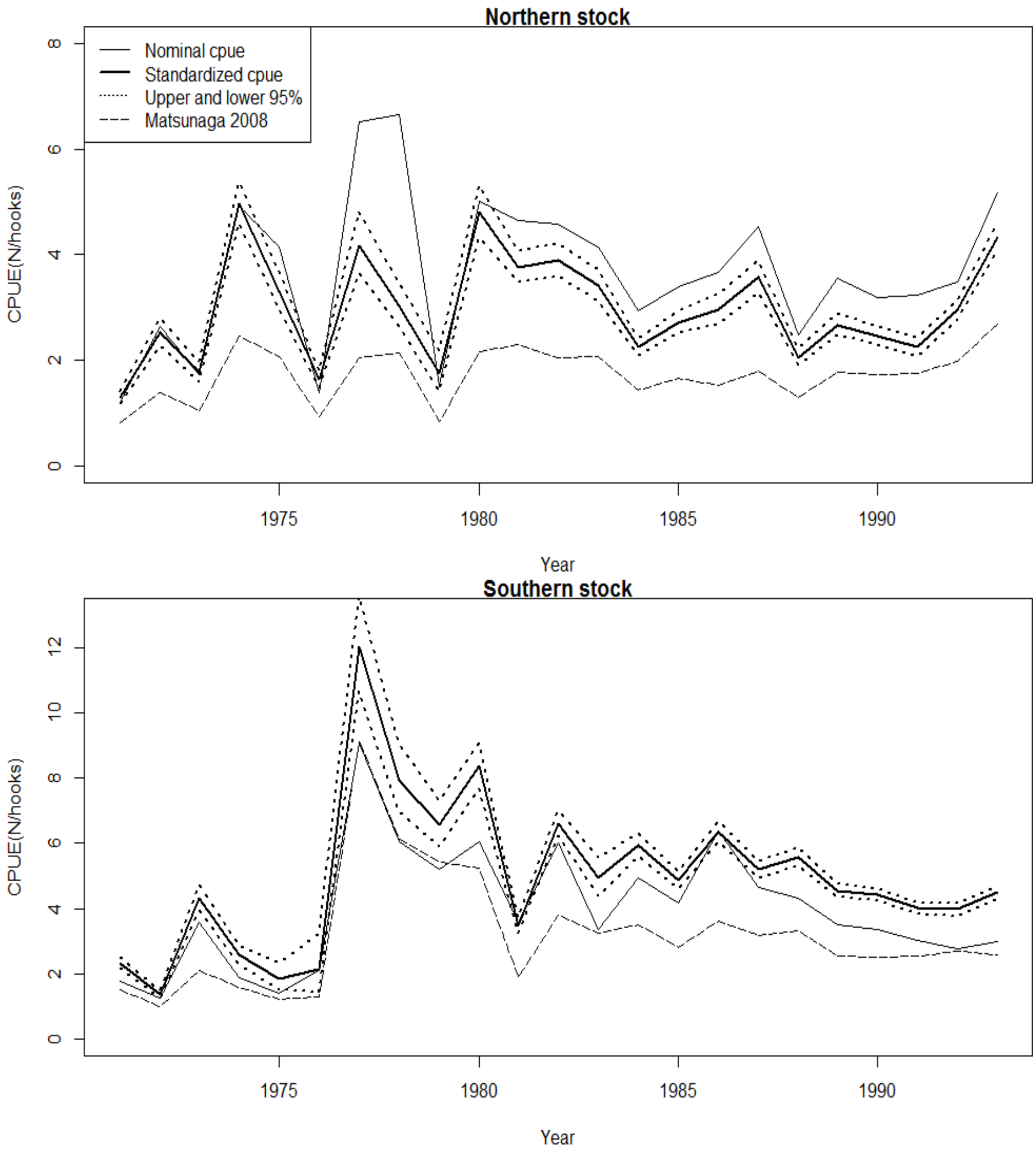

Figure 7. Nominal and standardized CPUE (Number of blueshark / 1000 hooks) estimated by negative binomial model with 95% confidence intervals for the northern (upper figure) and southern (lower figure) stocks from 1971 to 1993.

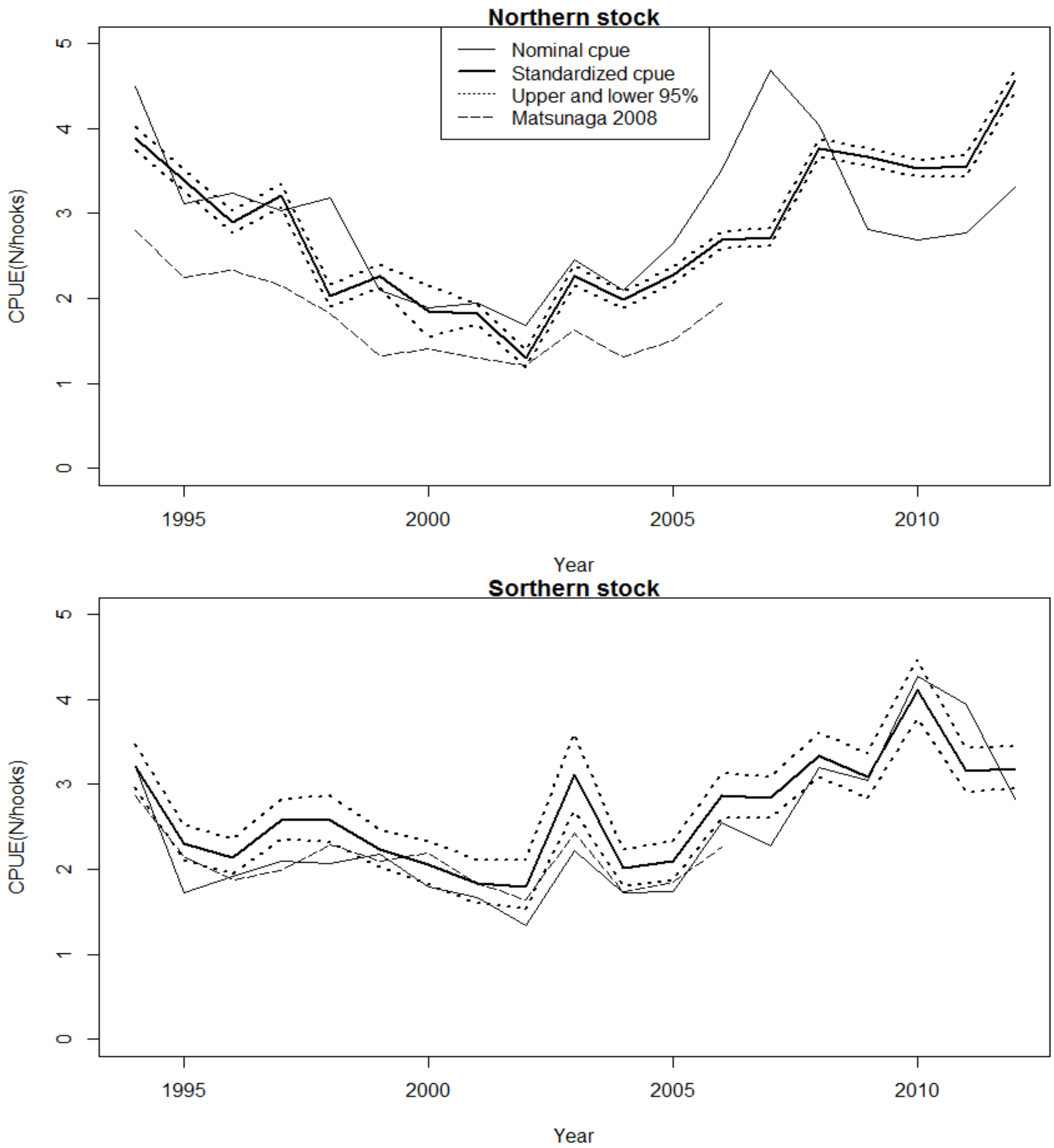

Figure 8. Nominal and standardized CPUE (Number of blueshark / 1000 hooks) estimated by negative binomial model with 95% confidence intervals for the northern (upper figure) and southern (lower figure) stocks from 1994 to 2012.

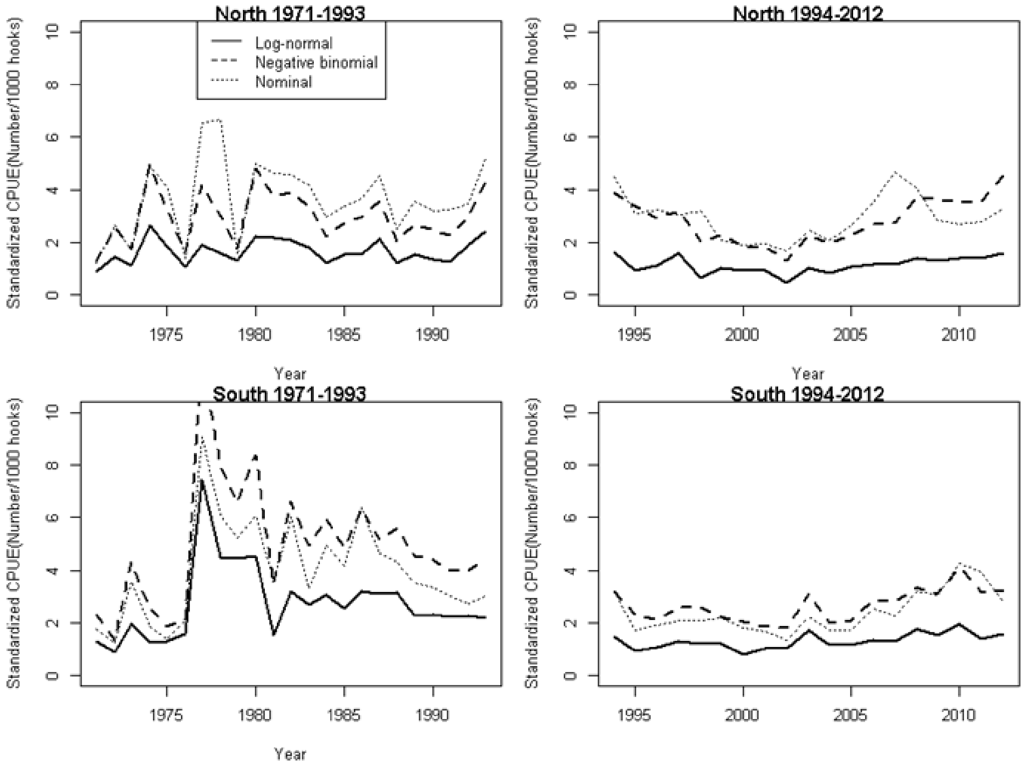

Figure 9. Comparisons of standardized CPUE (Number of blue shark / 1000 hooks) estimated by "Log-normal model" with "Negative binomial model" for the northern (upper figure) and southern (lower figure) stocks from 1971 to 2012.

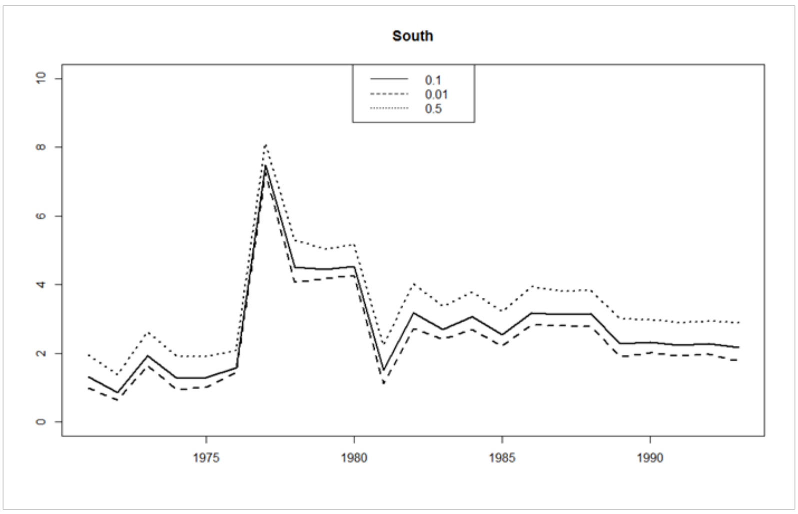

Figure 10. Comparison of CPUEs of the south Pacific blue shark caught by Japanese longliners during 1971 – 2012. CPUEs were standardized by the log-normal model with three different levels of constant values.

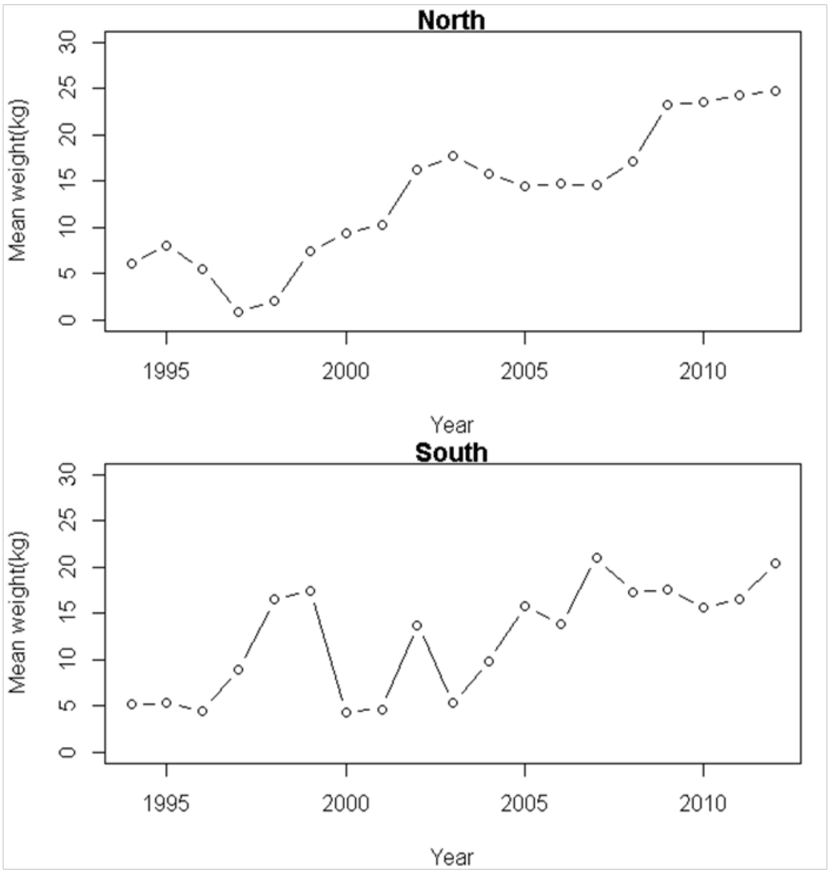

Figure 11. Annual changes of mean weight (kg) of blue shark after filtering by reporting ratio of blue shark catch for the northern and southern stocks from 1994 to 2012.

Appendix

Table A1. Nominal and standardized CPUE with 95% confidence intervals estimated by lognormal model for the northern stock.

Year	Nominal CPUE	Standardized CPUE	Lower-95%	Upper-95%
1971	1.22	0.87	0.79	0.97
1972	2.65	1.46	1.29	1.64
1973	1.73	1.12	1.00	1.26
1974	4.91	2.62	2.39	2.87
1975	4.14	1.85	1.64	2.08
1976	1.40	1.07	0.95	1.19
1977	6.51	1.89	1.61	2.21
1978	6.65	1.58	1.36	1.84
1979	1.53	1.30	1.00	1.67
1980	5.01	2.21	1.96	2.50
1981	4.65	2.19	2.00	2.40
1982	4.59	2.08	1.89	2.28
1983	4.15	1.81	1.63	2.01
1984	2.95	1.22	1.12	1.33
1985	3.40	1.51	1.38	1.65
1986	3.68	1.52	1.36	1.70
1987	4.54	2.13	1.93	2.35
1988	2.49	1.21	1.10	1.32
1989	3.56	1.51	1.38	1.65
1990	3.18	1.34	1.24	1.46
1991	3.23	1.26	1.14	1.38
1992	3.49	1.90	1.76	2.05
1993	5.18	2.43	2.27	2.60

Year	Nominal CPUE	Standardized CPUE	Lower-95%	Upper-95%
1994	4.49	1.63	1.38	1.92
1995	3.11	0.93	0.79	1.09
1996	3.25	1.11	0.94	1.30
1997	3.04	1.56	1.33	1.82
1998	3.18	0.67	0.56	0.79
1999	2.09	1.04	0.87	1.23
2000	1.89	0.92	0.62	1.34
2001	1.95	0.94	0.81	1.09
2002	1.69	0.47	0.40	0.55
2003	2.45	1.05	0.91	1.21
2004	2.09	0.82	0.72	0.94
2005	2.64	1.05	0.93	1.19
2006	3.52	1.15	1.01	1.30
2007	4.68	1.17	1.02	1.34
2008	4.04	1.40	1.23	1.59
2009	2.81	1.32	1.15	1.50
2010	2.69	1.40	1.23	1.59
2011	2.77	1.38	1.17	1.63
2012	3.31	1.57	1.33	1.84

Table A2. Nominal and standardized CPUE with 95% confidence intervals estimated by lognormal model for the southern stock.

Year	Nominal CPUE	Standardized CPUE	Lower-95%	Upper-95%
1971	1.77	1.29	1.18	1.41
1972	1.26	2.54	2.29	2.81
1973	3.57	1.77	1.60	1.96
1974	1.86	4.97	4.59	5.38
1975	1.39	3.31	2.98	3.68
1976	2.09	1.64	1.49	1.81
1977	9.10	4.18	3.64	4.80
1978	6.05	3.03	2.64	3.47
1979	5.21	1.76	1.41	2.20
1980	6.07	4.80	4.34	5.31
1981	3.56	3.77	3.48	4.08
1982	6.03	3.89	3.59	4.22
1983	3.35	3.41	3.12	3.72
1984	4.96	2.25	2.09	2.42
1985	4.18	2.72	2.53	2.93
1986	6.38	2.96	2.69	3.25
1987	4.64	3.57	3.28	3.89
1988	4.32	2.06	1.91	2.23
1989	3.51	2.68	2.48	2.89
1990	3.34	2.47	2.31	2.65
1991	3.00	2.25	2.08	2.44
1992	2.75	2.96	2.77	3.15
1993	2.99	4.33	4.09	4.59

Year	Nominal CPUE	Standardized CPUE	Lower-95%	Upper-95%
1994	3.21	1.47	1.34	1.63
1995	1.72	0.94	0.84	1.05
1996	1.92	1.06	0.94	1.20
1997	2.10	1.31	1.17	1.47
1998	2.07	1.23	1.07	1.40
1999	2.18	1.20	1.06	1.36
2000	1.80	0.81	0.69	0.95
2001	1.68	1.00	0.85	1.19
2002	1.34	1.01	0.82	1.23
2003	2.22	1.74	1.45	2.08
2004	1.73	1.18	1.04	1.35
2005	1.73	1.16	1.01	1.33
2006	2.55	1.34	1.20	1.50
2007	2.28	1.31	1.17	1.45
2008	3.19	1.78	1.61	1.96
2009	3.04	1.51	1.36	1.68
2010	4.27	1.97	1.78	2.18
2011	3.94	1.37	1.24	1.52
2012	2.83	1.56	1.42	1.72

Table A3. Nominal and standardized CPUE with 95% confidence intervals estimated by negative binomial model for the northern stock.

Year	Nominal CPUE	Standardized CPUE	Lower-95%	Upper-95%
1971	1.22	1.32	1.21	1.44
1972	2.65	0.87	0.79	0.95
1973	1.73	1.94	1.74	2.16
1974	4.91	1.28	1.11	1.46
1975	4.14	1.29	1.01	1.64
1976	1.40	1.58	0.97	2.53
1977	6.51	7.48	6.49	8.61
1978	6.65	4.51	3.87	5.25
1979	1.53	4.45	3.93	5.04
1980	5.01	4.52	4.10	4.99
1981	4.65	1.52	1.39	1.66
1982	4.59	3.18	2.97	3.41
1983	4.15	2.69	2.34	3.09
1984	2.95	3.07	2.86	3.30
1985	3.40	2.54	2.39	2.70
1986	3.68	3.18	3.00	3.38
1987	4.54	3.13	2.94	3.32
1988	2.49	3.14	2.96	3.34
1989	3.56	2.28	2.16	2.40
1990	3.18	2.31	2.20	2.43
1991	3.23	2.23	2.12	2.34
1992	3.49	2.27	2.14	2.41
1993	5.18	2.17	2.06	2.28
1994	3.21	3.21	2.97	3.47
1995	1.72	2.31	2.11	2.52
1996	1.92	2.14	1.94	2.35
1997	2.10	2.58	2.36	2.83
1998	2.07	2.58	2.31	2.87
1999	2.18	2.24	2.02	2.47
2000	1.80	2.06	1.82	2.33
2001	1.68	1.84	1.60	2.10
2002	1.34	1.80	1.53	2.11
2003	2.22	3.11	2.69	3.60
2004	1.73	2.01	1.81	2.23
2005	1.73	2.10	1.88	2.34
2006	2.55	2.86	2.61	3.13
2007	2.28	2.84	2.61	3.09
2008	3.19	3.34	3.08	3.61
2009	3.04	3.09	2.84	3.36
2010	4.27	4.11	3.77	4.47
2011	3.94	3.16	2.92	3.43
2012	2.83	3.19	2.95	3.45

Table A4. Nominal and standardized CPUE with 95% confidence intervals estimated by negative binomial model for the southern stock.

Year	Nominal CPUE	Standardized CPUE	Lower-95%	Upper-95%
1971	1.77	2.32	2.16	2.50
1972	1.26	1.36	1.25	1.47
1973	3.57	4.31	3.94	4.72
1974	1.86	2.57	2.28	2.89
1975	1.39	1.85	1.49	2.31
1976	2.09	2.14	1.41	3.25
1977	9.10	12.04	10.67	13.59
1978	6.05	7.95	6.98	9.07
1979	5.21	6.57	5.91	7.32
1980	6.07	8.37	7.70	9.10
1981	3.56	3.47	3.23	3.74
1982	6.03	6.62	6.24	7.01
1983	3.35	4.96	4.40	5.58
1984	4.96	5.95	5.60	6.33
1985	4.18	4.87	4.62	5.13
1986	6.38	6.36	6.05	6.68
1987	4.64	5.20	4.94	5.48
1988	4.32	5.59	5.30	5.89
1989	3.51	4.56	4.36	4.76
1990	3.34	4.42	4.24	4.61
1991	3.00	4.00	3.84	4.17
1992	2.75	3.97	3.77	4.17
1993	2.99	4.50	4.32	4.70
1994	4.49	3.89	3.75	4.02
1995	3.11	3.39	3.27	3.51
1996	3.25	2.90	2.77	3.03
1997	3.04	3.21	3.08	3.35
1998	3.18	2.03	1.90	2.16
1999	2.09	2.26	2.12	2.40
2000	1.89	1.85	1.54	2.15
2001	1.95	1.82	1.70	1.93
2002	1.69	1.30	1.19	1.40
2003	2.45	2.26	2.15	2.38
2004	2.09	1.98	1.89	2.08
2005	2.64	2.27	2.18	2.37
2006	3.52	2.69	2.59	2.78
2007	4.68	2.72	2.62	2.83
2008	4.04	3.77	3.67	3.88
2009	2.81	3.66	3.56	3.77
2010	2.69	3.53	3.43	3.63
2011	2.77	3.56	3.43	3.69
2012	3.31	4.56	4.43	4.69

Table A5. Anova table of lognormal model for the northern stock from 1971 to 1993.

	SS	Df	F	Pr(>F)	
as.factor(year.x)	1933.8	22	68.161	2.20E-16	***
as.factor(qt)	25.3	3	6.543	0.0002034	***
as.factor(area)	127.2	3	32.89	2.20E-16	***
as.factor(hpbc)	200.4	2	77.7	2.20E-16	***
as.factor(year.x):as.factor(qt)	1472	66	17.295	2.20E-16	***
as.factor(qt):as.factor(hpbc)	266.3	6	34.416	2.20E-16	***
Residuals	28051.1	21752			

Table A6. Anova table of lognormal model for the southern stock from 1971 to 1993.

	SS	Df	F	Pr(>F)	
as.factor(year.x)	2628	22	101.0745	2.20E-16	***
as.factor(qt)	140	3	39.5424	2.00E-16	***
as.factor(area)	519	2	219.5988	2.20E-16	***
as.factor(hpbc)	11	2	4.6764	0.00932	***
as.factor(qt):as.factor(hpbc)	224	6	31.5353	2.20E-16	***
as.factor(qt):as.factor(area)	241	6	34.0249	2.20E-16	***
Residuals	33875	28665			

Table A7. Anova table of negative binomial model for the northern stock from 1971 to 1993.

	SS	Df	F	Pr(>F)	
as.factor(year.x)	2985	22	82.749	2.20E-16	***
as.factor(qt)	23	3	4.616	0.003126	**
as.factor(area)	67	3	13.679	6.55E-09	***
as.factor(hpbc)	100	2	30.466	6.13E-14	***
as.factor(year.x):as.factor(qt)	1538	66	14.209	2.20E-16	***
as.factor(qt):as.factor(hpbc)	303	6	30.822	2.20E-16	***
Residuals	35670	21752			

Table A8. Anova table of negative binomial model for the southern stock from 1971 to 1993.

	SS	Df	F	Pr(>F)	
as.factor(year.x)	2839	22	74.561	2.20E-16	***
as.factor(qt)	243	3	46.8513	2.00E-16	***
as.factor(area)	1141	2	329.5751	2.20E-16	***
as.factor(hpbc)	16	2	4.6784	0.009301	**
as.factor(qt):as.factor(hpbc)	80	6	7.7496	2.39E-08	***
as.factor(qt):as.factor(area)	235	6	22.628	2.20E-16	***
Residuals	49614	28665			

Table A9. Anova table of lognormal model for the northern stock from 1994 to 2012.

	SS	Df	F	Pr(>F)	
as.factor(year.x)	2376	18	79.383	2.20E-16	***
as.factor(qt)	513	3	102.745	2.20E-16	***
as.factor(area)	881	3	176.583	2.20E-16	***
as.factor(hpbc)	953	2	286.508	2.20E-16	***
as.factor(year.x):as.factor(qt)	2271	54	25.286	2.20E-16	***
as.factor(year.x):as.factor(area)	3034	54	33.782	2.20E-16	***
as.factor(year.x):as.factor(hpbc)	833	36	13.916	2.20E-16	***
as.factor(qt):as.factor(hpbc)	442	6	44.245	2.20E-16	***
as.factor(area):as.factor(hpbc)	495	6	49.644	2.20E-16	***
Residuals	119654	71947			

Table A10. Anova table of log-normal model for the southern stock from 1994 to 2012.

	SS	Df	F	Pr(>F)	
as.factor(year.x)	1639	18	54.0398	2.20E-16	***
as.factor(qt)	409	3	80.8335	2.20E-16	***
as.factor(area)	186	2	55.1384	2.20E-16	***
as.factor(hpbc)	23	2	6.7238	0.001203	**
as.factor(year.x):as.factor(qt)	3327	54	36.5698	2.20E-16	***
as.factor(area):as.factor(hpbc)	538	4	79.7863	2.20E-16	***
Residuals	73467	43602			

Table A11. Anova table of negative binomial model for the northern stock from 1994 to 2012.

	Df	Chi-Square	Pr(>ChiSq)	
as.factor(year.x)	18	1437.07	< 0.001	***
as.factor(qt)	3	273.12	2.20E-16	***
as.factor(area)	3	60.65	2.20E-16	***
as.factor(hpbc)	2	39.39	2.20E-16	***
as.factor(year.x):as.factor(qt)	54	1544.14	2.20E-16	***
as.factor(year.x):as.factor(area)	54	1575.92	2.20E-16	***
as.factor(year.x):as.factor(hpbc)	36	589.1	2.20E-16	***
as.factor(qt):as.factor(hpbc)	6	398.25	2.20E-16	***
as.factor(area):as.factor(hpbc)	6	313.89	2.20E-16	***

Table A12. Anova table of negative binomial model for the southern stock from 1994 to 2012.

	SS	Df	F	Pr(>F)
as.factor(year.x)	1639	18	54.0398	2.20E-16 ***
as.factor(qt)	409	3	80.8335	2.20E-16 ***
as.factor(area)	186	2	55.1384	2.20E-16 ***
as.factor(hpbc)	23	2	6.7238	0.001203 **
as.factor(year.x):as.factor(qt)	3327	54	36.5698	2.20E-16 ***
as.factor(area):as.factor(hpbc)	538	4	79.7863	2.20E-16 ***
Residuals	73467	43602		

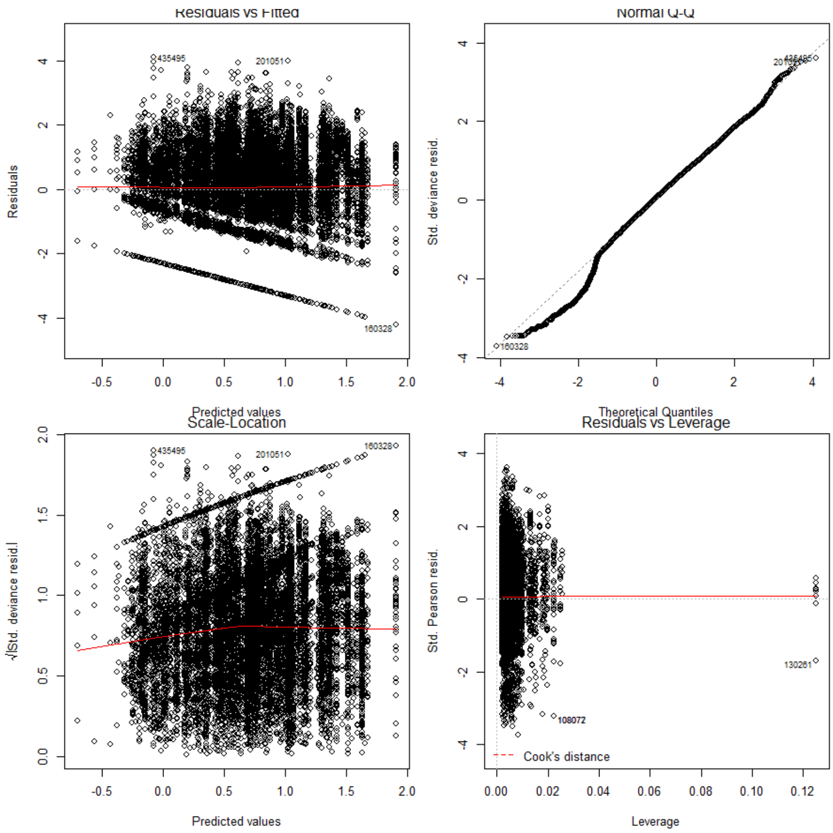

Figure A1a. Diagnostics of the goodness of the fits of the lognormal model for the northern stock from 1971 to 1993.

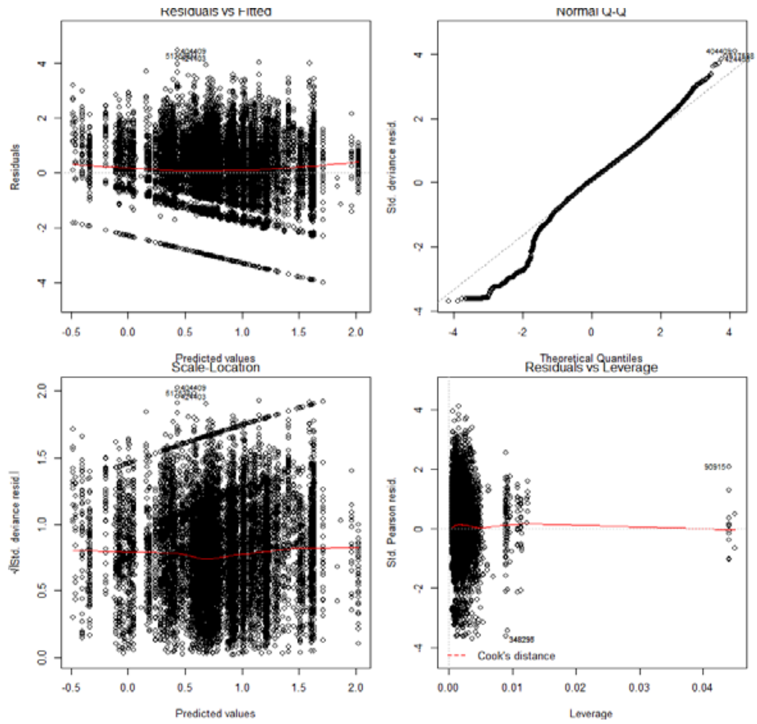

Figure A1b. Diagnostic of the goodness of the fits of the lognormal model for southern stock from 1971 to 1993.

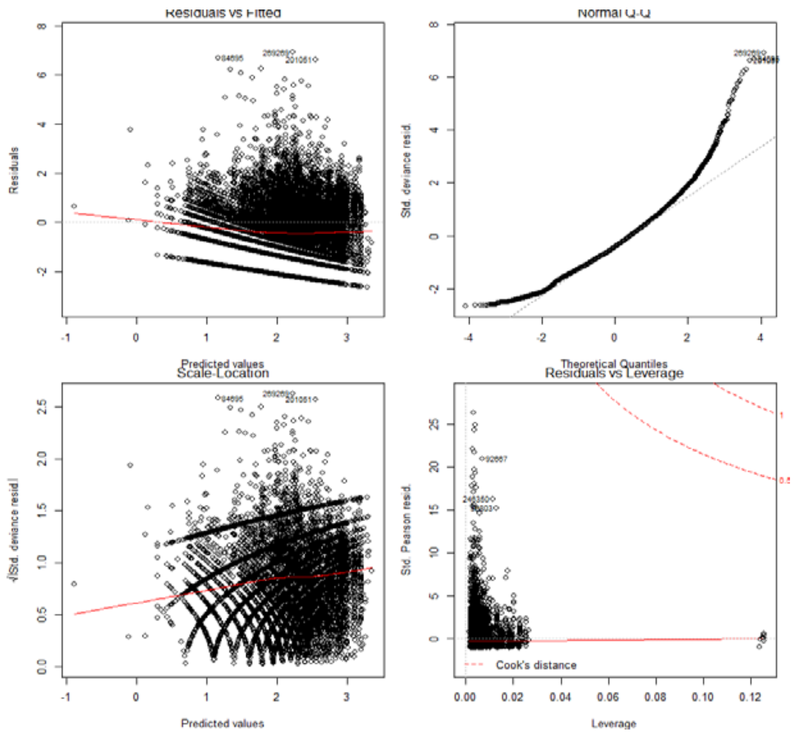

Figure A1c. Diagnostic of the goodness of the fit of the negative binomial model for the northern stock from 1971 to 1993.

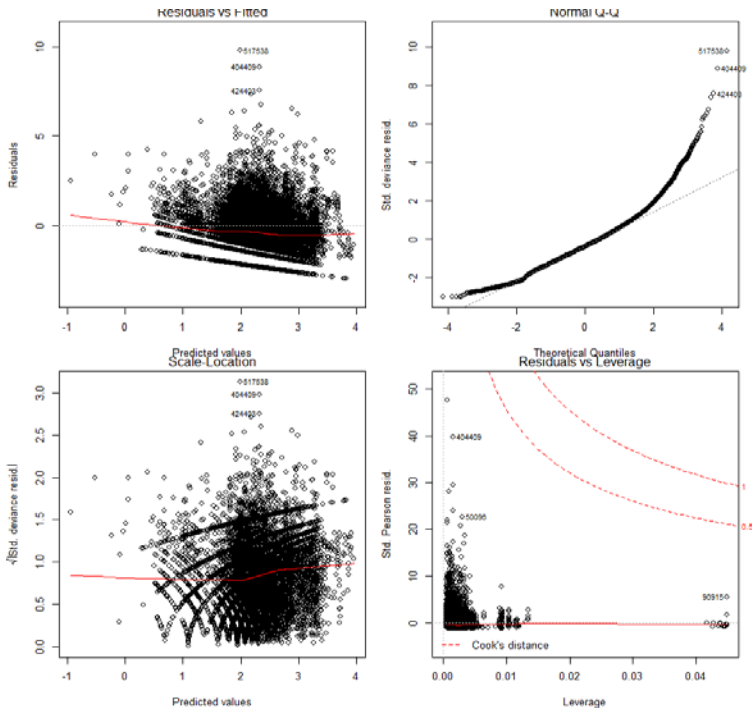

Figure A1d. Diagnostic of the goodness of the fit of the negative binomial model for the southern stock from 1971 to 1993.

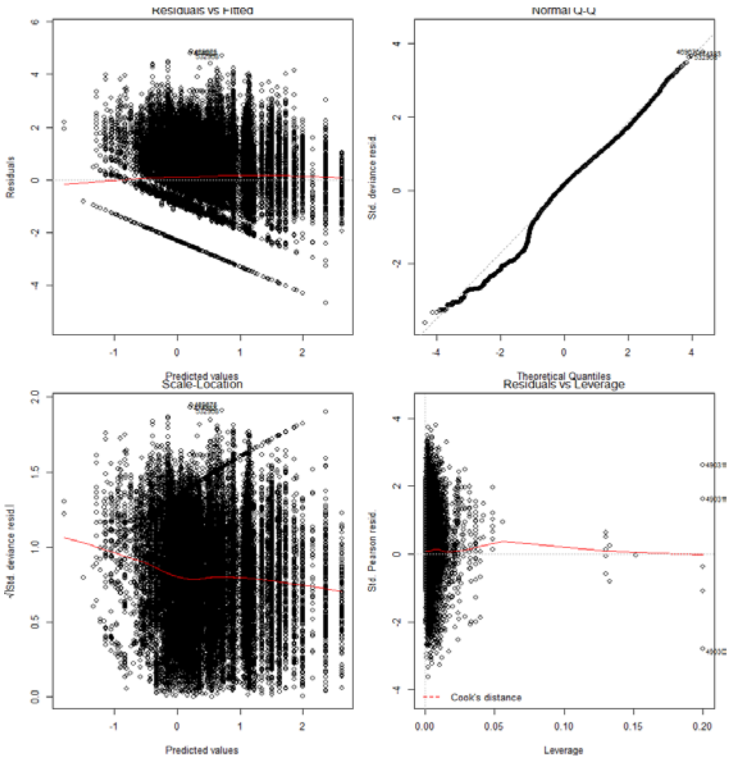

Figure A2a. Diagnostics of the goodness of the fits of the lognormal model for the northern stock from 1994 to 2012.

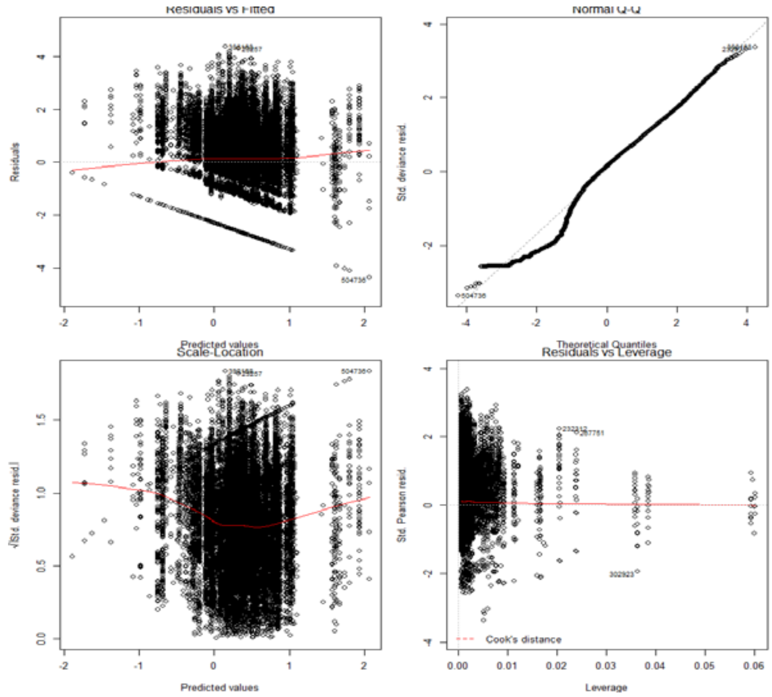

Figure A2b. Diagnostic of the goodness of the fits of the lognormal model for southern stock from 1994 to 2012.

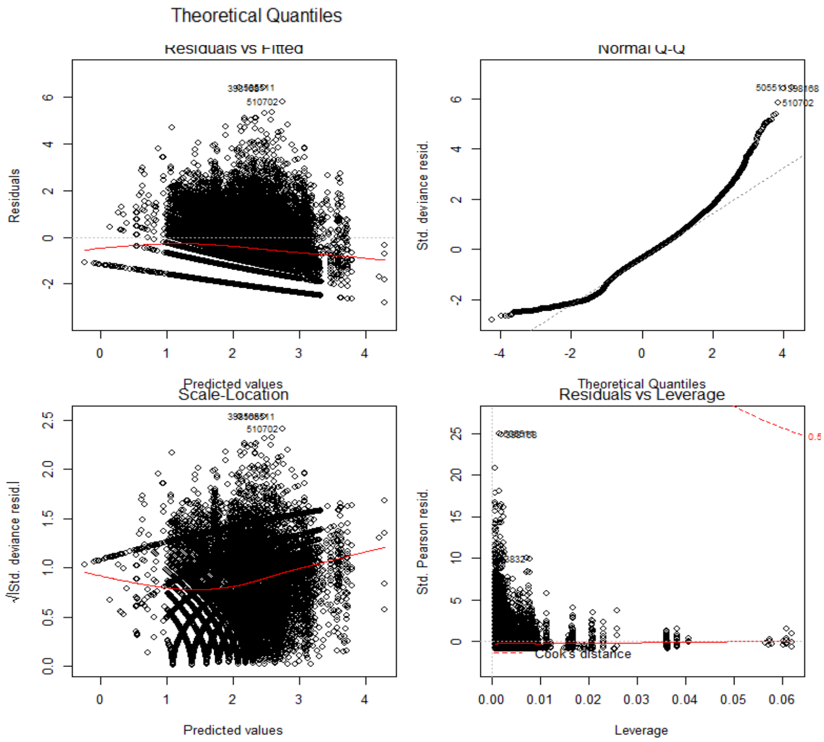

Figure A2d. Diagnostic of the goodness of the fit of the negative binomial model for the southern stock from 1994 to 2012.