IOTC–2016–WPTmT06–15
Received: 4 July 2016

Standardization of albacore CPUE by Japanese longline fishery in the Indian Ocean

Takayuki Matsumoto[1] and Toshihide Kitakado[2]

[1]*National Research Institute of Far Seas Fisheries (NRIFSF), Fisheries Research Agency (FRA), 5-7-1, Orido, Shimizu, Shizuoka, 424-8633, Japan*

[2]*Tokyo University of Marine Science and Technology, 5-7, Konan 4, Minato, Tokyo, 108-8477, Japan*

Summary

Standardization of albacore CPUE by Japanese longline fishery in the Indian Ocean was conducted using the Generalized Linear Model (GLM) with log-normal error structure (LN model). Original (operational level) catch and effort data as well as environmental factor (sea surface temperature) were used for standardization. CPUE was standardized as for several areas. All CPUEs sharply declined in the early period (until around 1970). CPUE in the north area was comparatively constant after that. CPUE in the south area increased after early 2000s. The effect of each factor in standardization usually differed between north and south.

1. INTRODUCTION

Albacore in the Indian Ocean has been exploited since the early 1950s. Albacore catch has been increasing with fluctuation, and it reached about 40,000 t in 2000 at the historical highest level, though the range of the catch had been from 12,000 t to 36,000 t during the period from the 1960s to the mid-1990s. Japanese longline fishery commenced in this Ocean in 1952. The fishery caught albacore ranging from 9,000 to 18,000 t in the 1960s that corresponds to the beginning of the long history of the fishery. Since then the catch decreased rapidly and reached 400 t in 1977. This drastic change is due to the change of target species of the longline fishery, i.e., from yellowfin tuna and albacore to southern bluefin tuna and bigeye tuna, during the 1970s. The catch continued to be in a low level ranging from 400 t to 2,500 t until early 1990s. After that the catch slightly increased and was 6,200 t in 2006, which was highest during the past 40 years. However, it is still about one third of the catch at the peak in 1964. In recent years, albacore has become one of target species Japanese longline vessels in the Indian Ocean.

For the Indian Ocean albacore caught by Japanese longline fishery, CPUE standardization using the Generalized Linear Model (GLM) with the assumption that the error structure belongs to log-normal had been carried out for 1960-1991 (Uozumi, 1994) and for 1960-2002 (Uosaki, 2004). Both log-normal and negative binomial error structures were examined by Matsumoto and Uosaki (2011) and Matsumoto et al. (2012) based on aggregated catch and effort data by 5 degree latitude-longitude and operational level data, respectively, considering that negative binomial error structure may be better for standardization of albacore CPUE by Japanese longline which includes certain amount of zero catch data, but log-normal error structure was considered to be better based on information criteria or distribution of the standardized residuals. Therefore, Matsumoto et al. (2014) used only log-normal and negative binomial error structure. This time, operational level catch and effort data were used for CPUE standardization as with previous analyses (Matsumoto et al., 2012; 2014). In April 2016, IOTC 1st joint CPUE analysis was conducted and standardized CPUEs for albacore were created using operational level data for Japanese, Korean and Taiwanese longline fishery combined. One of the objectives of this study is to compare CPUE indices with those by the abovementioned analysis.

2.MATERIALS AND METHODS

2.1. Catch and effort data

The data used here is the logbook data that has been compiled at National Research Institute of Far Seas Fisheries (NRIFSF) based on the logbook mandatory submitted by the fishermen of the longline vessel larger than 20 gross ton (GRT). Original (operational level) logbook data for 1952-2014 were used, which include the number of hooks per basket (HPB, only from 1975 onward). CPUE was defined as the number of fish caught per 1,000 hooks.

2.2. Area and period for CPUE

Matsumoto (2010) reported that as for albacore CPUE by Japanese longline fishery in the north Pacific, sharp decline in CPUE was observed and it was considered to be the results of target shift from albacore to bigeye tuna, which occurred in response to the change in market demand and so on. Therefore, CPUE for north Pacific albacore until 1972 was truncated for using in the stock assessment models at ISC meeting. Also in the Indian Ocean, sharp decline in albacore CPUE was observed in this period, and so the same situation may have occurred (Matsumoto et al., 2012). In conjunction with the availability of HPB data, Matsumoto et al. (2014) set the period for CPUE standardization as 1975-2012. In the present study, one of the objectives is to compare CPUE indices with those by the joint CPUE analysis in April 2016, in which start year of CPUEs is 1950s. Therefore, also in this study start year was set as early as possible, and it differed depending on availability of catch and effort data by area.

Albacore catch by Japanese longline in the Indian Ocean mainly occurred in the eastern and western side of temperate and subtropical areas (around and south of Madagascar, and west off Australia), but historically it was caught consistently in the southwestern part (Matsumoto, 2016). In this study, area definition was partly adjusted with that in the joint CPUE analysis in April 2016; the areas between 25 and 50°S and between 20 and 140°E, between 25 and 50°S and between 20 and 75°E, between 25 and 50°S and between 75 and 140°E were used. In addition, CPUE for north area (0-20°S, 20-120°E) was also calculated for the comparison with southern indices. Fig. 1 shows the areas for CPUE standardization. As for the effect of fishing area, 5 degree latitude and longitude blocks were incorporated.

2.3. Environmental factors

As an environmental factor, SST (Sea Surface Temperature) was incorporated into the regression analysis. The original SST data, whose resolution was 1-degree latitude and 1-degree longitude by month from 1946 to 2014, were downloaded from NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA) website (http://goos.kishou.go.jp/rrtdb/database.html).

The original data were merged with catch and effort data, and were used for the analyses. The SST was used as a categorical factor at 1 degree intervalin the GLM models.

2.4. Gear effects

The number of hooks between floats (hooks per basket, HPB), which was divided and categorized into four levels (4-7, 8-11, 12-15 and 16-21 HPB), was incorporated for gear effect. As the information on gear configuration was not available for the period before 1975, each observation was regarded as 4-7 HPB in that period. Main and branch line materials were categorized into two (1 = nylon, 2 = the others). Although this information on the materials has been collected since 1994, the nylon material was started to be used by distant water longliner around the late 1980s and spread quickly in the early 1990s (Okamoto, 2005). In this study, material of main and branch lines before 1994 was tentatively regarded as 'the others'.

2.5. Standardization

For standardizing albacore CPUE data, generalized linear model (GLM) with log-normal error structure (LN model) was employed as in the final models for the past analyses. Matsumoto et al. (2014) made several changes in the models used in Matsumoto and Uosaki (2011) and Matsumoto et al. (2012) by adding the effects of gear material and SST, and by using 5 degree blocks instead of subareas. The model in this study is the same as that in Matsumoto et al. (2014). In addition to the effects mentioned above, the effect of fishing season (quarter) was used as with the previous analyses. In order to deal with observations with no catch of albacore, a constant of 10% of mean CPUE was added to the CPUE. An initial model used is:

$$\ln(CPUE+C)= \mu + Y + Q + G + ML + BL + SST + LT5LN5 + Q*G + Y*Q + ML*G + BL*G + e$$

where
- μ: intercept — C: constant (10% of mean CPUE)
- Y: effect of year — Q: effect of quarter
- G: effect of gear (HPB) — ML: effect of material of main line
- BL: effect of material of branch line — SST: effect of sea surface temperature
- LT5LN5: effect of each latitude 5 degree and longitude 5 degree block
- Q*G: interaction term between quarter and gear
- Y*Q: interaction term between year and quarter
- ML*G: interaction term between material of main line and gear
- BL*G: interaction term between material of branch line and gear
- e : error term

Standardized CPUE was calculated as follows:

$$\text{Standardized } CPUE_i = EXP(LSM(Y_i)) - C \qquad \text{(annual CPUE)}$$

where
- $LSM(Y_i)$: least square mean of year effect in year *i*
- C: constant (10% of mean CPUE)

Based on the result of ANOVA (type III SS), non-significant effects ($p<0.05$ using F-test) were removed from the initial model in a step-wise way. In the cases if the factor was not significant as main effect but was significant as interaction with another factor, the main effect was kept in the model.

All the analyses were conducted using SAS version 9.3.

2.6. Catch and effort in each area used for standardization

Fig. 2 shows the trend of effort (number of hooks) and albacore catch (in number) in the north and south area. Until late 1960s, the amount of fishing effort in the north and south areas was similar. Fishing effort in the south area was much higher than in the north area after that until around 2000. The efforts in both areas sharply decreased during late 2000s, and were comparatively constant after 2010 with similar level. Albacore catch in number in the south area was high during 1960s, sharply decreased around 1070 and kept in a low level between 1970s and early 2000s. It sharply increased after that, but was still lower than the level during 1960s. Catch amount in the north area was high in the early period (mid-1950s-mid-1960s), and kept in a low level after that.

3. RESULT AND DISCUSSION

The analysis of variance for the GLM analyses is shown in Table 1. This shows all the effects were significant at 5 % level except for branch line effect in the north area, which was eliminated from the model. As for main factor except for year effect, in the north area, the effect of LT5LN5 was largest followed by quarter. In the south area A3R3+4 and A3R4, the effect of SST was largest, followed by quarter. In the south area A3R3, the effect of SST was largest followed by LT5LN5. Table 2 shows annual CPUE indices with CV (log scale standard error) and confidence limits. The distributions of standardized residual are shown in Fig. 3 (distribution of standardized residual and QQ-plot) and Fig. 4 (box plot for annual value). It seems that standardized residuals for north area are not largely unbiased, whereas those for south area are somewhat biased especially as for A3R4.

Fig. 5 shows relative effects of season (quarter), main and branch line materials, gear (HPB) and SST for GLM analyses. The trend was usually different between north and south areas. For example, in the south area, nylon main line got higher index, whereas the trend was opposite for the north area. Trend of gear (HPB) effect was almost opposite between north and south: higher index for shallower gear in the south area and the opposite for the north area. As for SST, a mode was observed around 18ºC both in the areas A3R3 and A3R4. Another mode was observed around 22ºC for the area A3R4. 24ºC got highest index for the north area.

Fig. 6 shows trend of standardized CPUE with confidence limits and nominal CPUE. Sharp decline of CPUE was observed in the early period (until around 1970) for all the areas. After that CPUE was almost constant in the north area. CPUE in the south area was also almost constant until early 2000s, and then increased especially in the A3R4 (southeast area). Standardized CPUE was usually similar to nominal CPUE except for a part of area and period.

REFERENCE

Matsumoto, T. 2010. Suggestion about how to deal with albacore CPUE by Japanese longline during 1960s in the northwest area. ISC/10/ALBWG-3/05. 21pp.

Matsumoto, T. 2016. Review of Japanese longline fishery and its albacore catch in the Indian Ocean. IOTC–2016–WPTmT06–14. 17pp.

Matsumoto, T.、T. Kitakado and H. Okamoto. 2012. Standardization of albacore CPUE by Japanese longline fishery in the Indian Ocean. IOTC–2012–WPTmT04–10. 16pp.

Matsumoto, T., T. Kitakado and T. Nishida. 2014. Standardization of albacore CPUE by Japanese longline fishery in the Indian Ocean. IOTC–2014–WPTmT05–18. 20pp.

Matsumoto, T. and K. Uosaki. 2011. Standardization of albacore CPUE by Japanese longline fishery in the Indian Ocean. IOTC–2011–WPTmT03–15. 10pp.

Okamoto, H. 2005. Recent trend of Japanese longline fishery in the Indian Ocean with special reference to the targeting. IOTC/WPTT/05/11, 15pp.

Uosaki, K. 2004. Update of the standardized CPUE of the albacore caught by Japanese longline fishery in the Indian Ocean. IOTC-WPTMP-2004-09.

Uozumi, Y. 1994. The CPUE trend for albacore in Indian Ocean waters caught by the Japanese longline fishery. Proceeding of 5th Expert Consultation on Indian Ocean tunas. IPTP Col. Vol. 8. 147-149.

Table 1. Analysis of variance for the GLM analyses for each area.

North (0-20S, 20-120E)□

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	316	292676.7	926.19	925.75	<.0001
Error	289400	289539.1	1.00		
Corr. Tot.	289716	582215.8			
R-square=	0.502694	C.V.=	714.9088		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	60	33640.05	560.67	560.40	<.0001
Q	3	1214.76	404.92	404.73	<.0001
G	3	1159.75	386.58	386.40	<.0001
ml	1	52.64	52.64	52.61	<.0001
sst	8	2704.19	338.02	337.86	<.0001
LT5LN5	49	126052.06	2572.49	2571.26	<.0001
Q*G	9	484.28	53.81	53.78	<.0001
y*Q	180	10400.52	57.78	57.75	<.0001
G*ml	3	259.41	86.47	86.43	<.0001

South A3R3+4 (25-50S, 20-140E)□

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	378	1029424.2	2723.3	2886.66	<.0001
Error	920523	868444.6	0.94		
Corr. Tot.	920901	1897868.8			
R-square=	0.542411	C.V.=	847.8483		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	55	88357.19	1606.49	1702.83	<.0001
Q	3	3859.31	1286.44	1363.58	<.0001
G	3	259.81	86.60	91.80	<.0001
ml	1	326.29	326.29	345.86	<.0001
bl	1	5.77	5.77	6.11	0.0134
sst	26	50977.81	1960.69	2078.26	<.0001
LT5LN5	109	50239.98	460.92	488.56	<.0001
Q*G	9	433.83	48.20	51.09	<.0001
y*Q	165	50040.75	303.28	321.46	<.0001
G*ml	3	393.73	131.24	139.11	<.0001
G*bl	3	450.41	150.14	159.14	<.0001

South A3R3 (25-50S, 20-75E)□

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	306	367728.3	1201.7	1176.06	<.0001
Error	435066	444561.9	1.02		
Corr. Tot.	435372	812290.2			
R-square=	0.452706	C.V.=	143.6434		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	52	36341.96	698.88	683.96	<.0001
Q	3	731.60	243.87	238.66	<.0001
G	3	324.73	108.24	105.93	<.0001
ml	1	173.92	173.92	170.21	<.0001
bl	1	179.71	179.71	175.88	<.0001
sst	25	25799.00	1031.96	1009.92	<.0001
LT5LN5	50	15640.62	312.81	306.13	<.0001
Q*G	9	652.43	72.49	70.94	<.0001
y*Q	156	13660.24	87.57	85.70	<.0001
G*ml	3	260.17	86.72	84.87	<.0001
G*bl	3	101.97	33.99	33.27	<.0001

South A3R4 (25-50S, 75-140E)□

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	323	670270.0	2075.1	2952.29	<.0001
Error	484164	340314.3	0.70		
Corr. Tot.	484487	1010584.3			
R-square=	0.66325	C.V.=	-126.6706		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	55	19277.43	350.50	498.65	<.0001
Q	3	2063.24	687.75	978.45	<.0001
G	3	172.00	57.33	81.57	<.0001
ml	1	185.04	185.04	263.25	<.0001
bl	1	47.29	47.29	67.27	<.0001
sst	22	15903.43	722.88	1028.44	<.0001
LT5LN5	58	15806.71	272.53	387.73	<.0001
Q*G	9	1569.97	174.44	248.18	<.0001
y*Q	165	25994.00	157.54	224.13	<.0001
G*ml	3	397.70	132.57	188.60	<.0001
G*bl	3	251.14	83.71	119.10	<.0001

Table 2. Standardized annual CPUE (number of fish/hooks) with the 95% confidence limits for each area. Std Err (standard error): log scale.

South	25-50S, 20-140E (A3R3+4)				South	25-50S, 20-75E (A3R3)			
Year	CPUE	Lower 95%	Upper 95%	Std Err	Year	CPUE	Lower 95%	Upper 95%	Std Err
1959	7.723	6.848	8.703	0.058					
1960	4.802	4.273	5.392	0.055					
1961	2.705	2.358	3.096	0.061					
1962	5.314	4.732	5.961	0.055	1962	12.995	11.114	15.180	0.076
1963	5.035	4.491	5.639	0.054	1963	11.960	10.433	13.700	0.066
1964	4.257	3.807	4.756	0.052	1964	9.931	8.513	11.572	0.074
1965	3.085	2.745	3.463	0.053	1965	10.617	9.189	12.256	0.070
1966	2.878	2.564	3.227	0.052	1966	9.945	8.529	11.581	0.074
1967	1.819	1.609	2.050	0.051	1967	10.847	9.517	12.352	0.063
1968	1.072	0.933	1.225	0.051	1968	4.601	3.630	5.798	0.107
1969	1.202	1.051	1.368	0.051	1969	2.522	2.196	2.887	0.057
1970	0.874	0.754	1.007	0.051	1970	1.889	1.626	2.185	0.058
1971	0.883	0.762	1.016	0.051	1971	2.396	2.065	2.769	0.061
1972	0.805	0.692	0.931	0.051	1972	1.327	1.118	1.562	0.060
1973	0.668	0.568	0.779	0.051	1973	0.971	0.806	1.155	0.058
1974	0.670	0.570	0.782	0.051	1974	0.849	0.697	1.018	0.058
1975	0.423	0.346	0.508	0.051	1975	0.380	0.278	0.494	0.059
1976	0.666	0.566	0.777	0.051	1976	1.255	1.049	1.489	0.062
1977	0.523	0.437	0.619	0.051	1977	0.688	0.532	0.865	0.068
1978	0.298	0.233	0.370	0.051	1978	0.384	0.280	0.500	0.060
1979	0.437	0.358	0.524	0.051	1979	0.560	0.433	0.703	0.062
1980	0.393	0.319	0.475	0.051	1980	0.564	0.432	0.713	0.064
1981	0.413	0.337	0.497	0.051	1981	0.516	0.396	0.652	0.061
1982	0.446	0.367	0.534	0.051	1982	0.595	0.468	0.737	0.060
1983	0.599	0.506	0.703	0.051	1983	0.843	0.689	1.017	0.060
1984	0.516	0.431	0.611	0.051	1984	0.744	0.601	0.904	0.060
1985	0.605	0.511	0.708	0.051	1985	0.779	0.629	0.947	0.061
1986	0.748	0.640	0.867	0.051	1986	1.484	1.246	1.752	0.063
1987	0.514	0.428	0.609	0.051	1987	1.023	0.845	1.224	0.061
1988	0.460	0.379	0.550	0.051	1988	0.568	0.444	0.707	0.060
1989	0.364	0.292	0.444	0.051	1989	0.333	0.236	0.443	0.059
1990	0.209	0.151	0.273	0.052	1990	0.393	0.288	0.512	0.060
1991	0.153	0.101	0.210	0.051	1991	0.460	0.350	0.584	0.059
1992	0.406	0.330	0.490	0.051	1992	0.967	0.793	1.164	0.062
1993	0.284	0.219	0.355	0.051	1993	0.694	0.556	0.849	0.060
1994	0.239	0.180	0.305	0.051	1994	0.507	0.395	0.632	0.057
1995	0.272	0.210	0.341	0.050	1995	0.407	0.305	0.522	0.058
1996	0.311	0.245	0.384	0.050	1996	0.438	0.334	0.555	0.057
1997	0.409	0.333	0.492	0.050	1997	0.497	0.386	0.620	0.057
1998	0.416	0.340	0.500	0.051	1998	0.421	0.318	0.535	0.057
1999	0.371	0.299	0.450	0.051	1999	0.421	0.318	0.536	0.057
2000	0.545	0.456	0.643	0.051	2000	0.608	0.484	0.746	0.057
2001	0.370	0.298	0.449	0.051	2001	0.576	0.456	0.710	0.057
2002	0.439	0.361	0.526	0.051	2002	0.372	0.271	0.486	0.059
2003	0.372	0.299	0.452	0.051	2003	0.491	0.379	0.618	0.058
2004	0.600	0.506	0.704	0.051	2004	0.856	0.707	1.024	0.057
2005	0.752	0.644	0.871	0.051	2005	1.117	0.941	1.314	0.057
2006	1.094	0.954	1.250	0.051	2006	1.798	1.550	2.074	0.057
2007	1.046	0.908	1.199	0.051	2007	1.636	1.402	1.899	0.058
2008	1.787	1.578	2.019	0.052	2008	2.479	2.152	2.846	0.058
2009	1.289	1.126	1.470	0.052	2009	1.305	1.101	1.534	0.059
2010	1.170	1.019	1.338	0.052	2010	0.966	0.801	1.151	0.059
2011	1.395	1.222	1.585	0.052	2011	1.585	1.354	1.842	0.058
2012	1.523	1.331	1.737	0.054	2012	1.703	1.451	1.986	0.060
2013	1.409	1.231	1.607	0.053	2013	1.167	0.977	1.381	0.060
2014	2.249	1.963	2.570	0.059	2014	1.704	1.424	2.024	0.068

Table 2. Standardized annual CPUE (number of fish/hooks) with the 95% confidence limits for each area. Std Err (standard error): log scale. (Continued)

South	25-50S, 75-140E (A3R4)				North	0-20S, 20-120E			
Year	CPUE	Lower 95%	Upper 95%	Std Err	Year	CPUE	Lower 95%	Upper 95%	Std Err
					1954	11.311	10.462	12.226	0.038
					1955	10.480	9.909	11.084	0.028
					1956	5.650	5.359	5.956	0.025
					1957	9.706	9.118	10.330	0.031
					1958	12.635	11.645	13.705	0.040
1959	3.191	2.711	3.748	0.077	1959	7.949	7.401	8.536	0.035
1960	1.010	0.753	1.335	0.119	1960	5.273	4.973	5.590	0.028
1961	0.293	0.227	0.370	0.069	1961	4.953	4.618	5.310	0.033
1962	1.902	1.579	2.281	0.084	1962	4.252	4.039	4.475	0.024
1963	0.940	0.780	1.124	0.075	1963	2.971	2.811	3.138	0.025
1964	1.233	1.061	1.429	0.064	1964	4.499	4.278	4.731	0.024
1965	0.580	0.495	0.675	0.057	1965	2.551	2.418	2.691	0.024
1966	0.569	0.481	0.668	0.060	1966	1.963	1.859	2.072	0.023
1967	0.691	0.600	0.791	0.053	1967	1.885	1.786	1.990	0.023
1968	0.442	0.376	0.515	0.053	1968	1.728	1.633	1.828	0.024
1969	0.374	0.314	0.441	0.053	1969	1.694	1.591	1.803	0.026
1970	0.384	0.323	0.452	0.053	1970	1.148	1.072	1.230	0.026
1971	0.346	0.290	0.409	0.053	1971	1.170	1.087	1.258	0.028
1972	0.359	0.301	0.424	0.053	1972	1.228	1.111	1.353	0.038
1973	0.300	0.248	0.359	0.053	1973	1.506	1.270	1.775	0.068
1974	0.350	0.292	0.413	0.053	1974	0.993	0.886	1.108	0.041
1975	0.256	0.208	0.309	0.053	1975	0.777	0.681	0.881	0.044
1976	0.336	0.280	0.398	0.053	1976	0.557	0.449	0.678	0.062
1977	0.242	0.195	0.293	0.053	1977	0.949	0.798	1.120	0.061
1978	0.213	0.169	0.262	0.053	1978	0.680	0.602	0.764	0.039
1979	0.183	0.141	0.229	0.054	1979	0.532	0.451	0.620	0.047
1980	0.262	0.213	0.316	0.054	1980	0.781	0.695	0.874	0.039
1981	0.404	0.341	0.475	0.054	1981	0.977	0.855	1.111	0.048
1982	0.203	0.159	0.254	0.056	1982	1.124	1.047	1.206	0.027
1983	0.251	0.203	0.305	0.054	1983	0.838	0.705	0.988	0.059
1984	0.267	0.218	0.321	0.053	1984	0.721	0.650	0.797	0.034
1985	0.355	0.298	0.419	0.053	1985	0.838	0.767	0.913	0.031
1986	0.270	0.221	0.325	0.053	1986	0.999	0.927	1.076	0.027
1987	0.198	0.156	0.245	0.053	1987	1.077	0.969	1.194	0.039
1988	0.264	0.215	0.320	0.054	1988	1.006	0.845	1.188	0.063
1989	0.244	0.196	0.298	0.054	1989	0.880	0.775	0.995	0.044
1990	0.102	0.068	0.140	0.055	1990	1.259	1.141	1.386	0.038
1991	0.026	0.000	0.055	0.055	1991	0.985	0.885	1.092	0.038
1992	0.033	0.005	0.063	0.056	1992	0.609	0.547	0.674	0.033
1993	0.120	0.084	0.160	0.055	1993	1.108	0.988	1.237	0.042
1994	0.038	0.012	0.068	0.053	1994	0.655	0.599	0.713	0.028
1995	0.102	0.070	0.138	0.052	1995	0.534	0.487	0.585	0.027
1996	0.182	0.142	0.227	0.052	1996	0.931	0.861	1.005	0.028
1997	0.295	0.243	0.353	0.053	1997	0.745	0.695	0.796	0.023
1998	0.315	0.260	0.375	0.054	1998	1.263	1.210	1.318	0.017
1999	0.320	0.266	0.380	0.053	1999	0.664	0.627	0.702	0.018
2000	0.457	0.389	0.532	0.053	2000	0.483	0.455	0.511	0.016
2001	0.266	0.217	0.320	0.053	2001	0.835	0.797	0.873	0.016
2002	0.452	0.384	0.527	0.053	2002	0.783	0.746	0.821	0.016
2003	0.365	0.302	0.436	0.057	2003	0.798	0.761	0.837	0.016
2004	0.708	0.598	0.833	0.064	2004	0.744	0.708	0.781	0.016
2005	0.788	0.674	0.917	0.061	2005	0.584	0.556	0.612	0.015
2006	0.633	0.544	0.733	0.056	2006	0.516	0.492	0.541	0.014
2007	0.439	0.369	0.518	0.057	2007	0.748	0.718	0.779	0.014
2008	0.830	0.714	0.960	0.059	2008	0.582	0.554	0.612	0.015
2009	0.504	0.353	0.694	0.118	2009	0.595	0.563	0.628	0.017
2010	1.279	1.116	1.462	0.058	2010	0.542	0.493	0.593	0.028
2011	1.333	1.159	1.529	0.060	2011	0.643	0.428	0.915	0.119
2012	1.100	0.910	1.323	0.079	2012	0.361	0.307	0.419	0.038
2013	1.443	1.159	1.786	0.095	2013	0.370	0.324	0.420	0.032
2014	2.861	2.364	3.454	0.089	2014	0.511	0.448	0.579	0.037

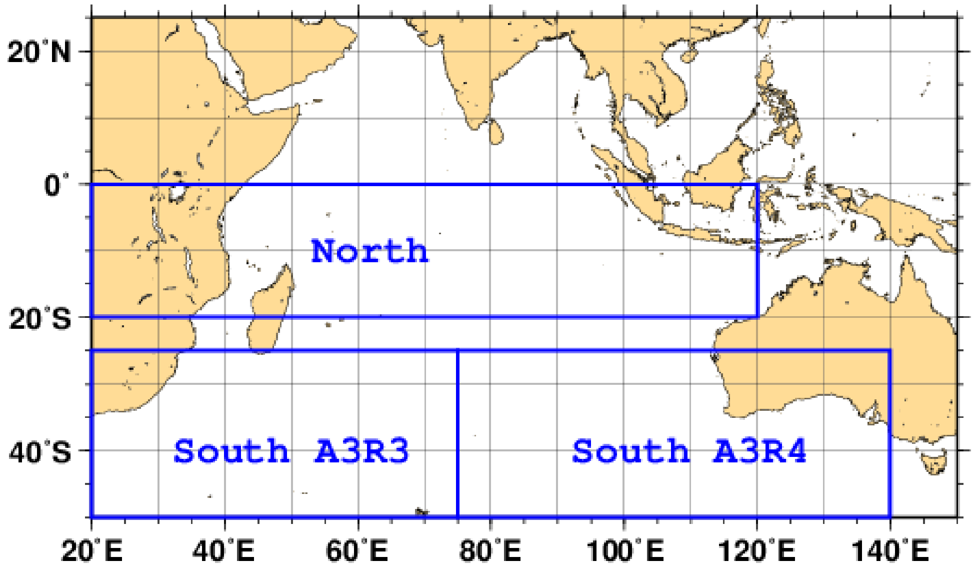


Fig. 1. Area used for the GLM analysis.

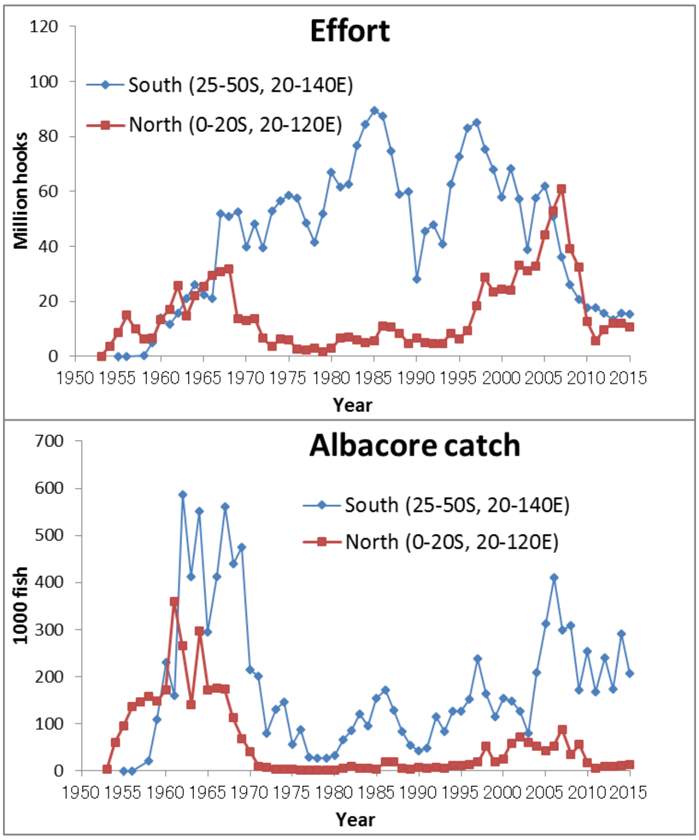
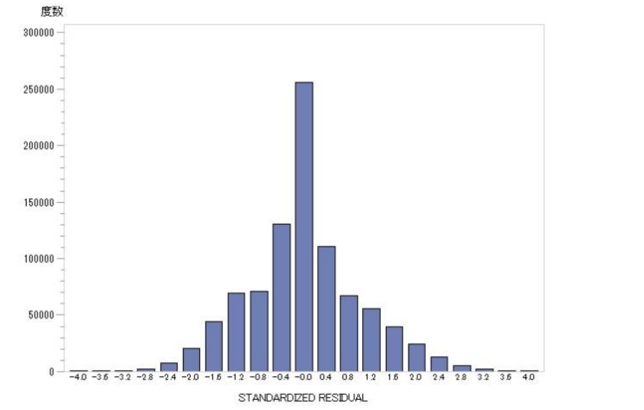
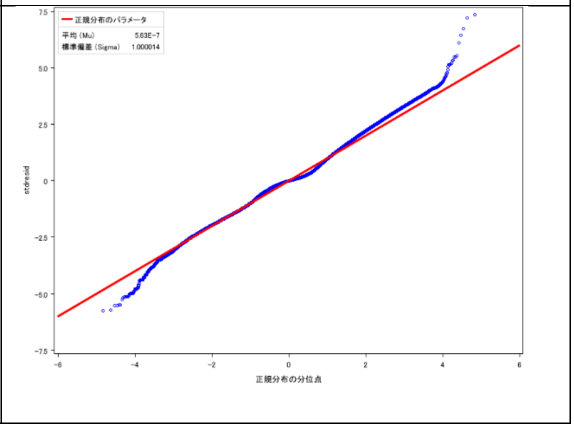


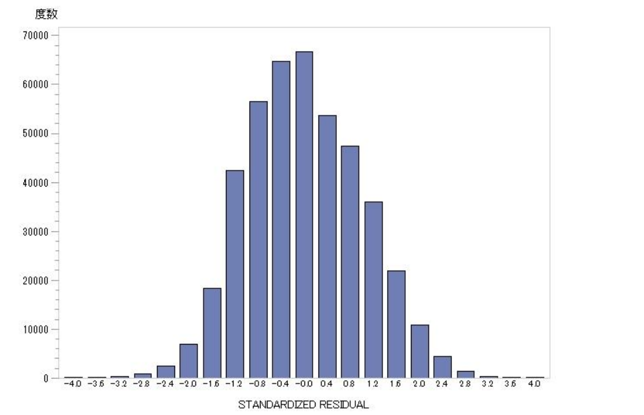
Fig. 2. Catch and effort in each area used for the GLM analysis.

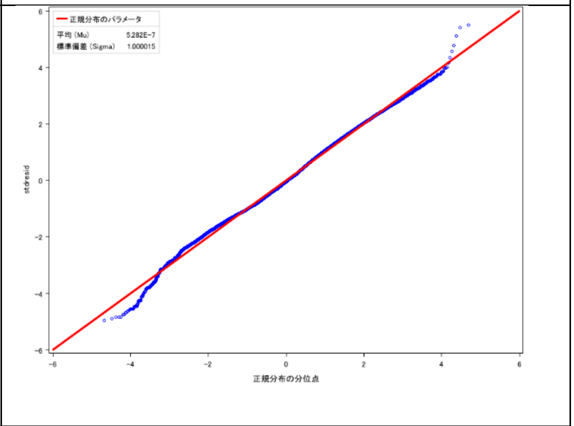
South A3R3+4 (25-50S, 20-140E)



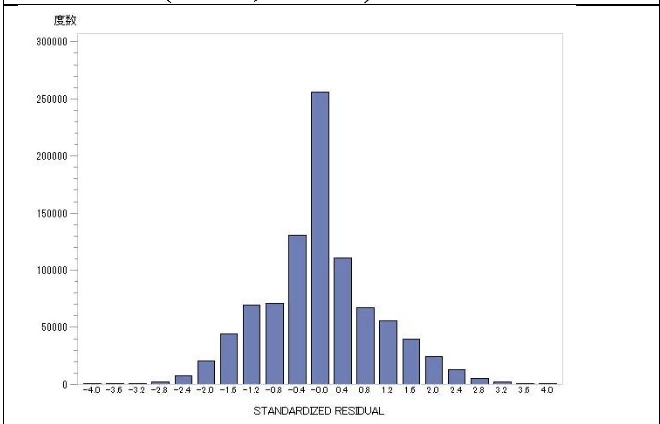


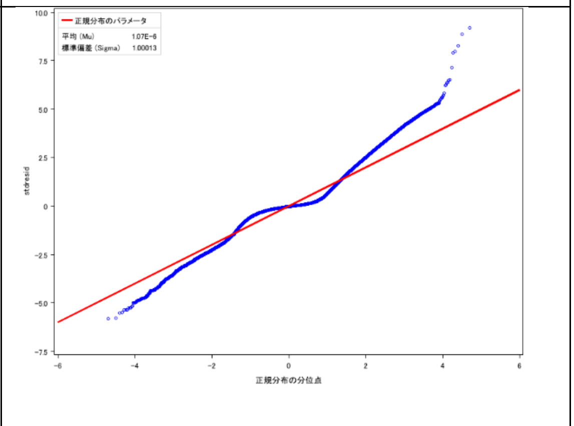
South A3R3 (25-50S, 20-75E)



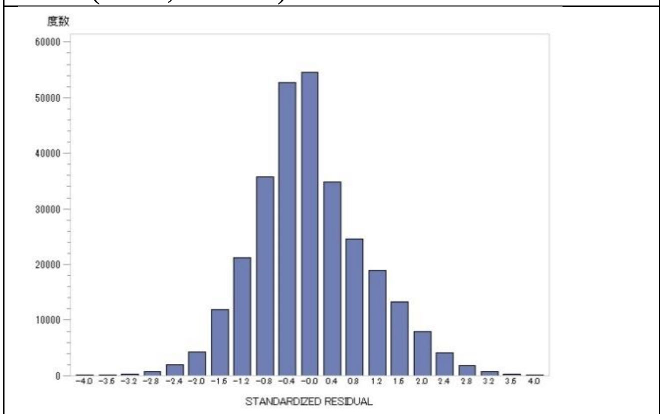


South A3R4 (25-50S, 75-140E)





North (0-20S, 20-120E)



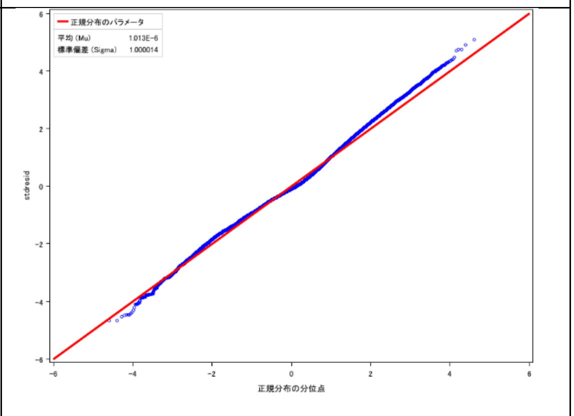
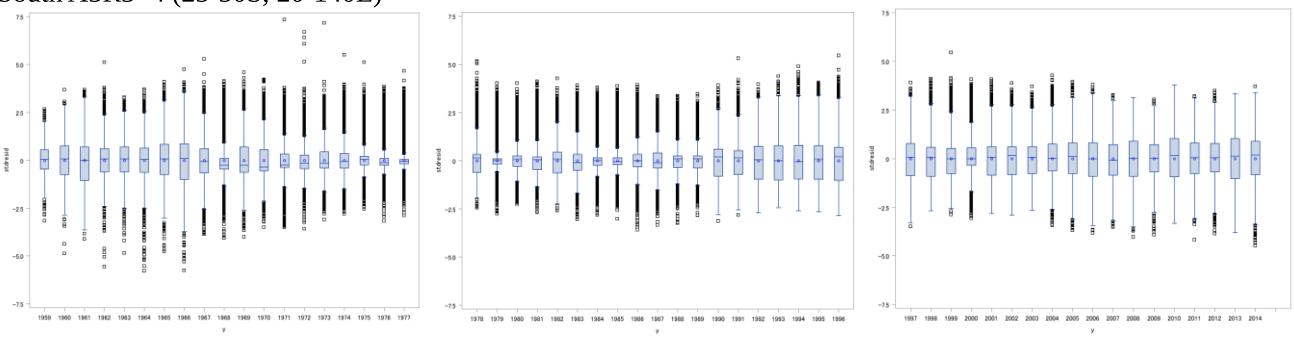
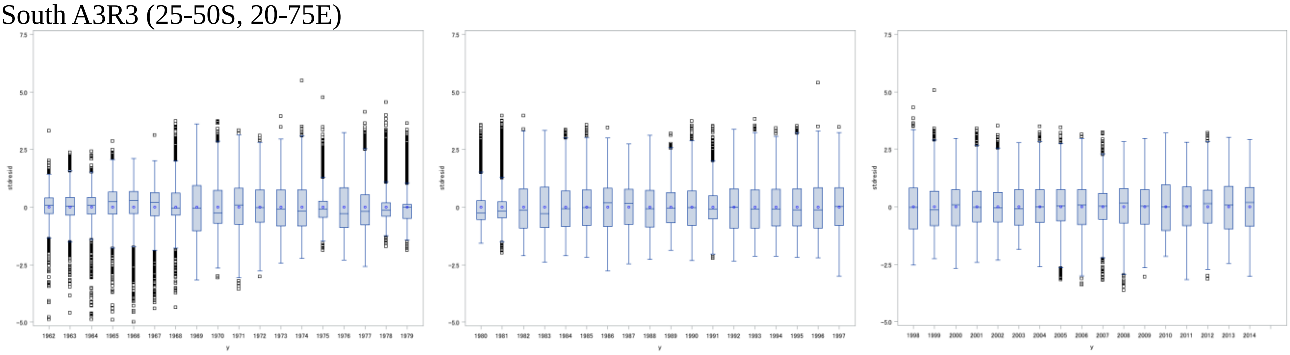


Fig. 3. Distribution of the standardized residual and QQ-plot of standardized residual.

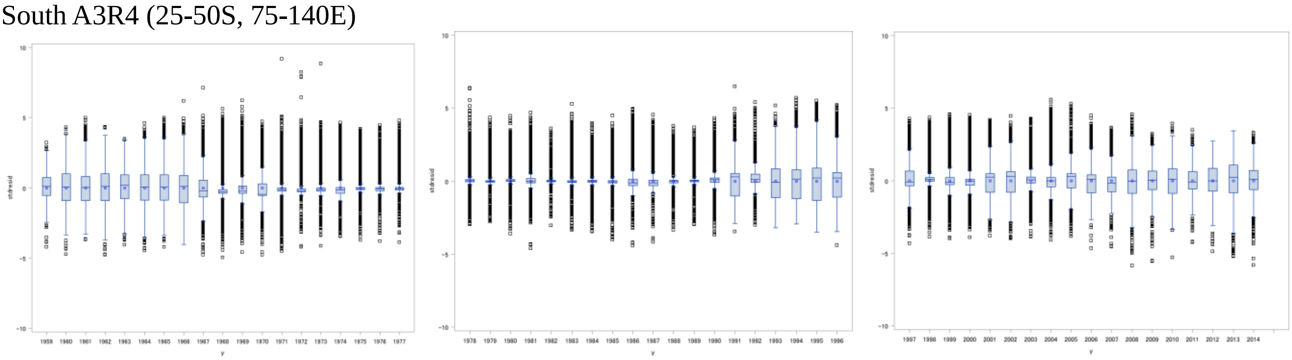
South A3R3+4 (25-50S, 20-140E)



South A3R3 (25-50S, 20-75E)



South A3R4 (25-50S, 75-140E)



North (0-20S, 20-120E)

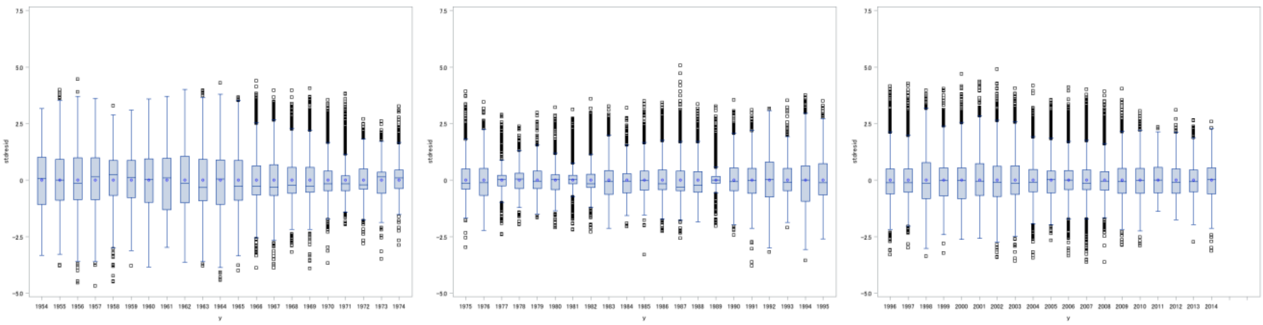


Fig. 4. Box plot of the standardized residual by year for the GLM analysis. Circle: mean, box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR below 25th percentile, squares: outliers.

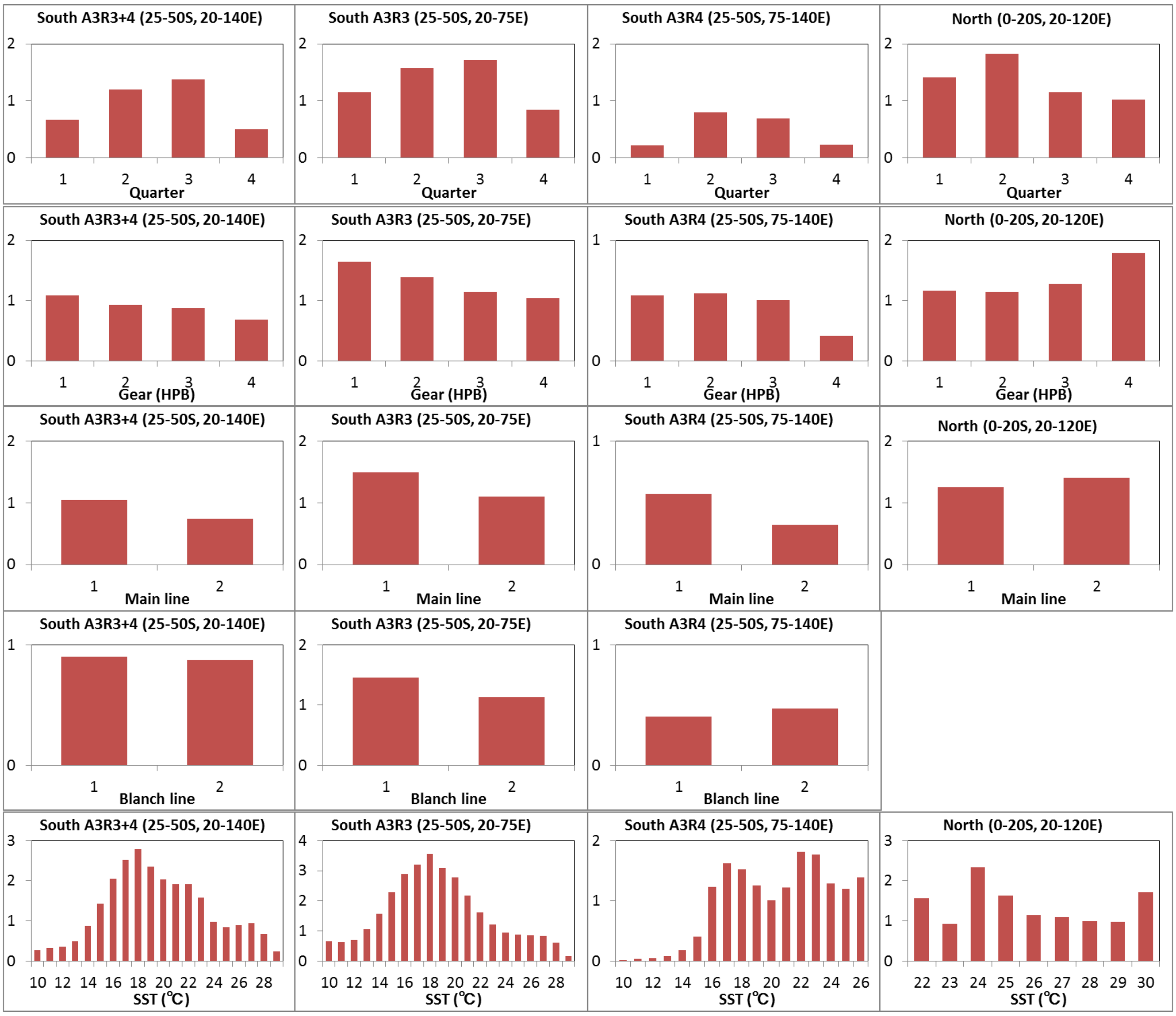


Fig. 5. Relative effects of for each factor.

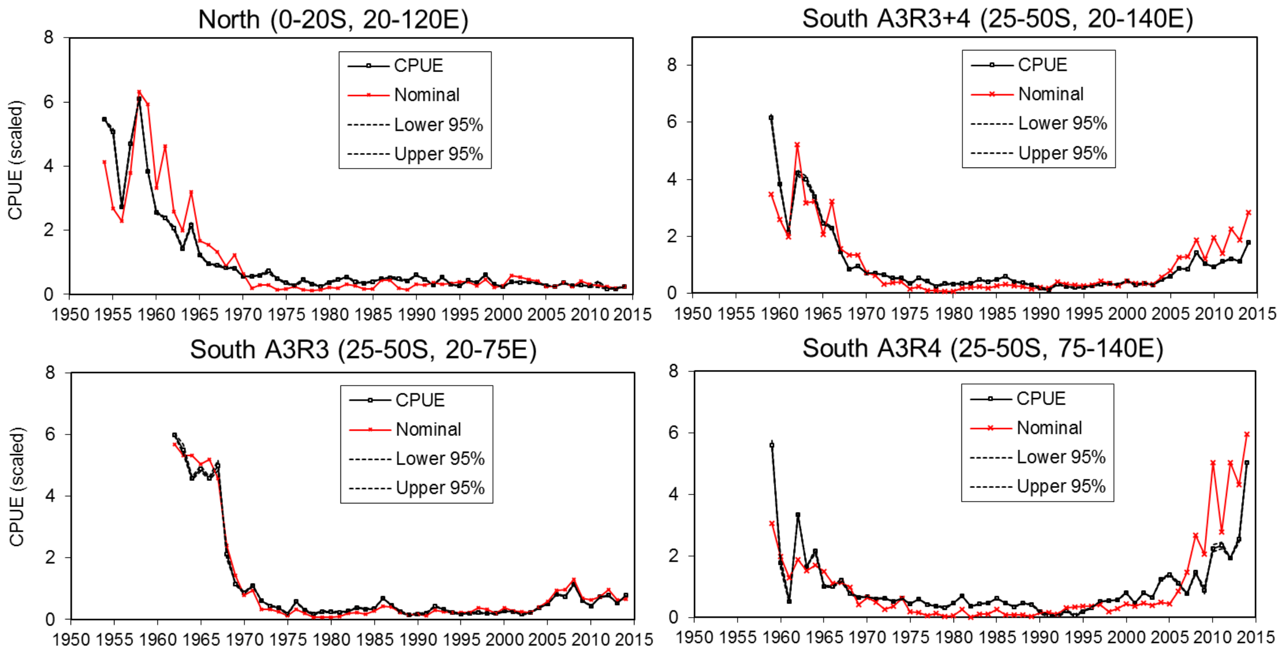


Fig. 6. Standardized CPUE (annual) for albacore in the Indian Ocean for each area with 95% confidence limits and nominal CPUE.