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

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Summary

Standardization of albacore CPUE by Japanese longline fishery in the Indian Ocean during 1975-2012 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 north and south area, of which the latter is regarded as core area. CPUE in the south area was comparatively constant until 2003 and then rapidly increased and decreased. CPUE in the north area increased with fluctuation between 1975 and 1993, and slightly decreased or kept similar level after that. Quarterly CPUE indicated strong seasonality. The effect of each factor in standardization usually differed by area.

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 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. Summary of albacore fishery by Japanese longline in the Indian Ocean including recent situations is reported by Matsumoto (2014).

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. This time, operational level catch and effort data were used for CPUE standardization as with previous analyses (Matsumoto et al., 2012). Along with annual CPUEs, quarterly CPUEs were also calculated for analyses based on stock synthesis 3 (SS3).

One concern for Indian Ocean albacore CPUE is different trend between Japanese and Taiwanese longline. It causes of non-convergence for stock assessment models. To solve this problem, 'core area' approach was examined, which is different from previous studies which used data for almost entire Indian Ocean.

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 1975-2012 were used, which include the number of hooks per basket (HPB). 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. 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, the period for CPUE standardization was set as 1975-2012.

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, 2014). Therefore, the area between 25 and 40°S and between 20 and 50°E was selected as core area. In addition, CPUE for north area (0-20°S, 20-120°E) was also calculated for SS3 two area analysis, in which boundary is suggested to be 20°S. 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 environmental factor, SST (Sea Surface Temperature) was applied. The original SST data, whose resolution was 1-degree latitude and 1-degree longitude by month from 1946 to 2013, was 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. SST was converted into integer value, and was used as categorical effect in 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). 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 the model of standardization of albacore CPUE, generalized linear model (GLM) with log-normal error structure (LN model) was used, which is the same as final models for the past analyses. Several changes were made from the models used by Matsumoto and Uosaki (2011) or Matsumoto et al. (2012) by adding the effects of gear material and SST, and by using 5 degree blocks instead of subareas. In addition to the effects mentioned above, the effect of fishing season (quarter) was used as with previous analyses. In order to include observations with no catch of albacore, a constant of 10% of mean CPUE was added to the CPUE. Initial model used is:

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

where
- μ: intercept — const: 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:

Standardized $CPUE_i$= EXP (LSM (Y_i)) – C (annual CPUE)

Standardized $CPUE_i$= EXP (LSM (Y_i*Q_j)) – C (quarterly CPUE)

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

Based on the result of ANOVA (type III SS), non-significant effects were removed in step-wise from the initial model based on the F-value ($p<0.05$). 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.

In the case of quarter based CPUE, least square means of Year-Quarter interaction in the result of above were used to calculate quarterly index. The analyses were conducted using SAS 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 each area. During early period (until around early 1970s), fishing effort mainly distributed in the north (tropical and subtropical) area. Fishing effort in both areas was similar level until around 1980. The effort in the south area was higher than that in the north area between mid-1980s and mid-1990s, and it reversed after that. The efforts in both areas sharply decreased during late 2000s, and were comparatively constant after 2010. Albacore catch in number was similar in both areas during early 1960s, and after that catch amount in the south area was usually larger than that in the north area.

Fig. 4 shows historical change in the number of operations for each 5-drgree latitude longitude block. In the south area, fishing effort had been comparatively constantly deployed in the block 10-12 (around 35^{o}S), whereas fishing effort increased in early 1990s in the block 2-3 (around 25^{o}S). In the north area, fishing effort had been comparatively equally distributed throughout the period.

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 material effect in the north area. As for main factor except for year effect, the effect of quarter was largest, followed by LT5LN5 in the south area. In the north area, the effect of LT5LN5 was largest, followed by SST. Table 2 shows annual CPUE indices with CV (log scale standard error) and confidence limits. The distributions of standardized residual are shown in Fig. 4 (distribution of standardized residual and QQ-plot) and Fig. 5 (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. It is probably because of several outliers observed during 2006-2008.

Fig. 6 shows relative effects of season, main and branch line materials, gear (HPB) and SST for GLM analyses. The trend was usually different between two areas. For example, Quarter 3 and had highest index for south, whereas quarter 2 in the north area. In the south area, nylon line got higher index for both main and branch lines, whereas the trend was opposite or almost the same effect was observed for north area. Trend of gear (HPB) effect was almost opposite between two areas: higher index for shallower gear in the south area and the opposite for north area. As for SST, 18^{o}C and 24^{o}C got highest index for south and north area, respectively. High value for 28^{o}C in the south area may be biased by small sample size and outliers.

Fig. 7 shows trend of standardized CPUE with confidence limits or nominal CPUE. CPUE in the south area was almost constant with fluctuation between 1975 and 2003, then rapidly increased, kept high between 2006 and 2008, and sharply decreased in 2009, although the index during 2009-2012 was higher than that before 2003.

CPUE in the north area increased with fluctuation between 1975 and 1993, and slightly decreased or kept similar level after that. Comparing standardized CPUE in the present study with that in the previous study (Matsumoto et al., 2012), trend of CPUE in the south area is similar to the previous one except for recent years (Fig. 8).

Table 3-4 and Fig. 9 show quarterly CPUEs. Strong seasonality of CPUE was observed in both areas.

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Table 1. Analysis of variance for the GLM analyses for 1975-2012.

South

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	199	86679.2359	435.574	335.16	<.0001
Error	187352	243482.735	1.2996		
Corr. Tot.	187551	330161.971			

R-square=	0.262535	C.V.=	132.0939		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	37	14157.08	382.62	294.42	<.0001
Q	3	771.17	257.06	197.80	<.0001
G	3	334.06	111.35	85.68	<.0001
ml	1	182.52	182.52	140.44	<.0001
bl	1	99.20	99.20	76.33	<.0001
sst	14	1887.86	134.85	103.76	<.0001
LT5LN5	14	3280.89	234.35	180.32	<.0001
Q*G	9	530.39	58.93	45.35	<.0001
y*Q	111	8368.38	75.39	58.01	<.0001
G*ml	3	236.87	78.96	60.75	<.0001
G*bl	3	45.42	15.14	11.65	<.0001

North

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	228	106118.128	465.4304	305.43	<.0001
Error	173322	264114.748	1.5238		
Corr. Tot.	173550	370232.876			

R-square=	0.286625	C.V.=	-142.3372		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	37	5117.31	138.31	90.76	<.0001
Q	3	653.24	217.75	142.89	<.0001
G	3	475.08	158.36	103.92	<.0001
ml	1	67.26	67.26	44.14	<.0001
bl	1	3.73	3.73	2.45	0.1176
sst	8	3554.92	444.37	291.61	<.0001
LT5LN5	49	57893.07	1181.49	775.34	<.0001
Q*G	9	849.89	94.43	61.97	<.0001
y*Q	111	6668.15	60.07	39.42	<.0001
G*ml	3	299.21	99.74	65.45	<.0001
G*bl	3	16.20	5.40	3.54	0.0139

Table 2. Standardized annual CPUE (number of fish/hooks) with the 95% confidence limits for each area for 1975-2012. Std Err (standard error): log scale.

	South				North			
Year	Std CPUE	Std Err	Lower CL	Upper CL	Std CPUE	Std Err	Lower CL	Upper CL
1975	0.882	0.0447	0.767	1.008	0.289	0.0553	0.246	0.338
1976	2.166	0.0466	1.934	2.420	0.230	0.0769	0.179	0.290
1977	1.533	0.0696	1.274	1.829	0.420	0.0762	0.343	0.509
1978	0.854	0.0361	0.762	0.953	0.274	0.0488	0.236	0.315
1979	0.936	0.0399	0.828	1.052	0.291	0.0586	0.245	0.343
1980	1.069	0.0453	0.936	1.214	0.356	0.0491	0.311	0.405
1981	0.901	0.0356	0.807	1.002	0.428	0.0598	0.366	0.498
1982	0.948	0.0316	0.861	1.040	0.579	0.0347	0.532	0.630
1983	1.196	0.0337	1.088	1.312	0.451	0.0732	0.373	0.542
1984	1.046	0.0345	0.946	1.154	0.406	0.0429	0.362	0.453
1985	1.130	0.0340	1.026	1.243	0.463	0.0389	0.419	0.511
1986	2.175	0.0384	1.981	2.383	0.579	0.0348	0.532	0.630
1987	1.417	0.0375	1.281	1.563	0.532	0.0491	0.470	0.599
1988	0.997	0.0321	0.906	1.094	0.511	0.0777	0.420	0.618
1989	0.731	0.0333	0.654	0.814	0.406	0.0553	0.351	0.468
1990	0.806	0.0311	0.729	0.887	0.770	0.0474	0.689	0.858
1991	1.029	0.0276	0.949	1.114	0.650	0.0481	0.580	0.728
1992	1.679	0.0342	1.538	1.830	0.564	0.0412	0.510	0.623
1993	1.325	0.0290	1.224	1.432	0.686	0.0529	0.605	0.776
1994	1.142	0.0196	1.080	1.206	0.468	0.0355	0.427	0.511
1995	0.863	0.0225	0.804	0.924	0.512	0.0344	0.470	0.557
1996	0.888	0.0188	0.838	0.941	0.568	0.0352	0.521	0.618
1997	0.985	0.0183	0.933	1.039	0.437	0.0293	0.405	0.471
1998	0.821	0.0196	0.772	0.873	0.861	0.0218	0.820	0.905
1999	0.836	0.0200	0.784	0.889	0.432	0.0238	0.406	0.459
2000	1.220	0.0219	1.148	1.295	0.330	0.0217	0.310	0.350
2001	1.166	0.0226	1.094	1.242	0.557	0.0208	0.530	0.586
2002	0.839	0.0293	0.765	0.918	0.586	0.0212	0.557	0.617
2003	1.121	0.0261	1.041	1.206	0.567	0.0214	0.538	0.597
2004	1.611	0.0225	1.520	1.706	0.446	0.0214	0.422	0.471
2005	2.225	0.0205	2.118	2.336	0.326	0.0196	0.308	0.344
2006	4.079	0.0193	3.909	4.255	0.304	0.0183	0.289	0.320
2007	3.306	0.0240	3.132	3.489	0.505	0.0185	0.482	0.529
2008	4.600	0.0245	4.362	4.851	0.361	0.0203	0.341	0.381
2009	2.180	0.0292	2.032	2.338	0.428	0.0219	0.404	0.452
2010	1.387	0.0277	1.288	1.492	0.406	0.0362	0.369	0.446
2011	2.060	0.0248	1.939	2.188	0.577	0.1617	0.384	0.843
2012	2.356	0.0316	2.185	2.538	0.246	0.0515	0.209	0.286

Table 3. Standardized quarterly CPUE (number of fish/hooks) for south area for 1975-2012. Std Err (standard error): log scale.

Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err
1975	1	0.59526	0.1121	1985	1	0.89456	0.0727	1995	1	1.33644	0.0314	2005	1	1.92622	0.0427
1975	2	1.77171	0.1027	1985	2	1.32604	0.0378	1995	2	0.7285	0.0244	2005	2	1.46227	0.0309
1975	3	1.58484	0.0380	1985	3	2.20161	0.0297	1995	3	1.03454	0.0277	2005	3	3.60251	0.0234
1975	4	0.20455	0.0750	1985	4	0.52812	0.0964	1995	4	0.49683	0.0688	2005	4	2.32196	0.0419
1976	1	0.95934	0.0688	1986	1	2.16331	0.0585	1996	1	1.14844	0.0313	2006	1	1.91856	0.0381
1976	2	3.71786	0.1100	1986	2	2.72028	0.0433	1996	2	0.51163	0.0243	2006	2	6.03855	0.0317
1976	3	3.6324	0.0434	1986	3	2.36568	0.0285	1996	3	0.82044	0.0249	2006	3	8.62746	0.0248
1976	4	1.48732	0.1192	1986	4	1.58221	0.1268	1996	4	1.18814	0.0487	2006	4	2.54702	0.0383
1977	1	1.21896	0.1709	1987	1	1.29819	0.0908	1997	1	0.71158	0.0337	2007	1	1.20715	0.0456
1977	2	2.677	0.1646	1987	2	2.24235	0.0471	1997	2	0.81862	0.0253	2007	2	5.05381	0.0526
1977	3	2.30354	0.0505	1987	3	2.8296	0.0276	1997	3	2.1884	0.0233	2007	3	5.88074	0.0275
1977	4	0.61656	0.1279	1987	4	0.3238	0.1007	1997	4	0.63253	0.0423	2007	4	2.9722	0.0479
1978	1	0.23247	0.0568	1988	1	0.96568	0.0716	1998	1	1.11715	0.0315	2008	1	2.45195	0.0511
1978	2	1.3673	0.0814	1988	2	1.2484	0.0492	1998	2	0.70068	0.0260	2008	2	4.4984	0.0479
1978	3	0.75393	0.0385	1988	3	1.66597	0.0273	1998	3	1.56283	0.0251	2008	3	9.36713	0.0336
1978	4	1.46365	0.0865	1988	4	0.40608	0.0823	1998	4	0.26207	0.0503	2008	4	4.15024	0.0477
1979	1	0.54762	0.0576	1989	1	0.43651	0.0910	1999	1	0.85776	0.0359	2009	1	2.76176	0.0536
1979	2	1.26693	0.0794	1989	2	1.06198	0.0466	1999	2	0.60741	0.0281	2009	2	1.20812	0.0641
1979	3	1.23907	0.0444	1989	3	1.14122	0.0246	1999	3	1.12262	0.0291	2009	3	4.38757	0.0366
1979	4	0.82155	0.1095	1989	4	0.4571	0.0723	1999	4	0.80408	0.0453	2009	4	1.39641	0.0614
1980	1	1.34665	0.0610	1990	1	0.58249	0.0588	2000	1	0.81062	0.0491	2010	1	1.23319	0.0625
1980	2	1.38863	0.0948	1990	2	0.85896	0.0408	2000	2	0.68735	0.0340	2010	2	2.13168	0.0441
1980	3	0.79695	0.0367	1990	3	1.13637	0.0264	2000	3	2.14097	0.0268	2010	3	1.36826	0.0418
1980	4	0.83896	0.1306	1990	4	0.70716	0.0898	2000	4	1.62929	0.0442	2010	4	0.98885	0.0558
1981	1	0.55811	0.0541	1991	1	0.48404	0.0575	2001	1	1.18025	0.0462	2011	1	1.69136	0.0452
1981	2	1.07389	0.0611	1991	2	0.74801	0.0445	2001	2	0.54693	0.0378	2011	2	2.16146	0.0421
1981	3	1.5678	0.0326	1991	3	1.54872	0.0280	2001	3	1.30823	0.0272	2011	3	3.95918	0.0357
1981	4	0.61842	0.1046	1991	4	1.67605	0.0690	2001	4	1.92597	0.0473	2011	4	1.15318	0.0593
1982	1	0.49554	0.0527	1992	1	1.39244	0.0413	2002	1	1.3306	0.0418	2012	1	1.30005	0.0548
1982	2	1.26269	0.0529	1992	2	1.42796	0.0287	2002	2	0.65938	0.0352	2012	2	3.80812	0.0426
1982	3	1.18263	0.0259	1992	3	1.97655	0.0243	2002	3	1.61796	0.0301	2012	3	5.5487	0.0370
1982	4	0.98808	0.0894	1992	4	1.99538	0.1188	2002	4	0.2166	0.0906	2012	4	0.92036	0.0908
1983	1	0.52036	0.0708	1993	1	1.19378	0.0487	2003	1	1.46935	0.0492				
1983	2	1.69019	0.0626	1993	2	1.35416	0.0326	2003	2	0.77626	0.0388				
1983	3	2.13515	0.0330	1993	3	1.29843	0.0264	2003	3	0.70983	0.0328				
1983	4	0.9065	0.0808	1993	4	1.46495	0.0888	2003	4	1.77256	0.0634				
1984	1	0.81066	0.0806	1994	1	1.64602	0.0368	2004	1	1.80559	0.0487				
1984	2	1.29935	0.0519	1994	2	1.03316	0.0235	2004	2	0.94313	0.0328				
1984	3	1.18422	0.0273	1994	3	1.19987	0.0244	2004	3	2.00166	0.0241				

1984	4	0.94018	0.0860	1994	4	0.79841	0.0502	2004	4	1.88479	0.0494

Table 4. Standardized quarterly CPUE (number of fish/hooks) for north area for 1975-2012. Std Err (standard error): log scale.

Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err
1975	1	0.27723	0.0726	1985	1	0.30377	0.0440	1995	1	0.61391	0.0513	2005	1	0.29721	0.0273
1975	2	0.38925	0.1753	1985	2	0.82477	0.0936	1995	2	0.5226	0.0848	2005	2	0.87773	0.0348
1975	3	0.43706	0.0546	1985	3	0.42942	0.0558	1995	3	0.38122	0.0751	2005	3	0.21175	0.0339
1975	4	0.12695	0.0552	1985	4	0.40392	0.0822	1995	4	0.55336	0.0413	2005	4	0.16156	0.0272
1976	1	0.29452	0.0636	1986	1	0.84874	0.0323	1996	1	0.41987	0.0508	2006	1	0.40838	0.0272
1976	2	0.32881	0.2613	1986	2	0.53251	0.0927	1996	2	0.5899	0.1000	2006	2	0.66675	0.0307
1976	3	0.1379	0.0880	1986	3	0.47908	0.0672	1996	3	1.12813	0.0608	2006	3	0.13574	0.0310
1976	4	0.19238	0.0905	1986	4	0.5111	0.0435	1996	4	0.34584	0.0327	2006	4	0.18014	0.0247
1977	1	1.04067	0.1035	1987	1	0.80005	0.0333	1997	1	0.38324	0.0347	2007	1	0.52847	0.0250
1977	2	0.26939	0.2604	1987	2	0.24006	0.1067	1997	2	0.50692	0.0822	2007	2	0.81613	0.0280
1977	3	0.27262	0.0787	1987	3	0.436	0.1466	1997	3	0.44554	0.0504	2007	3	0.41271	0.0318
1977	4	0.35317	0.0595	1987	4	0.85072	0.0401	1997	4	0.41951	0.0285	2007	4	0.35004	0.0270
1978	1	0.51596	0.0789	1988	1	0.88596	0.0365	1998	1	1.05986	0.0267	2008	1	0.40817	0.0286
1978	2	0.22657	0.1402	1988	2	0.5743	0.2929	1998	2	1.46256	0.0438	2008	2	0.64321	0.0357
1978	3	0.1926	0.0682	1988	3	0.38933	0.0665	1998	3	0.7815	0.0447	2008	3	0.20774	0.0375
1978	4	0.22655	0.0621	1988	4	0.32408	0.0501	1998	4	0.42801	0.0311	2008	4	0.28147	0.0278
1979	1	0.29519	0.1051	1989	1	0.37227	0.0426	1999	1	0.24111	0.0355	2009	1	0.42157	0.0280
1979	2	0.23667	0.1507	1989	2	0.30398	0.1424	1999	2	1.4594	0.0551	2009	2	0.87412	0.0375
1979	3	0.30737	0.0909	1989	3	0.53874	0.1372	1999	3	0.49411	0.0414	2009	3	0.16964	0.0474
1979	4	0.32991	0.0946	1989	4	0.43687	0.0658	1999	4	0.13845	0.0276	2009	4	0.45065	0.0291
1980	1	0.34476	0.0750	1990	1	0.71696	0.0392	2000	1	0.35843	0.0318	2010	1	0.43222	0.0355
1980	2	0.23192	0.1397	1990	2	2.59803	0.1495	2000	2	0.62289	0.0392	2010	2	0.61659	0.0645
1980	3	0.38204	0.0831	1990	3	0.42923	0.0862	2000	3	0.14491	0.0373	2010	3	0.3459	0.1102
1980	4	0.50199	0.0544	1990	4	0.3746	0.0488	2000	4	0.31065	0.0334	2010	4	0.28234	0.0388
1981	1	0.37067	0.0421	1991	1	0.48066	0.0497	2001	1	0.49856	0.0318	2011	1	0.24742	0.0557
1981	2	0.57402	0.2134	1991	2	1.27263	0.1478	2001	2	1.26269	0.0412	2011	2	1.08998	0.4674
1981	3	0.54481	0.0636	1991	3	0.66596	0.0771	2001	3	0.42655	0.0356	2011	3	1.42787	0.4378
1981	4	0.27743	0.0449	1991	4	0.41273	0.0596	2001	4	0.3267	0.0336	2011	4	0.21626	0.0491
1982	1	0.69195	0.0510	1992	1	0.54833	0.0567	2002	1	0.42694	0.0324	2012	1	0.34041	0.0490
1982	2	0.47968	0.0905	1992	2	1.15679	0.1099	2002	2	1.92355	0.0464	2012	2	0.36603	0.1603
1982	3	0.63866	0.0520	1992	3	0.20788	0.0757	2002	3	0.32355	0.0353	2012	3	0.14682	0.1025
1982	4	0.5271	0.0438	1992	4	0.65301	0.0629	2002	4	0.37547	0.0262	2012	4	0.17804	0.0386
1983	1	0.37326	0.0499	1993	1	0.49354	0.0628	2003	1	0.52374	0.0274				
1983	2	0.21856	0.2715	1993	2	1.37427	0.1746	2003	2	0.89544	0.0421				
1983	3	0.64883	0.0470	1993	3	0.66811	0.0748	2003	3	0.35983	0.0402				
1983	4	0.70291	0.0576	1993	4	0.46217	0.0458	2003	4	0.58729	0.0321				
1984	1	0.64077	0.0716	1994	1	0.38622	0.0441	2004	1	0.46239	0.0301				
1984	2	0.17972	0.1067	1994	2	0.87961	0.0946	2004	2	1.12581	0.0442				
1984	3	0.44422	0.0492	1994	3	0.29701	0.0721	2004	3	0.19286	0.0385				
1984	4	0.46864	0.0833	1994	4	0.44351	0.0408	2004	4	0.32601	0.0276				

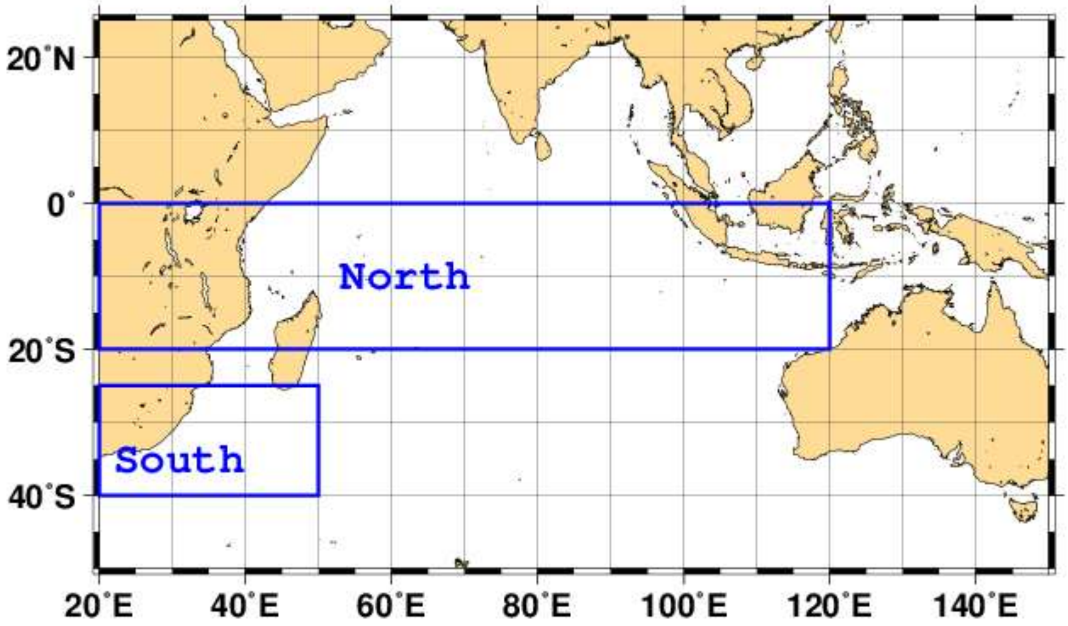

Fig. 1. Area used for the GLM analysis.

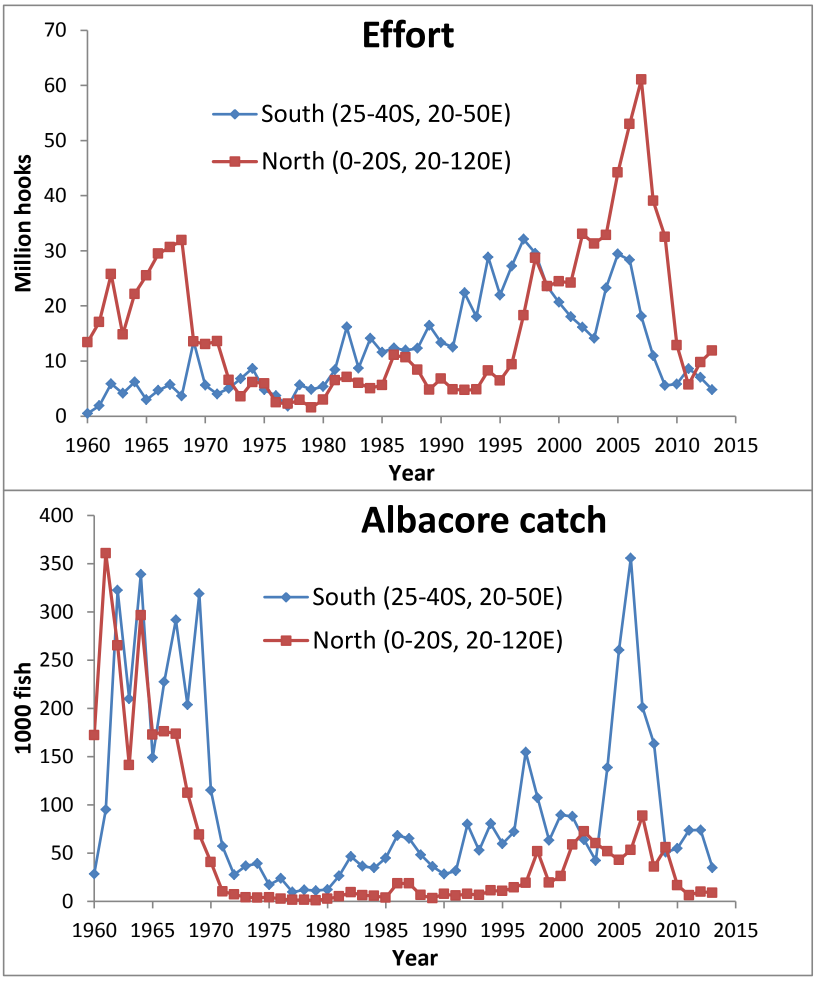

Fig. 2. Catch and effort in each area used for the GLM analysis.

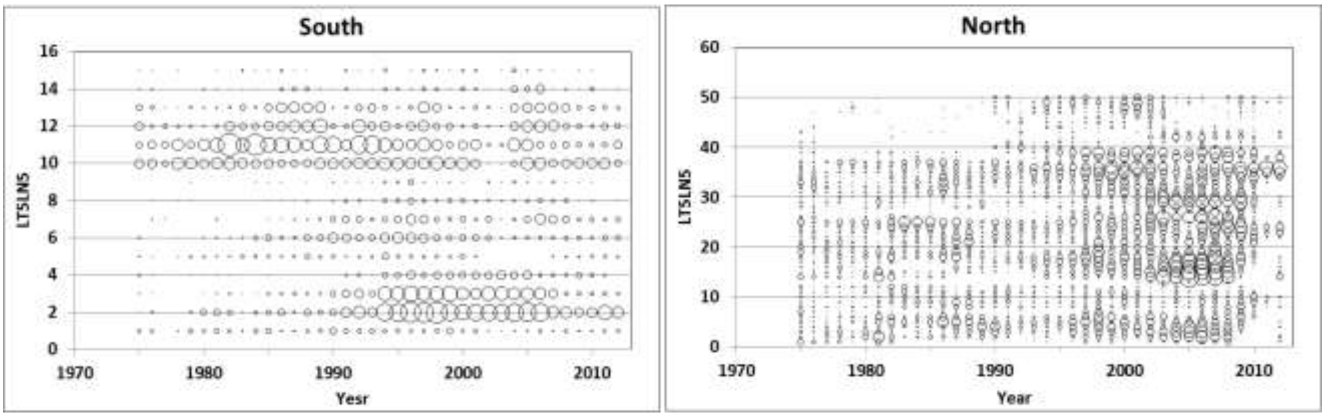

Fig. 3. Historical distribution of the fishing effort in each 5-degree latitude longitude block. Left: south area, right: north area.

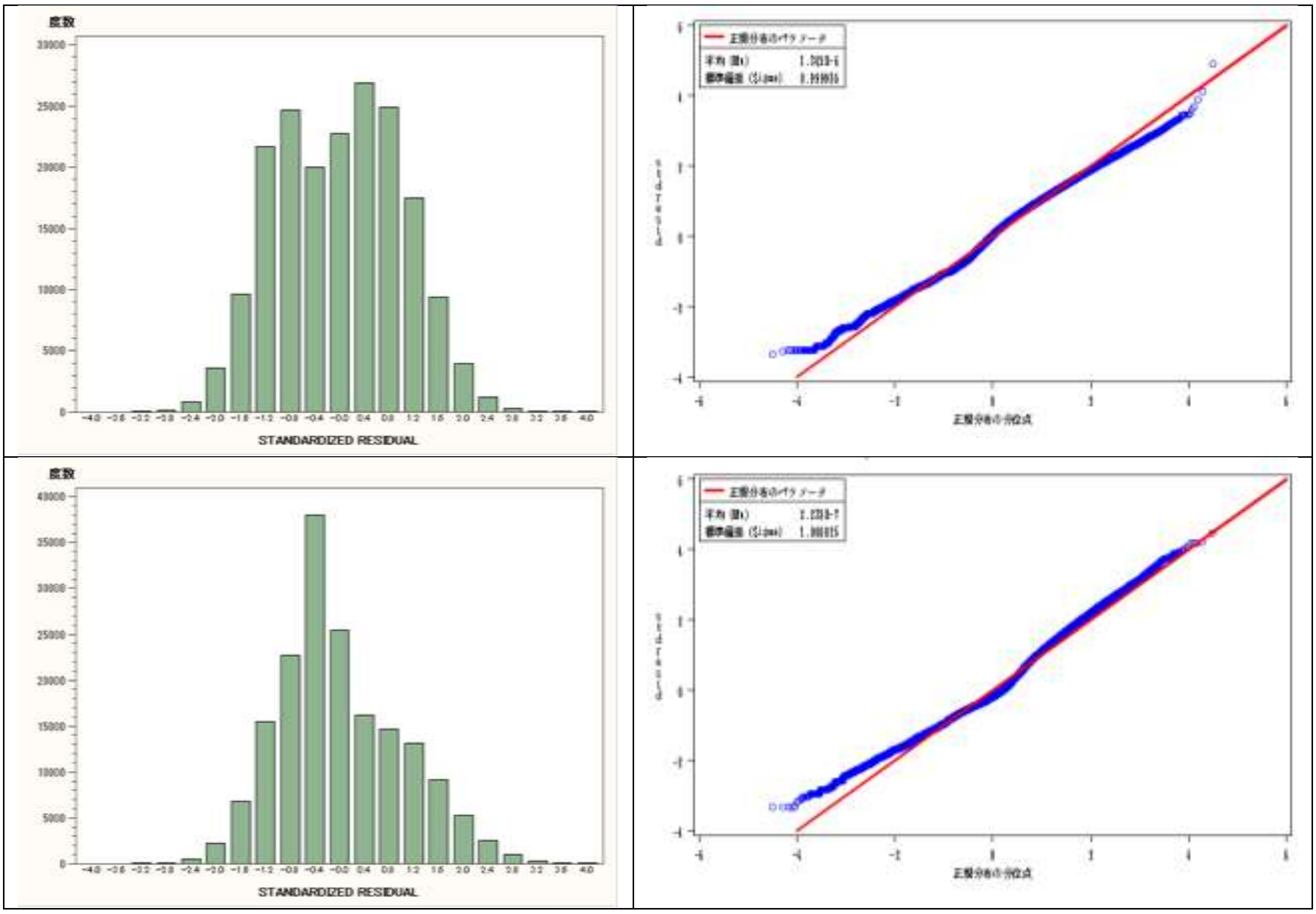

Fig. 4. Distribution of the standardized residual and QQ-plot of standardized residual. Upper: south area, lower: north area.

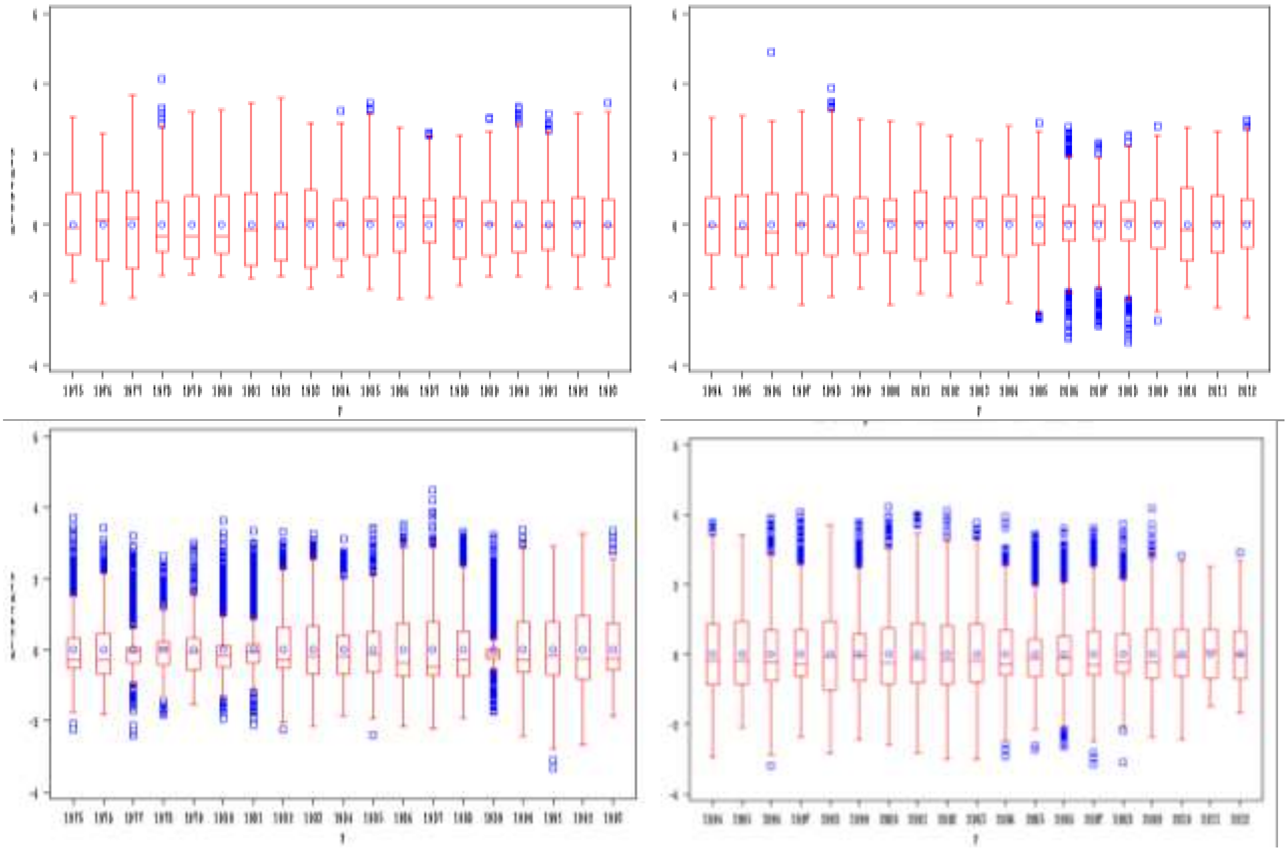

Fig. 5. Box plot of the standardized residual by year for the GLM analysis (upper: south area, lower: north area). Circle: mean, box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR below 25th percentile, squares: outliers.

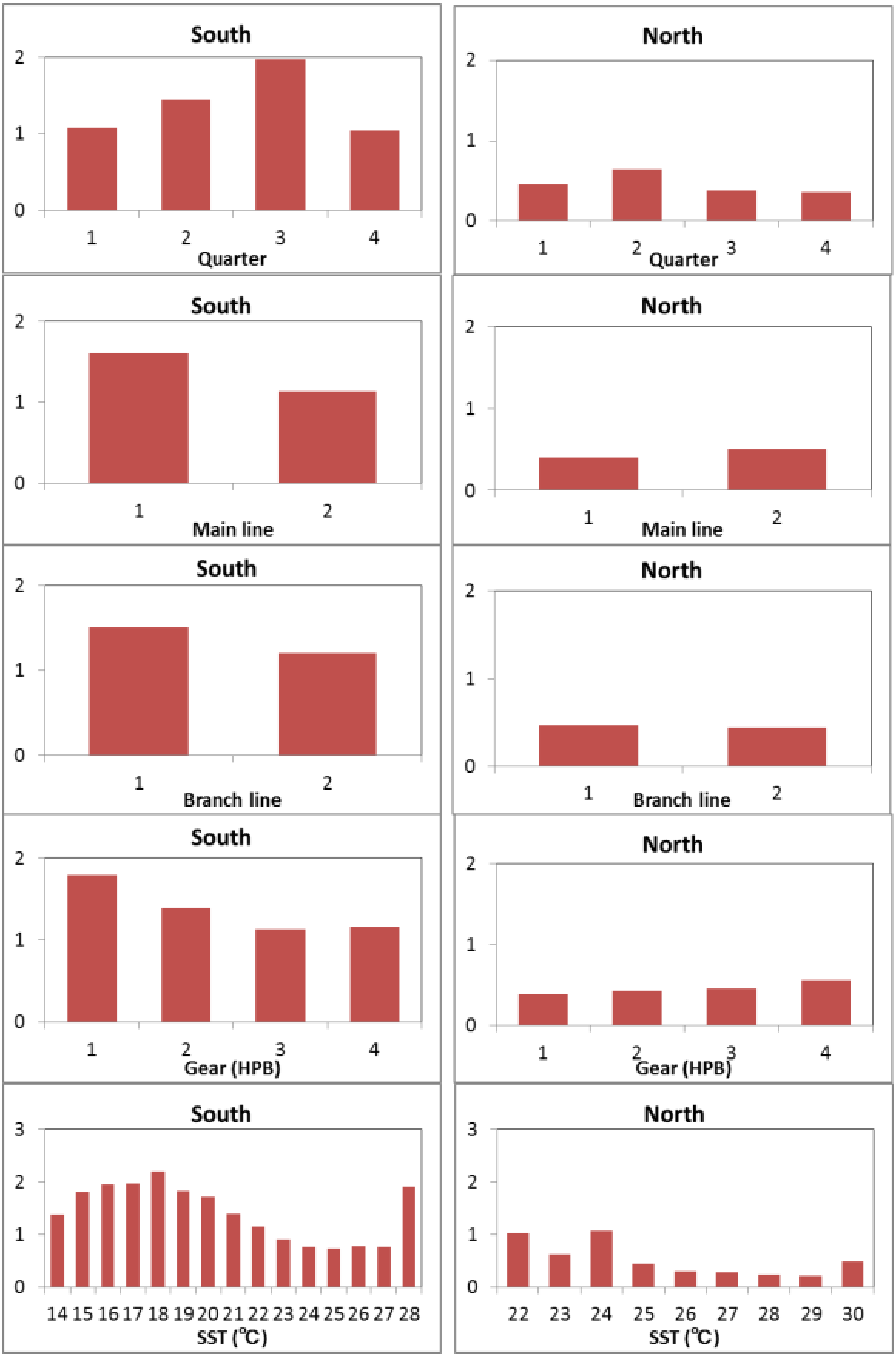

Fig. 6. Relative effects of for each factor.

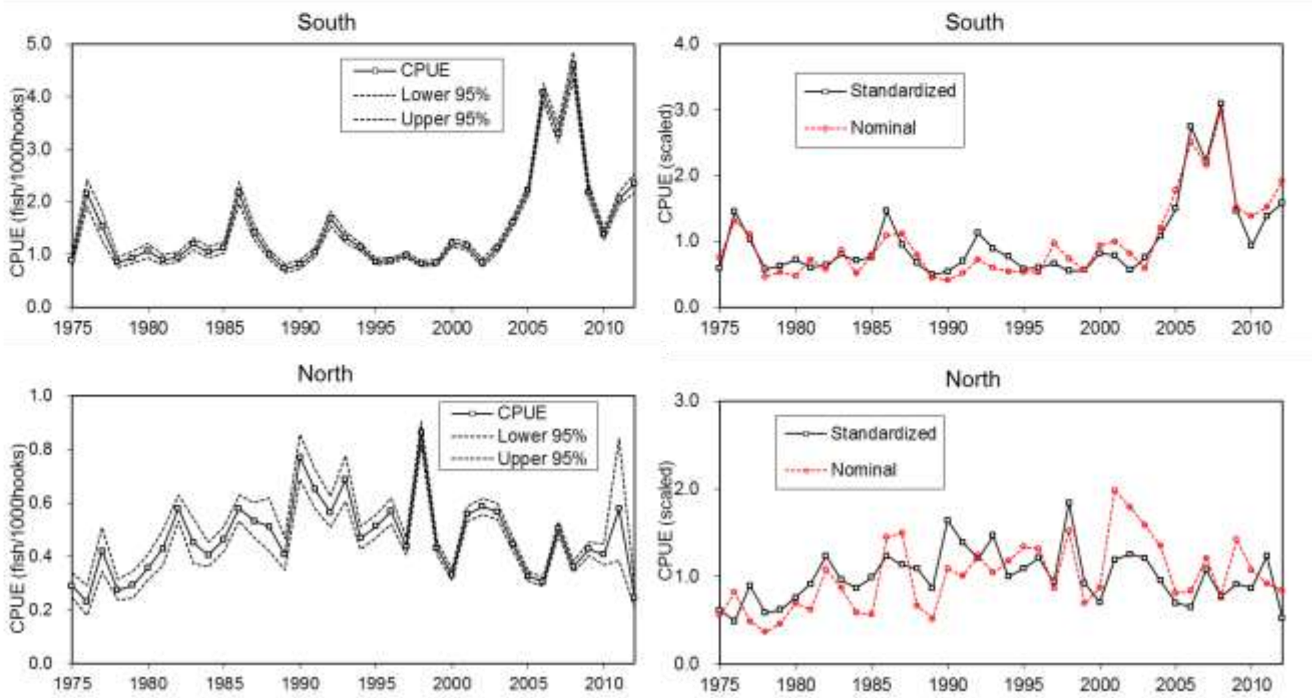

Fig. 7. Standardized CPUE (annual) for albacore in the Indian Ocean for each area. Left: real scale CPUE with 95% confidence limits, right: relative scale CPUE along with nominal CPUE, in which the indices were scaled by dividing by the average.

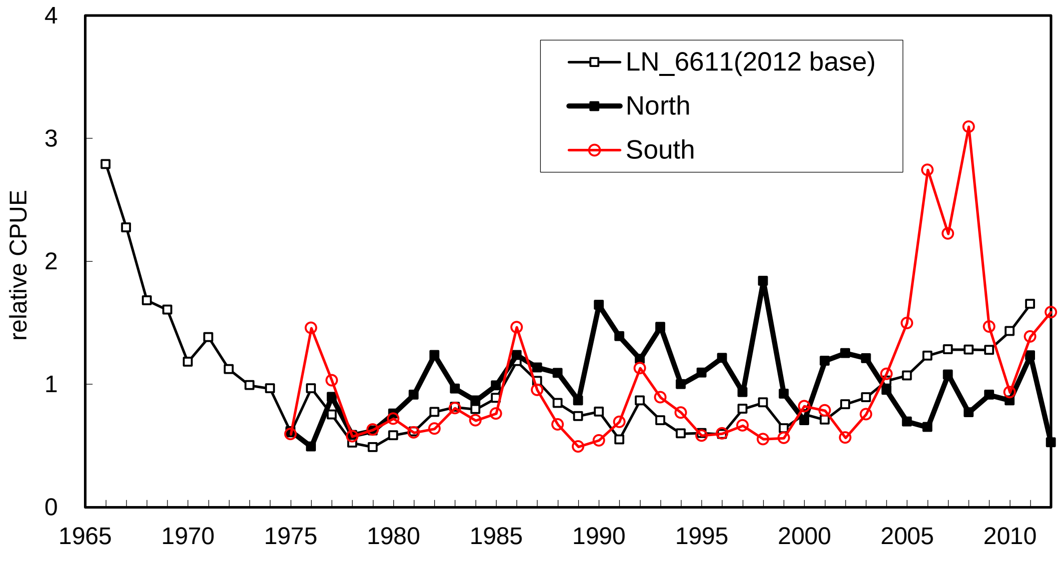

Fig. 8. Comparison of standardized CPUEs (annual) with that for previous study (Matsumoto et al., 2012, LN model).

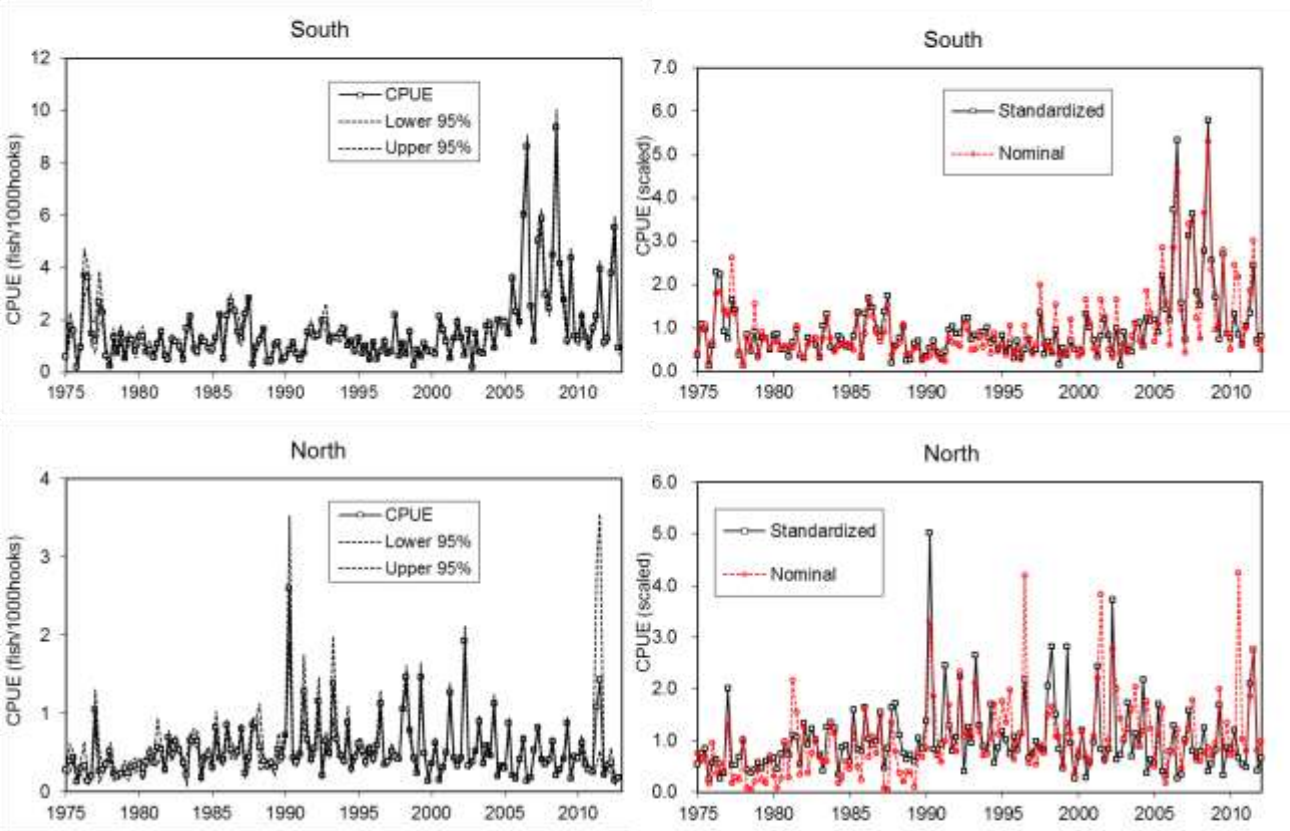

Fig. 9. Standardized CPUE (quarterly) for albacore in the Indian Ocean for each area. Left: real scale CPUE with 95% confidence limits, right: relative scale CPUE along with nominal CPUE, in which the indices were scaled by dividing by the average.

Appendix

In response to the request at IOTC WPTmT05, CPUE series covering the period up to 2013 was created. The methods are the same as those described in the MATERIALS AND METHODS. Catch and effort data for 2013 are preliminary.

The analysis of variance for the GLM analyses is shown in Table 5 .The results are similar to those for the analyses for 1975-2012. CPUE in 2013 slightly decreased in the south area and slightly increased in the north area (Fig. 10).

Table 5. Analysis of variance for the GLM analyses for 1975-2013.

South

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	203	87163.9807	429.3792	330.42	<.0001
Error	189346	246051.389	1.2995		
Corr. Tot.	189549	333215.37			
R-square=	0.261585	C.V.=	131.5369		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	38	14035.03	369.34	284.22	<.0001
Q	3	750.48	250.16	192.51	<.0001
G	3	326.37	108.79	83.72	<.0001
ml	1	184.56	184.56	142.02	<.0001
bl	1	101.11	101.11	77.81	<.0001
sst	14	1925.36	137.53	105.83	<.0001
LT5LN5	14	3615.34	258.24	198.72	<.0001
Q*G	9	526.55	58.51	45.02	<.0001
y*Q	114	8369.31	73.42	56.50	<.0001
G*ml	3	239.01	79.67	61.31	<.0001
G*bl	3	43.90	14.63	11.26	<.0001

North

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	232	107493.565	463.3343	304.49	<.0001
Error	175668	267308.227	1.5217		
Corr. Tot.	175900	374801.792			
R-square=	0.286801	C.V.=	-141.8358		

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
y	38	5206.62	137.02	90.04	<.0001
Q	3	735.98	245.33	161.22	<.0001
G	3	475.93	158.64	104.26	<.0001
ml	1	64.51	64.51	42.40	<.0001
bl	1	3.04	3.04	2.00	0.1574
sst	8	3614.98	451.87	296.96	<.0001
LT5LN5	49	58624.67	1196.42	786.26	<.0001
Q*G	9	877.96	97.55	64.11	<.0001
y*Q	114	6755.33	59.26	38.94	<.0001
G*ml	3	315.90	105.30	69.20	<.0001
G*bl	3	19.49	6.50	4.27	0.0051

Table 6. Standardized annual CPUE (number of fish/hooks) with the 95% confidence limits for each area for 1975-2013. Std Err (standard error): log scale.

	South				North			
Year	Std CPUE	Std Err	Lower CL	Upper CL	Std CPUE	Std Err	Lower CL	Upper CL
1975	0.893	0.0447	0.776	1.020	0.291	0.0552	0.247	0.339
1976	2.187	0.0466	1.953	2.444	0.232	0.0768	0.180	0.291
1977	1.548	0.0696	1.287	1.846	0.421	0.0762	0.344	0.511
1978	0.864	0.0361	0.771	0.964	0.274	0.0487	0.237	0.315
1979	0.951	0.0399	0.842	1.069	0.292	0.0585	0.245	0.343
1980	1.082	0.0453	0.948	1.229	0.357	0.0491	0.312	0.407
1981	0.912	0.0356	0.817	1.014	0.430	0.0598	0.367	0.500
1982	0.954	0.0316	0.867	1.047	0.581	0.0346	0.534	0.632
1983	1.206	0.0337	1.097	1.323	0.451	0.0731	0.373	0.542
1984	1.058	0.0345	0.957	1.167	0.406	0.0429	0.363	0.454
1985	1.140	0.0340	1.034	1.252	0.464	0.0388	0.420	0.512
1986	2.182	0.0384	1.988	2.392	0.582	0.0347	0.534	0.632
1987	1.423	0.0375	1.287	1.569	0.534	0.0491	0.473	0.601
1988	1.003	0.0321	0.912	1.101	0.513	0.0776	0.422	0.620
1989	0.735	0.0332	0.657	0.818	0.408	0.0552	0.352	0.470
1990	0.811	0.0311	0.733	0.893	0.773	0.0474	0.692	0.861
1991	1.032	0.0276	0.951	1.117	0.654	0.0480	0.583	0.731
1992	1.683	0.0341	1.542	1.834	0.565	0.0412	0.510	0.623
1993	1.329	0.0290	1.228	1.436	0.689	0.0528	0.608	0.778
1994	1.150	0.0196	1.088	1.214	0.470	0.0355	0.430	0.514
1995	0.867	0.0225	0.808	0.928	0.514	0.0344	0.471	0.559
1996	0.888	0.0188	0.837	0.940	0.570	0.0351	0.523	0.620
1997	0.984	0.0183	0.932	1.037	0.439	0.0292	0.407	0.473
1998	0.824	0.0196	0.774	0.876	0.865	0.0218	0.824	0.909
1999	0.836	0.0199	0.785	0.890	0.434	0.0237	0.408	0.461
2000	1.222	0.0219	1.150	1.298	0.331	0.0216	0.311	0.351
2001	1.171	0.0226	1.098	1.246	0.559	0.0208	0.531	0.587
2002	0.836	0.0292	0.762	0.915	0.587	0.0211	0.558	0.618
2003	1.121	0.0260	1.040	1.205	0.568	0.0214	0.540	0.599
2004	1.610	0.0225	1.520	1.705	0.447	0.0213	0.424	0.472
2005	2.220	0.0205	2.113	2.332	0.327	0.0195	0.310	0.345
2006	4.054	0.0192	3.886	4.229	0.305	0.0183	0.290	0.321
2007	3.285	0.0240	3.111	3.467	0.506	0.0184	0.483	0.530
2008	4.575	0.0245	4.337	4.824	0.362	0.0202	0.343	0.382
2009	2.174	0.0292	2.025	2.331	0.430	0.0219	0.406	0.454
2010	1.384	0.0276	1.285	1.489	0.407	0.0361	0.370	0.447
2011	2.057	0.0248	1.936	2.184	0.576	0.1616	0.383	0.841
2012	2.345	0.0316	2.174	2.526	0.246	0.0514	0.210	0.287
2013	1.848	0.0306	1.711	1.993	0.309	0.0421	0.273	0.347

Table 7. Standardized quarterly CPUE (number of fish/hooks) for south area for 1975-2013. Std Err (standard error): log scale.

Year	Quarter	Std CPUE	Std Err
1975	1	0.60551	0.1121
1975	2	1.79344	0.1027
1975	3	1.58309	0.0379
1975	4	0.21302	0.0750
1976	1	0.97668	0.0687
1976	2	3.75544	0.1100
1976	3	3.65713	0.0434
1976	4	1.49735	0.1192
1977	1	1.23864	0.1709
1977	2	2.70045	0.1645
1977	3	2.31344	0.0505
1977	4	0.62424	0.1278
1978	1	0.23655	0.0567
1978	2	1.38675	0.0814
1978	3	0.76065	0.0385
1978	4	1.48026	0.0865
1979	1	0.55817	0.0575
1979	2	1.28970	0.0794
1979	3	1.25183	0.0444
1979	4	0.83617	0.1095
1980	1	1.36393	0.0610
1980	2	1.40119	0.0948
1980	3	0.80775	0.0367
1980	4	0.85164	0.1306
1981	1	0.56756	0.0541
1981	2	1.08849	0.0611
1981	3	1.57927	0.0326
1981	4	0.62825	0.1045
1982	1	0.50270	0.0527
1982	2	1.27370	0.0529
1982	3	1.18841	0.0258
1982	4	0.99007	0.0894
1983	1	0.53343	0.0707
1983	2	1.70150	0.0626
1983	3	2.13937	0.0329
1983	4	0.91281	0.0807
1984	1	0.82631	0.0806
1984	2	1.30778	0.0519
1984	3	1.18713	0.0273
1984	4	0.95835	0.0860
1985	1	0.90581	0.0726
1985	2	1.33467	0.0378
1985	3	2.20316	0.0297
1985	4	0.53754	0.0964
1986	1	2.18535	0.0585
1986	2	2.72764	0.0432
1986	3	2.36900	0.0284
1986	4	1.58139	0.1268
1987	1	1.31510	0.0908
1987	2	2.25420	0.0471
1987	3	2.82819	0.0276
1987	4	0.32265	0.1007
1988	1	0.97397	0.0716
1988	2	1.25702	0.0492
1988	3	1.66577	0.0273
1988	4	0.41139	0.0823
1989	1	0.44450	0.0910
1989	2	1.06269	0.0466
1989	3	1.13910	0.0245
1989	4	0.46132	0.0723
1990	1	0.59217	0.0588
1990	2	0.86625	0.0408
1990	3	1.14001	0.0263
1990	4	0.70568	0.0898
1991	1	0.48445	0.0575
1991	2	0.75516	0.0445
1991	3	1.54764	0.0280
1991	4	1.67711	0.0690
1992	1	1.39706	0.0413
1992	2	1.43427	0.0287
1992	3	1.97880	0.0243
1992	4	1.99575	0.1188
1993	1	1.20605	0.0487
1993	2	1.36072	0.0326
1993	3	1.30302	0.0264
1993	4	1.45578	0.0888
1994	1	1.66411	0.0368
1994	2	1.03739	0.0235
1994	3	1.20504	0.0244
1994	4	0.80537	0.0502
1995	1	1.34760	0.0314
1995	2	0.73033	0.0244
1995	3	1.03550	0.0277
1995	4	0.49996	0.0688
1996	1	1.15430	0.0313
1996	2	0.51208	0.0242
1996	3	0.81479	0.0249
1996	4	1.18402	0.0487
1997	1	0.71606	0.0336
1997	2	0.81774	0.0253
1997	3	2.17645	0.0232
1997	4	0.63002	0.0423
1998	1	1.12279	0.0315
1998	2	0.70498	0.0260
1998	3	1.55980	0.0251
1998	4	0.26366	0.0503
1999	1	0.86172	0.0358
1999	2	0.60973	0.0281
1999	3	1.11877	0.0291
1999	4	0.80396	0.0453
2000	1	0.81968	0.0490
2000	2	0.69147	0.0340
2000	3	2.13779	0.0268
2000	4	1.62304	0.0442
2001	1	1.19510	0.0462
2001	2	0.55004	0.0378
2001	3	1.31202	0.0272
2001	4	1.91593	0.0472
2002	1	1.34312	0.0418
2002	2	0.66520	0.0352
2002	3	1.59725	0.0301
2002	4	0.20861	0.0906
2003	1	1.48235	0.0492
2003	2	0.78322	0.0387
2003	3	0.70533	0.0328
2003	4	1.75077	0.0634
2004	1	1.81949	0.0487
2004	2	0.94826	0.0328
2004	3	1.99403	0.0241
2004	4	1.86763	0.0494
2005	1	1.93751	0.0427
2005	2	1.46157	0.0309
2005	3	3.60008	0.0233
2005	4	2.29394	0.0419
2006	1	1.91916	0.0380
2006	2	5.98979	0.0317
2006	3	8.55480	0.0247
2006	4	2.52783	0.0383
2007	1	1.21373	0.0456
2007	2	4.97217	0.0526
2007	3	5.83356	0.0274
2007	4	2.95701	0.0479
2008	1	2.44572	0.0510
2008	2	4.46092	0.0478
2008	3	9.30788	0.0336
2008	4	4.12874	0.0477
2009	1	2.72299	0.0535
2009	2	1.21302	0.0641
2009	3	4.38117	0.0366
2009	4	1.39753	0.0614
2010	1	1.22502	0.0625
2010	2	2.14378	0.0440
2010	3	1.35698	0.0418
2010	4	0.98897	0.0558
2011	1	1.67141	0.0451
2011	2	2.17503	0.0421
2011	3	3.95007	0.0357
2011	4	1.15436	0.0593
2012	1	1.28326	0.0547
2012	2	3.80865	0.0426
2012	3	5.48425	0.0370
2012	4	0.92530	0.0908
2013	1	1.52770	0.0559
2013	2	2.07196	0.0475
2013	3	2.13549	0.0519
2013	4	1.71152	0.0727

Table 8. Standardized quarterly CPUE (number of fish/hooks) for north area for 1975-2013. Std Err (standard error): log scale.

Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err	Year	Quarter	Std CPUE	Std Err
1975	1	0.27921	0.0725	1985	1	0.30558	0.0439	1995	1	0.61675	0.0513	2005	1	0.29924	0.0273
1975	2	0.39193	0.1752	1985	2	0.82379	0.0935	1995	2	0.52524	0.0847	2005	2	0.88432	0.0348
1975	3	0.43784	0.0546	1985	3	0.42925	0.0557	1995	3	0.38116	0.0750	2005	3	0.21134	0.0338
1975	4	0.12760	0.0552	1985	4	0.40606	0.0822	1995	4	0.55619	0.0413	2005	4	0.16227	0.0271
1976	1	0.29664	0.0636	1986	1	0.85424	0.0323	1996	1	0.42294	0.0507	2006	1	0.41146	0.0271
1976	2	0.33174	0.2611	1986	2	0.53334	0.0926	1996	2	0.59111	0.0999	2006	2	0.67111	0.0306
1976	3	0.13817	0.0879	1986	3	0.47913	0.0671	1996	3	1.12779	0.0608	2006	3	0.13525	0.0309
1976	4	0.19297	0.0904	1986	4	0.51465	0.0435	1996	4	0.34705	0.0326	2006	4	0.18007	0.0247
1977	1	1.04596	0.1034	1987	1	0.80444	0.0332	1997	1	0.38576	0.0347	2007	1	0.53182	0.0250
1977	2	0.27059	0.2602	1987	2	0.24059	0.1066	1997	2	0.50997	0.0821	2007	2	0.82111	0.0280
1977	3	0.27197	0.0786	1987	3	0.43748	0.1465	1997	3	0.44635	0.0504	2007	3	0.41133	0.0318
1977	4	0.35585	0.0594	1987	4	0.85594	0.0400	1997	4	0.42153	0.0285	2007	4	0.34995	0.0269
1978	1	0.51991	0.0788	1988	1	0.89068	0.0364	1998	1	1.06544	0.0267	2008	1	0.41110	0.0285
1978	2	0.22697	0.1401	1988	2	0.57471	0.2927	1998	2	1.47538	0.0438	2008	2	0.64818	0.0356
1978	3	0.19105	0.0682	1988	3	0.39065	0.0664	1998	3	0.78347	0.0447	2008	3	0.20765	0.0375
1978	4	0.22692	0.0620	1988	4	0.32718	0.0501	1998	4	0.42912	0.0311	2008	4	0.28255	0.0278
1979	1	0.29806	0.1050	1989	1	0.37462	0.0426	1999	1	0.24277	0.0354	2009	1	0.42458	0.0280
1979	2	0.23653	0.1506	1989	2	0.30462	0.1423	1999	2	1.46985	0.0550	2009	2	0.88027	0.0375
1979	3	0.30674	0.0908	1989	3	0.53979	0.1371	1999	3	0.49427	0.0414	2009	3	0.16994	0.0474
1979	4	0.33086	0.0945	1989	4	0.44075	0.0657	1999	4	0.13896	0.0275	2009	4	0.45182	0.0291
1980	1	0.34796	0.0749	1990	1	0.72085	0.0391	2000	1	0.36057	0.0318	2010	1	0.43559	0.0355
1980	2	0.23166	0.1396	1990	2	2.60595	0.1494	2000	2	0.62636	0.0391	2010	2	0.62230	0.0645
1980	3	0.38292	0.0830	1990	3	0.43038	0.0861	2000	3	0.14451	0.0373	2010	3	0.34444	0.1101
1980	4	0.50432	0.0543	1990	4	0.37730	0.0487	2000	4	0.31115	0.0333	2010	4	0.28268	0.0388
1981	1	0.37493	0.0421	1991	1	0.48363	0.0496	2001	1	0.50037	0.0318	2011	1	0.24893	0.0556
1981	2	0.57412	0.2133	1991	2	1.28087	0.1477	2001	2	1.26965	0.0411	2011	2	1.09707	0.4671
1981	3	0.54487	0.0635	1991	3	0.66723	0.0770	2001	3	0.42541	0.0355	2011	3	1.41198	0.4375
1981	4	0.27915	0.0448	1991	4	0.41534	0.0595	2001	4	0.32752	0.0336	2011	4	0.21494	0.0490
1982	1	0.69820	0.0510	1992	1	0.55196	0.0567	2002	1	0.42956	0.0324	2012	1	0.34256	0.0489
1982	2	0.47914	0.0904	1992	2	1.15062	0.1097	2002	2	1.93401	0.0464	2012	2	0.36953	0.1601
1982	3	0.64022	0.0519	1992	3	0.20767	0.0756	2002	3	0.32199	0.0353	2012	3	0.14433	0.1024
1982	4	0.52897	0.0437	1992	4	0.65660	0.0629	2002	4	0.37537	0.0261	2012	4	0.17875	0.0386
1983	1	0.37512	0.0498	1993	1	0.49647	0.0628	2003	1	0.52656	0.0273	2013	1	0.33055	0.0505
1983	2	0.21672	0.2712	1993	2	1.37799	0.1745	2003	2	0.90355	0.0420	2013	2	0.82691	0.1005
1983	3	0.65024	0.0469	1993	3	0.66734	0.0748	2003	3	0.35878	0.0401	2013	3	0.17561	0.1094
1983	4	0.70453	0.0575	1993	4	0.46503	0.0457	2003	4	0.58661	0.0321	2013	4	0.14332	0.0383
1984	1	0.64434	0.0715	1994	1	0.38940	0.0441	2004	1	0.46547	0.0300				
1984	2	0.17908	0.1066	1994	2	0.88493	0.0945	2004	2	1.13488	0.0441				
1984	3	0.44435	0.0492	1994	3	0.29817	0.0721	2004	3	0.19224	0.0384				
1984	4	0.47010	0.0832	1994	4	0.44489	0.0407	2004	4	0.32602	0.0275				

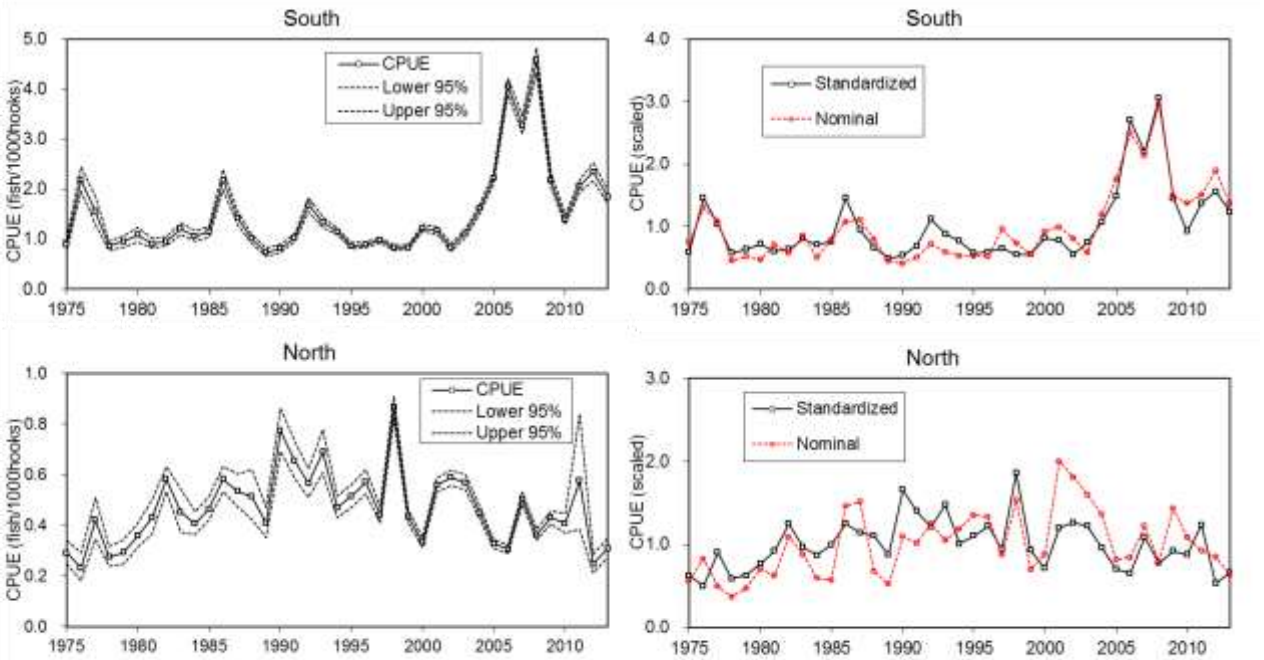

Fig. 10. Standardized CPUE (annual) for albacore in the Indian Ocean for each area for 1975-2013. Left: real scale CPUE with 95% confidence limits, right: relative scale CPUE along with nominal CPUE, in which the indices were scaled by dividing by the average.

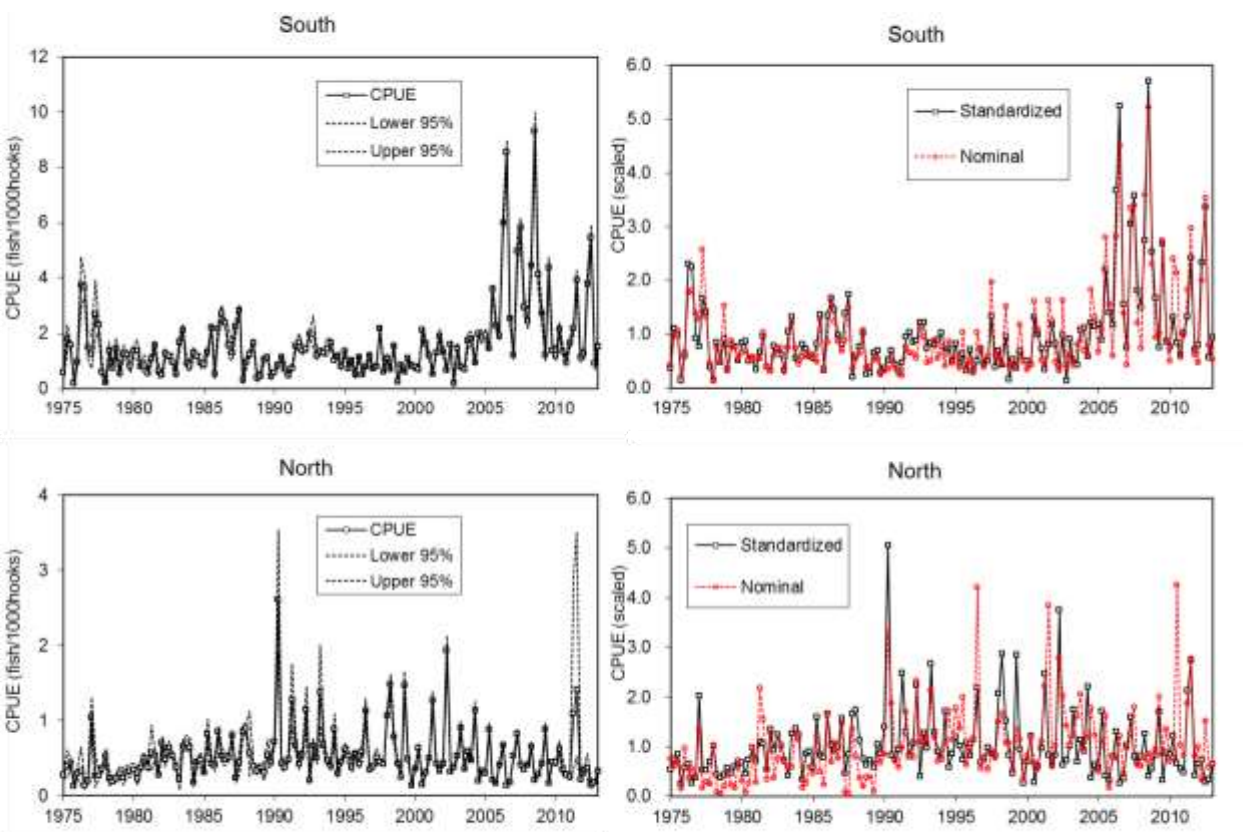

Fig. 11. Standardized CPUE (quarterly) for albacore in the Indian Ocean for each area for 1975-2013. Left: real scale CPUE with 95% confidence limits, right: relative scale CPUE along with nominal CPUE, in which the indices were scaled by dividing by the average.