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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 1966-2011 was conducted using the General Linear Model (GLM) with log-normal (LN model) and negative binomial (NB model) error structures. Original (operational level) catch and effort data were used for standardization. Based on the distributions of standardized residuals, LN model was considered to be better. CPUE declined during 1966-1979, was comparatively stable until mid-1990s and increased after that until the latest year. CPUE in 2011 was similar level to that in in the late 1960s. CPUE for both LN and NB models indicated similar trend. Quarterly CPUE indicated strong seasonality and was usually higher in the second and third quarter. Based on targeting strategy for Japanese longline fishery, it may be better to truncate CPUE in the early period (for example until 1960s) for using in the stock assessment models.

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 44,000 t in 2008 at the historical highest level, though the range of the catch had been from 10,000 t to 30,000 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 in the Indian Ocean including recent situations by Japanese longline is reported by Matsumoto (2012).

For the Indian albacore caught by Japanese longline fishery, CPUE standardization using the General 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, 2004b). Both log-normal and negative binomial error structures were examined by Matsumoto and Uosaki (2011) based on aggregated catch and effort data by 5 degree latitude-longitude, 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. This time, operational level catch and effort data, which may reflect more in detail about actual catch of albacore, were used for CPUE standardization based on similar methods as those by the previous study. Along with annual CPUEs, quarterly CPUEs were also calculated for analyses based on stock synthesis 3 (SS3).

2.MATERIALS AND METHODS

2.1. 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 1966-2011 were available and used, which include the number of hooks per basket (HPB) for 1975-2011. The data for 2011 are preliminary. CPUE was defined as the number of fish caught per 1,000 hooks.

2.2. Standardization

For the model of standardization of albacore CPUE, generalized linear model were used. Albacore catch by Japanese longline fishery includes a certain proportion of zero-catch data. In that case, the model with negative binomial error structure (NB model), instead of that with log-normal error structure (LN model), may be better. Therefore, these two models were examined. These models are similar to that by Matsumoto and Uosaki (2011). These models include main effects of year, season, subarea and gear configuration. Quarter was used for fishing season categorized into four levels. The subarea was categorized into eight levels (Fig. 1) and the gear configuration was categorized into four levels (4-7, 8-11, 12-15 and 16-21 HPB). Because the information of gear configuration was not available for 1966-1974, each observation was regarded as 4-7 HPB. The classification of subarea was defined based on the spatial distribution patterns of nominal CPUE of albacore and of species composition of longline catch. This stratification was modified from Uozumi (1994), and the same as that by Uosaki (2004b) or Matsumoto and Uosaki (2011). In order to include observations with no catch of albacore, a constant of 10% of mean CPUE was added to the CPUE. The models used were:

Error structure	Model
LN model	$\ln(CPUE+const)= \mu + Y_i + Q_j + A_k + G_l + Q_j{*}A_{jk} + Q{*}G_{jl} + Y_i {*}Q_j + e_{ijkl}$ ----------------- (1)
NB model	$Catch = H\cdot\exp(\mu + Y_i + Q_j + A_k + G_l + Q_j{*}A_{jk} + Q{*}G_{jl} + Y_i {*}Q_j + e_{ijkl})$ --------------- (2)

where μ: intercept; const: constant (10% of mean CPUE)

Y_i: effect of year in year *i*; Q_j: effect of quarter in quarter *j*

A_k: effect of subarea in area *k*; G_l: effect of gear in gear *l*

$Q_j{*}A_{jk}$: interaction term between quarter and area in quarter *j* and area *k*

$Q_j{*}G_{jl}$: interaction term between quarter and gear in quarter *j* and gear *l*

$Y_i {*}Q_j$: interaction term between year and quarter in year *i* and quarter *j*

H: number of hooks used. Catch: catch in number

e_{ijkl} : error term

Standardized CPUE for LN model was calculated as follows:

Standardized $CPUE_i$= EXP ($LSM(Y_i)$ + MSE/2) – *C* where LSM(Y_i): least square mean of year effect in year *i*

MSE: Mean square error

C: constant (10% of mean CPUE)

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.

2.3. Catch and effort in each area used for standardization

Fig. 2 shows trend of effort and catch in each area, and Appendix Fig. 1 shows geographical distribution of effort, catch and nominal CPUE for each decade. During early period (until around early 1970s), fishing effort mainly distributed in Area 1 (tropical area). After that, larger proportion of effort was deployed in Area 6 and 7 (temperate area). Around 1990 the proportion in these areas decreased and those or Area 1 and 5 increased. The proportion of Area 1 and 2 sharply decreased in recent years probably due to pirates. The proportion of albacore catch was high in Area 4 during late 1960s. After that the catch in Area 6 (southwest area) was dominant. After around 1990 the proportion in Area 2 and 5 increased, and that in Area 3 was dominant in recent years.

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 0.1 % level. Table 2 shows annual CPUE indices with CV (log scale standard error) and confidence intervals. The distributions of standardized residual are shown in Fig. 3 (distribution of standardized residual and QQ-plot for LN model), Fig. 4 (box plot for both models) and Fig. 5 (relationship between predicted catch and distribution of the standardized residual for the NB model). It seems that standardized residuals for LN model are not largely unbiased, whereas those for NB models are somewhat biased. Therefore, LN model seems to be better.

Fig. 6 shows relative effects of season, area and gear for GLM analyses. The trend was similar between two models. Quarter 2 had highest index and quarter 3 followed. Area 4 and/or 5 had highest index and indices for areas 1, 7 and 8 was very low. The deeper the gear became, the higher the index became.

Scaled CPUE by LN model indicates that it was high at about 2.8 in 1966, and then rapidly decreased to about 0.5-0.6 during the 1978-1980 (Fig. 7). Since then the CPUE became stable at the level in the view of whole time series analyzed. However, the CPUE showed slight increasing trend since 1995. CPUE in 2011 recovered to the level in the late 1960s. The trend of CPUE for LN and NB models was similar, although decrease during early period for NB model is steeper than that for LN model. Trend of nominal CPUE was similar to that by LN and NB models. However, recent increase for nominal CPUE was larger than that for standardized CPUEs. Comparing standardized CPUE in the present study with that in the previous study (Matsumoto and Uosaki, 2011), the trend was similar, but larger fluctuation was observed for the indices for the present study (Fig. 8).

Table 3-4 and Fig. 9 show quarterly CPUEs by LN and NB models. Strong seasonality of CPUE was observed and usually CPUE in the second and third quarter was higher.

Uosaki (2004a) demonstrated that since late 1960s, Japanese longline fishery has been running without targeting albacore, and that the fishing effort has not deployed in the region where albacore is abundant, though a part of the longline fleet had primarily caught albacore in the 1960s. At least after 1975 Japanese longline has caught albacore only in the geographical margin of the region where albacore abundantly distributed, as pointed out by Uozumi (1994). Therefore, it may be better to truncate CPUE in the early period (for example, until early 1970s) for using in the stock assessment models.

The standardized CPUE using the data only from Area 2 and Area 4 (named "modified model"), where albacore is generally abundant, is shown in Fig. 10 just for comparison to that shown above (reference model). This indicated that the CPUE for the modified model showed the similar trend to that for the reference model, and that the standardized CPUE even in the abundant region was as low as in the other region after 1970s. This suggests that the longline fishery operated without targeting albacore even in this region. The difference of the trend in the recent years (during 2000s) indicates that CPUE in the eastern part (west of Australia) got higher.

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Table 1. Analysis of variance for the GLM analyses.

LN model 1966-2011

Source	DF	SS	Mean Sq.	F Value	Pr > F
Model	223	982152.2	4404.27	3202.9	<.0001
Error	1410000	1941963.3	1.4		
Corr. Tot.	1410000	2924115.5			

R-square= 0.33588 C.V.= -427.4094

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Y	45	107266.3	2383.7	1733.5	<.0001
Q	3	15238.2	5079.4	3693.9	<.0001
A	7	331813.1	47401.9	34471.8	<.0001
G	3	1900.1	633.4	460.6	<.0001
Q*A	21	73174.6	3484.5	2534.0	<.0001
Q*G	9	2187.5	243.1	176.8	<.0001
Y*Q	135	48395.7	358.5	260.7	<.0001

NB model 1966-2011

Source	DF	Chi-Square	Pr>Chi
Y	45	54513.3	<.0001
Q	3	12294.6	<.0001
A	7	119974.0	<.0001
G	3	1285.8	<.0001
Q*A	21	67648.7	<.0001
Q*G	9	1458.2	<.0001
Y*Q	135	22978.2	<.0001

Table 2. Standardized annual CPUE (number of fish/hooks) with the 95% confidence intervals for each model.

	LN model				NB model			
Year	Std CPUE	Std Err	Upper CL	Lower CL	Std CPUE	Std Err	Upper CL	Lower CL
1966	4.153	0.0089	4.231	4.077	6.804	0.0147	7.003	6.611
1967	3.384	0.0074	3.438	3.331	5.803	0.0131	5.953	5.656
1968	2.503	0.0078	2.545	2.461	4.595	0.0134	4.717	4.476
1969	2.388	0.0081	2.431	2.346	4.800	0.0139	4.932	4.671
1970	1.757	0.0112	1.802	1.713	3.879	0.0169	4.010	3.752
1971	2.055	0.0088	2.096	2.015	3.212	0.0147	3.306	3.121
1972	1.668	0.0116	1.712	1.625	3.054	0.0166	3.154	2.956
1973	1.474	0.0108	1.512	1.438	2.394	0.0151	2.466	2.324
1974	1.436	0.0094	1.467	1.405	2.711	0.0141	2.787	2.637
1975	0.904	0.0087	0.924	0.884	1.304	0.0144	1.341	1.268
1976	1.439	0.0100	1.472	1.406	1.766	0.0142	1.816	1.718
1977	1.118	0.0103	1.146	1.090	1.016	0.0154	1.048	0.986
1978	0.777	0.0088	0.795	0.759	0.630	0.0148	0.648	0.612
1979	0.724	0.0098	0.744	0.706	0.492	0.0162	0.508	0.477
1980	0.868	0.0083	0.886	0.850	0.589	0.0141	0.605	0.573
1981	0.914	0.0078	0.932	0.897	1.119	0.0130	1.148	1.091
1982	1.151	0.0078	1.173	1.130	1.123	0.0142	1.155	1.092
1983	1.211	0.0073	1.233	1.190	1.040	0.0135	1.068	1.013
1984	1.184	0.0069	1.204	1.165	1.284	0.0127	1.316	1.252
1985	1.319	0.0068	1.340	1.298	0.889	0.0128	0.912	0.867
1986	1.765	0.0068	1.793	1.739	2.086	0.0140	2.144	2.030
1987	1.527	0.0073	1.553	1.501	1.707	0.0147	1.757	1.659
1988	1.258	0.0079	1.282	1.234	1.104	0.0164	1.140	1.070
1989	1.102	0.0087	1.125	1.079	0.819	0.0175	0.847	0.791
1990	1.156	0.0106	1.185	1.126	0.973	0.0182	1.008	0.939
1991	0.818	0.0098	0.839	0.797	0.577	0.0183	0.598	0.556
1992	1.292	0.0103	1.323	1.261	1.122	0.0195	1.166	1.080
1993	1.050	0.0105	1.078	1.023	1.023	0.0202	1.064	0.983
1994	0.890	0.0058	0.903	0.876	1.235	0.0157	1.273	1.197
1995	0.895	0.0052	0.907	0.883	1.115	0.0144	1.147	1.084
1996	0.881	0.0048	0.892	0.871	0.897	0.0139	0.921	0.872
1997	1.187	0.0048	1.201	1.174	1.103	0.0133	1.132	1.075
1998	1.266	0.0050	1.281	1.251	1.282	0.0138	1.317	1.248
1999	0.952	0.0058	0.966	0.939	0.813	0.0147	0.837	0.790
2000	1.125	0.0072	1.144	1.105	1.521	0.0147	1.566	1.478
2001	1.057	0.0063	1.074	1.041	1.331	0.0141	1.369	1.295
2002	1.244	0.0068	1.264	1.224	1.172	0.0148	1.207	1.139
2003	1.327	0.0077	1.351	1.303	1.779	0.0167	1.838	1.721
2004	1.529	0.0070	1.554	1.505	2.092	0.0154	2.156	2.029
2005	1.593	0.0066	1.618	1.569	1.720	0.0146	1.770	1.672
2006	1.833	0.0065	1.860	1.807	1.673	0.0139	1.720	1.628
2007	1.908	0.0071	1.939	1.878	1.531	0.0148	1.576	1.487
2008	1.907	0.0079	1.941	1.874	1.824	0.0159	1.882	1.768
2009	1.904	0.0087	1.941	1.867	1.852	0.0182	1.919	1.787
2010	2.130	0.0111	2.183	2.079	2.201	0.0229	2.302	2.104
2011	2.458	0.0164	2.548	2.372	2.859	0.0344	3.059	2.672

Table 3. Standardized quarterly CPUE (number of fish/hooks) for lognormal model. 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
1966	1	2.472	0.0167	1977	3	1.158	0.0134	1989	1	0.768	0.0227	2000	3	1.442	0.0127
1966	2	7.289	0.0206	1977	4	1.101	0.0195	1989	2	1.655	0.0154	2000	4	1.039	0.0129
1966	3	6.735	0.0190	1978	1	0.572	0.0205	1989	3	1.129	0.0131	2001	1	0.873	0.0146
1966	4	2.368	0.0144	1978	2	1.056	0.0168	1989	4	0.997	0.0167	2001	2	1.250	0.0126
1967	1	2.624	0.0135	1978	3	0.623	0.0141	1990	1	1.055	0.0223	2001	3	1.197	0.0108
1967	2	6.468	0.0167	1978	4	0.933	0.0187	1990	2	2.269	0.0164	2001	4	0.948	0.0122
1967	3	4.215	0.0150	1979	1	0.664	0.0266	1990	3	0.969	0.0152	2002	1	1.243	0.0146
1967	4	1.769	0.0142	1979	2	0.638	0.0183	1990	4	0.722	0.0283	2002	2	1.507	0.0148
1968	1	2.731	0.0165	1979	3	0.630	0.0134	1991	1	0.718	0.0251	2002	3	1.148	0.0121
1968	2	4.851	0.0171	1979	4	1.012	0.0178	1991	2	0.891	0.0176	2002	4	1.109	0.0128
1968	3	2.354	0.0136	1980	1	0.833	0.0218	1991	3	0.882	0.0141	2003	1	1.209	0.0148
1968	4	1.197	0.0147	1980	2	0.917	0.0156	1991	4	0.791	0.0200	2003	2	1.592	0.0165
1969	1	2.162	0.0194	1980	3	0.735	0.0128	1992	1	0.884	0.0257	2003	3	1.271	0.0154
1969	2	3.286	0.0166	1980	4	1.003	0.0148	1992	2	2.200	0.0149	2003	4	1.264	0.0151
1969	3	2.642	0.0131	1981	1	0.911	0.0187	1992	3	1.469	0.0147	2004	1	1.310	0.0163
1969	4	1.713	0.0154	1981	2	1.090	0.0142	1992	4	0.930	0.0245	2004	2	1.664	0.0139
1970	1	1.310	0.0359	1981	3	0.761	0.0128	1993	1	0.834	0.0284	2004	3	1.889	0.0124
1970	2	2.014	0.0176	1981	4	0.919	0.0157	1993	2	1.986	0.0178	2004	4	1.319	0.0134
1970	3	2.512	0.0131	1982	1	0.911	0.0193	1993	3	0.873	0.0156	2005	1	1.057	0.0144
1970	4	1.413	0.0159	1982	2	1.954	0.0149	1993	4	0.799	0.0200	2005	2	1.938	0.0132
1971	1	2.501	0.0197	1982	3	0.915	0.0127	1994	1	0.740	0.0144	2005	3	3.202	0.0127
1971	2	2.491	0.0182	1982	4	1.042	0.0147	1994	2	1.165	0.0101	2005	4	0.917	0.0126
1971	3	2.094	0.0141	1983	1	0.801	0.0174	1994	3	0.973	0.0098	2006	1	0.985	0.0135
1971	4	1.347	0.0182	1983	2	2.249	0.0140	1994	4	0.734	0.0117	2006	2	2.816	0.0133
1972	1	1.223	0.0327	1983	3	1.088	0.0119	1995	1	0.931	0.0120	2006	3	3.564	0.0123
1972	2	2.328	0.0182	1983	4	1.046	0.0145	1995	2	0.933	0.0099	2006	4	1.049	0.0125
1972	3	2.020	0.0152	1984	1	0.870	0.0167	1995	3	0.918	0.0093	2007	1	1.105	0.0132
1972	4	1.318	0.0227	1984	2	1.811	0.0138	1995	4	0.805	0.0101	2007	2	2.403	0.0147
1973	1	0.769	0.0330	1984	3	1.202	0.0116	1996	1	0.732	0.0112	2007	3	3.804	0.0132
1973	2	2.273	0.0154	1984	4	1.011	0.0130	1996	2	0.961	0.0093	2007	4	1.235	0.0153
1973	3	1.768	0.0147	1985	1	0.911	0.0157	1996	3	0.978	0.0089	2008	1	1.015	0.0155
1973	4	1.451	0.0176	1985	2	2.614	0.0134	1996	4	0.872	0.0091	2008	2	3.117	0.0174
1974	1	1.281	0.0261	1985	3	1.323	0.0109	1997	1	0.692	0.0112	2008	3	3.099	0.0149
1974	2	2.068	0.0158	1985	4	0.906	0.0141	1997	2	1.565	0.0096	2008	4	1.264	0.0154
1974	3	1.560	0.0137	1986	1	1.202	0.0152	1997	3	1.688	0.0085	2009	1	0.906	0.0161
1974	4	1.005	0.0169	1986	2	4.026	0.0142	1997	4	1.036	0.0087	2009	2	2.479	0.0191
1975	1	0.639	0.0216	1986	3	1.796	0.0119	1998	1	1.338	0.0100	2009	3	3.632	0.0165
1975	2	0.953	0.0151	1986	4	1.046	0.0130	1998	2	1.604	0.0102	2009	4	1.501	0.0177
1975	3	1.196	0.0134	1987	1	0.947	0.0161	1998	3	1.398	0.0094	2010	1	1.125	0.0210
1975	4	0.896	0.0186	1987	2	2.558	0.0155	1998	4	0.838	0.0103	2010	2	5.968	0.0205
1976	1	1.191	0.0280	1987	3	1.883	0.0122	1999	1	0.616	0.0129	2010	3	3.339	0.0230
1976	2	2.285	0.0176	1987	4	1.137	0.0142	1999	2	1.319	0.0115	2010	4	0.789	0.0238
1976	3	1.396	0.0134	1988	1	1.152	0.0183	1999	3	1.321	0.0105	2011	1	1.376	0.0252
1976	4	1.101	0.0179	1988	2	1.863	0.0150	1999	4	0.727	0.0110	2011	2	5.541	0.0233
1977	1	1.386	0.0268	1988	3	1.228	0.0128	2000	1	0.829	0.0158	2011	3	4.841	0.0235
1977	2	0.875	0.0205	1988	4	0.930	0.0169	2000	2	1.266	0.0160	2011	4	0.866	0.0509

Table 4. Standardized quarterly CPUE (number of fish/hooks) for negative binomial model. 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
1966	1	3.266	0.0302	1977	3	0.869	0.0305	1989	1	0.486	0.0452	2000	3	1.295	0.0231
1966	2	19.806	0.0358	1977	4	1.617	0.0452	1989	2	1.894	0.0278	2000	4	0.950	0.0285
1966	3	8.906	0.0332	1978	1	0.302	0.0439	1989	3	0.825	0.0265	2001	1	0.901	0.0284
1966	4	3.708	0.0277	1978	2	1.433	0.0315	1989	4	0.569	0.0434	2001	2	1.977	0.0245
1967	1	3.371	0.0247	1978	3	0.346	0.0303	1990	1	1.122	0.0404	2001	3	1.482	0.0207
1967	2	16.880	0.0295	1978	4	0.570	0.0484	1990	2	2.559	0.0293	2001	4	0.470	0.0264
1967	3	6.223	0.0271	1979	1	0.816	0.0506	1990	3	0.963	0.0295	2002	1	1.083	0.0269
1967	4	2.908	0.0292	1979	2	0.875	0.0349	1990	4	0.768	0.0549	2002	2	2.119	0.0279
1968	1	3.888	0.0293	1979	3	0.504	0.0283	1991	1	0.622	0.0486	2002	3	0.962	0.0226
1968	2	12.541	0.0302	1979	4	0.751	0.0514	1991	2	0.747	0.0323	2002	4	0.808	0.0258
1968	3	3.716	0.0255	1980	1	0.521	0.0419	1991	3	0.735	0.0269	2003	1	1.351	0.0280
1968	4	2.176	0.0293	1980	2	1.423	0.0284	1991	4	0.638	0.0384	2003	2	2.481	0.0312
1969	1	3.226	0.0341	1980	3	0.459	0.0268	1992	1	1.166	0.0458	2003	3	1.361	0.0292
1969	2	13.640	0.0294	1980	4	0.620	0.0404	1992	2	3.497	0.0269	2003	4	0.696	0.0311
1969	3	4.062	0.0247	1981	1	1.146	0.0348	1992	3	1.272	0.0269	2004	1	1.320	0.0301
1969	4	1.883	0.0316	1981	2	2.220	0.0256	1992	4	0.737	0.0497	2004	2	2.599	0.0258
1970	1	2.069	0.0641	1981	3	0.783	0.0253	1993	1	1.096	0.0502	2004	3	1.598	0.0230
1970	2	5.888	0.0314	1981	4	0.550	0.0385	1993	2	2.704	0.0315	2004	4	1.540	0.0289
1970	3	3.260	0.0252	1982	1	0.879	0.0371	1993	3	0.946	0.0278	2005	1	1.066	0.0268
1970	4	2.004	0.0320	1982	2	3.063	0.0270	1993	4	0.547	0.0375	2005	2	3.630	0.0241
1971	1	2.606	0.0350	1982	3	0.795	0.0241	1994	1	0.910	0.0354	2005	3	2.653	0.0228
1971	2	4.977	0.0327	1982	4	0.782	0.0339	1994	2	1.596	0.0240	2005	4	0.650	0.0284
1971	3	2.252	0.0274	1983	1	0.449	0.0350	1994	3	0.856	0.0246	2006	1	0.824	0.0248
1971	4	3.845	0.0395	1983	2	3.716	0.0253	1994	4	0.771	0.0301	2006	2	4.479	0.0239
1972	1	1.498	0.0601	1983	3	1.125	0.0232	1995	1	1.059	0.0287	2006	3	2.938	0.0225
1972	2	3.567	0.0330	1983	4	1.070	0.0353	1995	2	1.343	0.0240	2006	4	0.540	0.0248
1972	3	2.291	0.0295	1984	1	0.629	0.0326	1995	3	1.297	0.0248	2007	1	1.133	0.0249
1972	4	3.019	0.0499	1984	2	2.729	0.0247	1995	4	0.556	0.0276	2007	2	3.434	0.0259
1973	1	1.063	0.0608	1984	3	0.944	0.0224	1996	1	0.926	0.0272	2007	3	2.947	0.0235
1973	2	3.700	0.0281	1984	4	0.613	0.0319	1996	2	1.510	0.0224	2007	4	0.683	0.0297
1973	3	1.730	0.0277	1985	1	0.519	0.0314	1996	3	1.246	0.0224	2008	1	0.865	0.0281
1973	4	5.267	0.0372	1985	2	3.661	0.0241	1996	4	0.507	0.0263	2008	2	5.031	0.0294
1974	1	1.437	0.0467	1985	3	1.026	0.0213	1997	1	0.701	0.0274	2008	3	3.428	0.0266
1974	2	3.829	0.0287	1985	4	0.379	0.0384	1997	2	2.504	0.0228	2008	4	0.858	0.0284
1974	3	1.695	0.0256	1986	1	1.405	0.0278	1997	3	1.698	0.0209	2009	1	0.710	0.0287
1974	4	1.605	0.0364	1986	2	6.763	0.0259	1997	4	0.673	0.0241	2009	2	2.615	0.0331
1975	1	0.532	0.0417	1986	3	3.011	0.0241	1998	1	2.200	0.0240	2009	3	7.727	0.0302
1975	2	1.389	0.0278	1986	4	0.892	0.0331	1998	2	2.987	0.0237	2009	4	0.931	0.0333
1975	3	1.106	0.0273	1987	1	1.537	0.0297	1998	3	1.228	0.0228	2010	1	1.122	0.0375
1975	4	0.733	0.0463	1987	2	3.832	0.0281	1998	4	0.525	0.0275	2010	2	10.932	0.0353
1976	1	1.286	0.0504	1987	3	2.267	0.0247	1999	1	0.674	0.0286	2010	3	4.435	0.0404
1976	2	4.706	0.0311	1987	4	1.214	0.0314	1999	2	1.774	0.0242	2010	4	0.361	0.0427
1976	3	1.413	0.0280	1988	1	1.340	0.0342	1999	3	1.666	0.0244	2011	1	2.735	0.0461
1976	4	2.271	0.0452	1988	2	2.578	0.0271	1999	4	0.321	0.0261	2011	2	9.798	0.0396
1977	1	1.107	0.0522	1988	3	0.933	0.0258	2000	1	0.729	0.0281	2011	3	5.341	0.0417
1977	2	0.955	0.0388	1988	4	0.540	0.0442	2000	2	2.392	0.0284	2011	4	0.470	0.0966

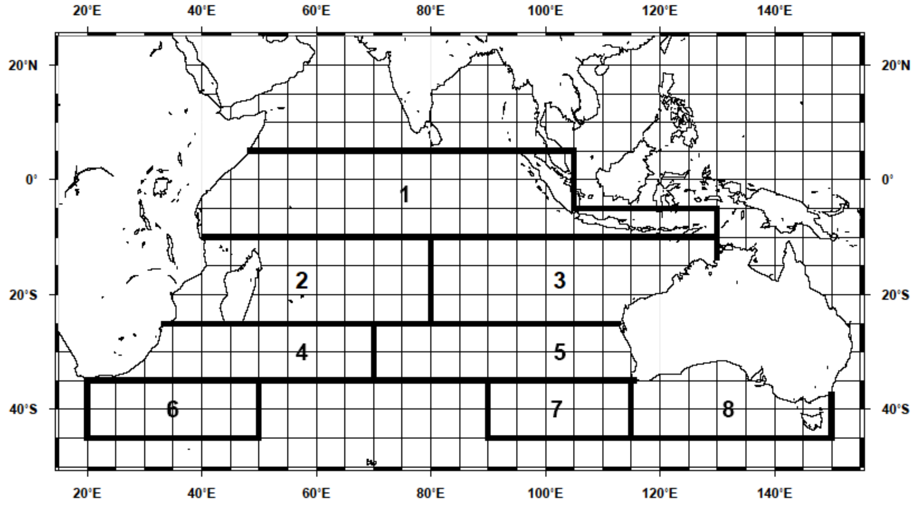


Fig. 1. Subarea used for the GLM analysis.

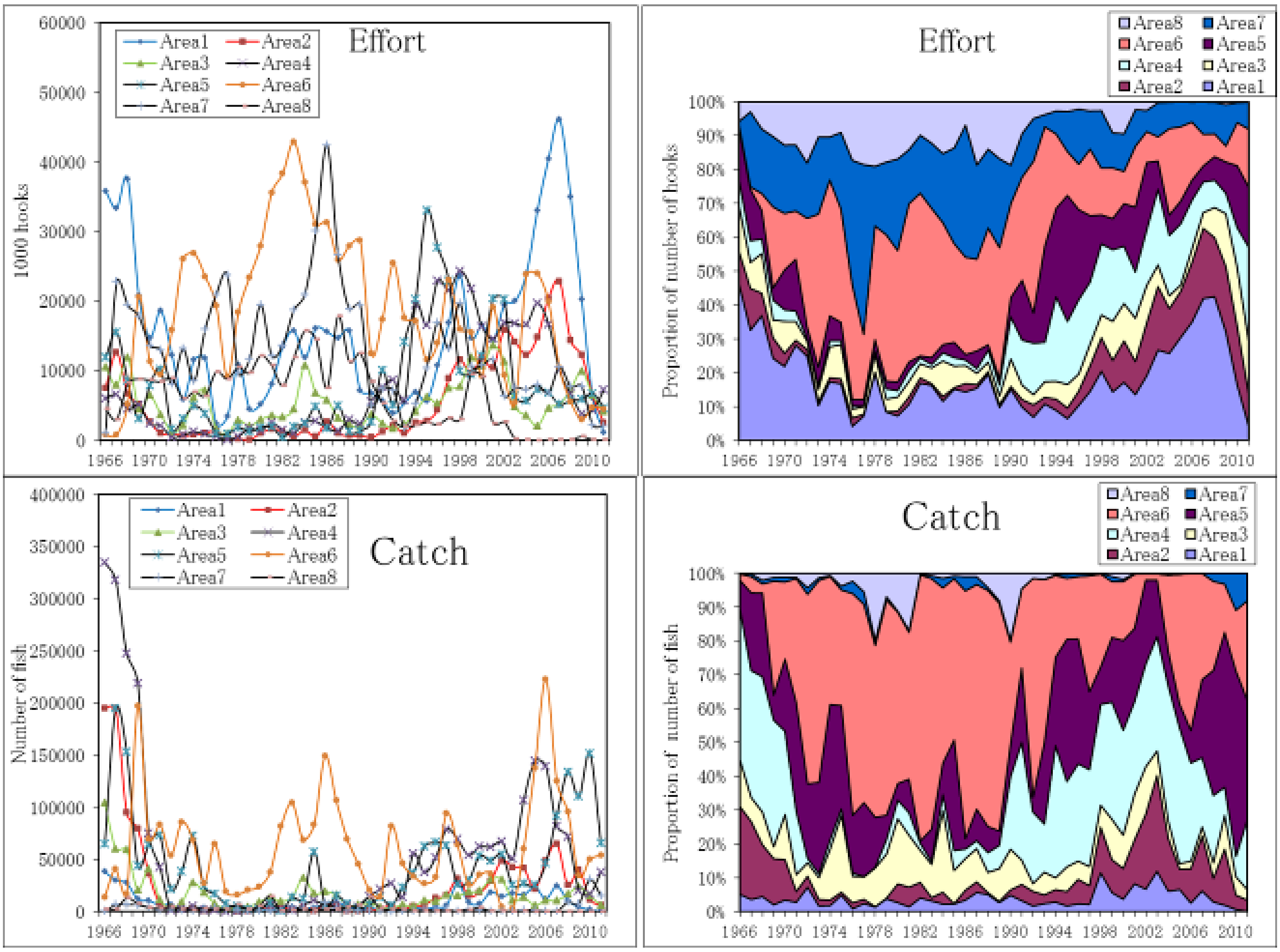


Fig. 2. Catch and effort and their proportion in each area used for the GLM analysis.

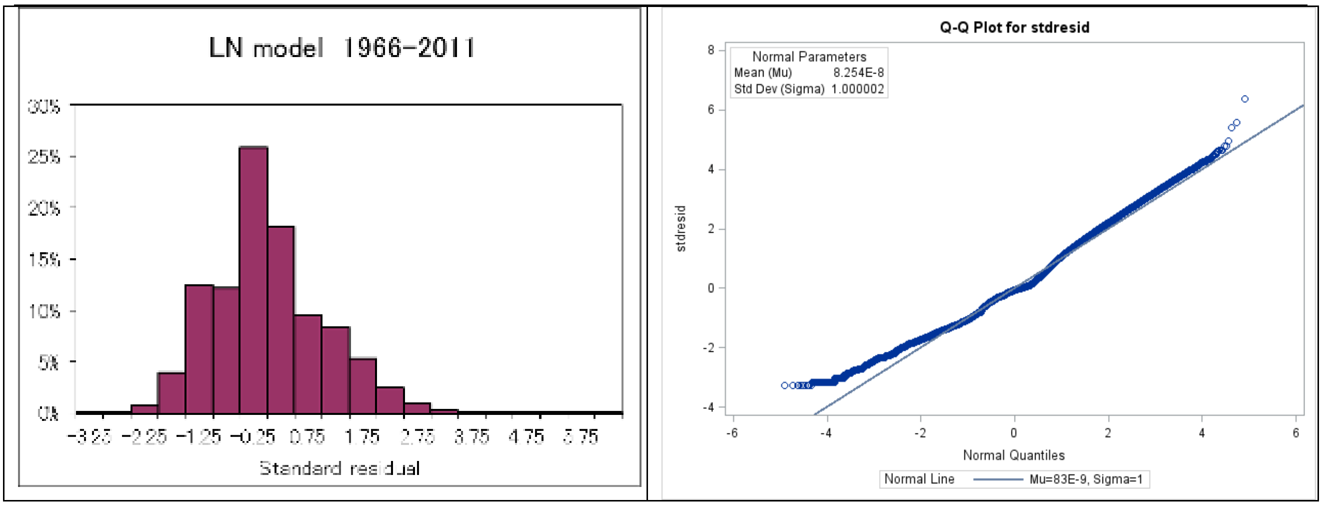


Fig. 3. Distribution of the standardized residual and QQ-plot of standardized residual for the LN model.

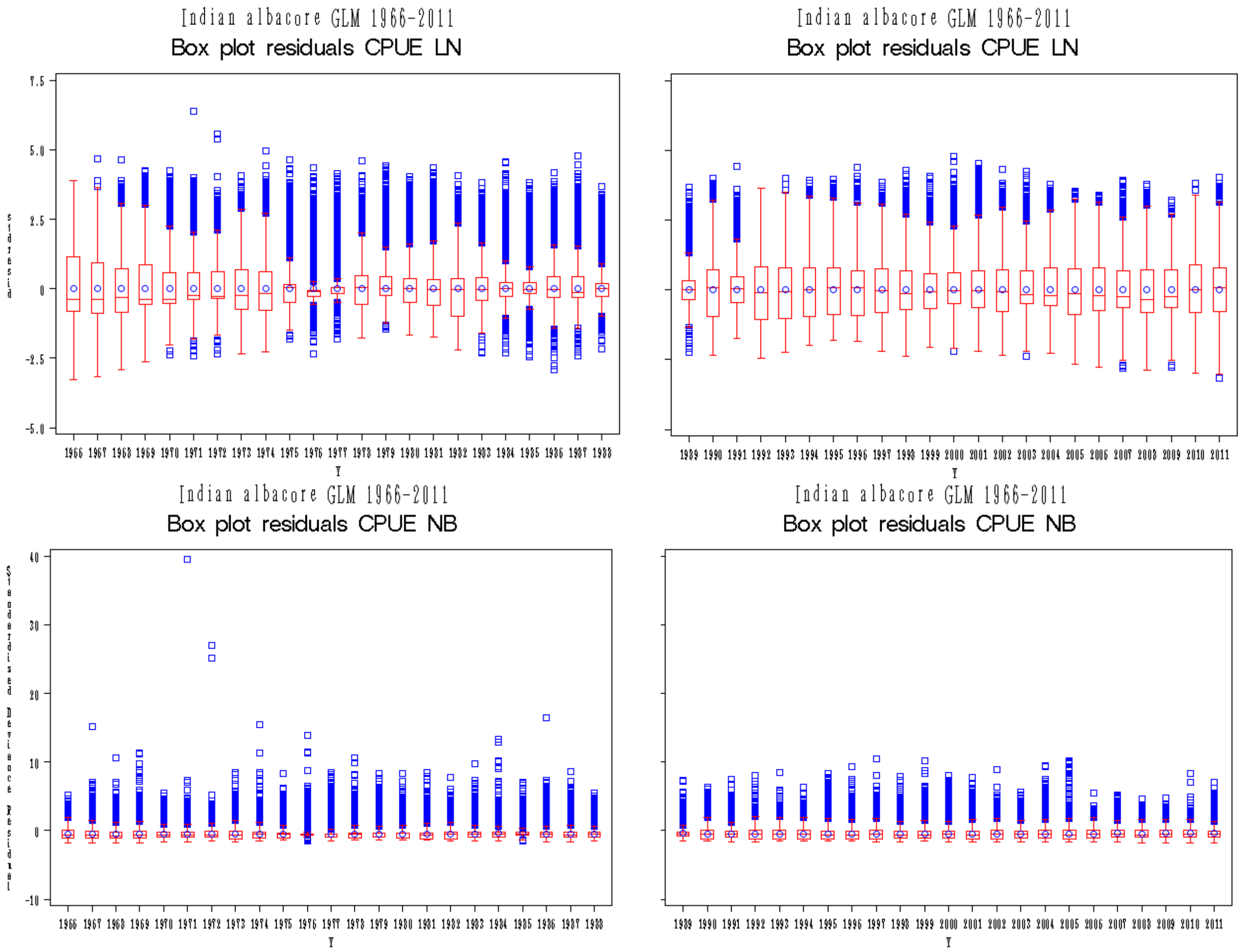


Fig. 4. Box plot of the standardized residual by year for the GLM analysis (upper: LN model, lower: NB model). Circle: mean, box: 25th and 75th percentile, horizontal line in the box: median, bars: maximum and minimum observation between 1.5 IQR (interquartile range) above 75th percentile and 1.5 IQR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

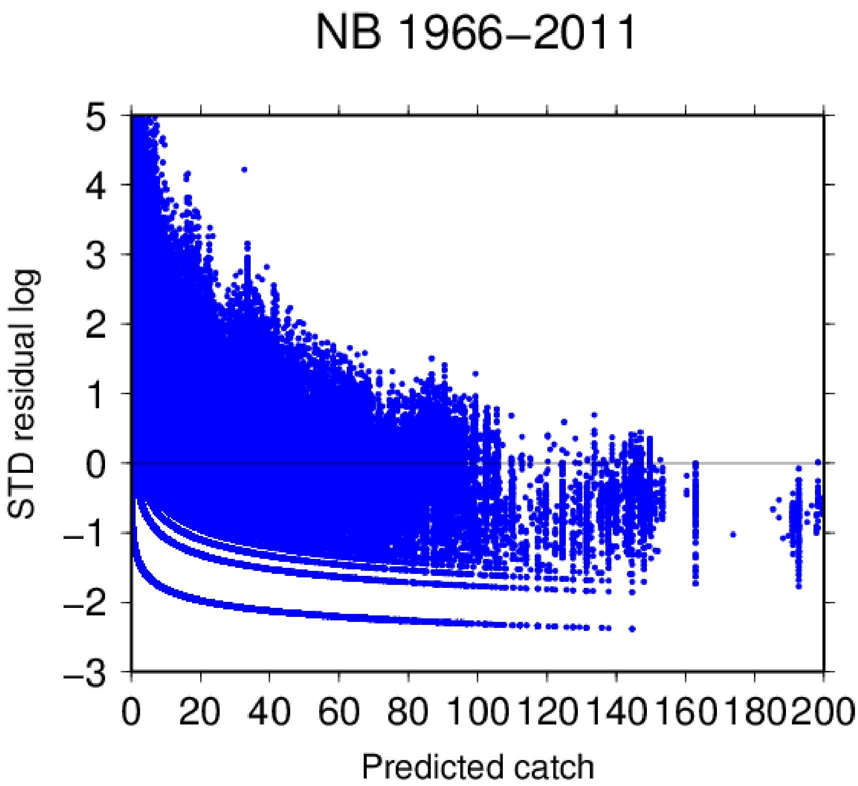


Fig. 5. The relationship between predicted catch and distribution of the standardized residual for the NB model.

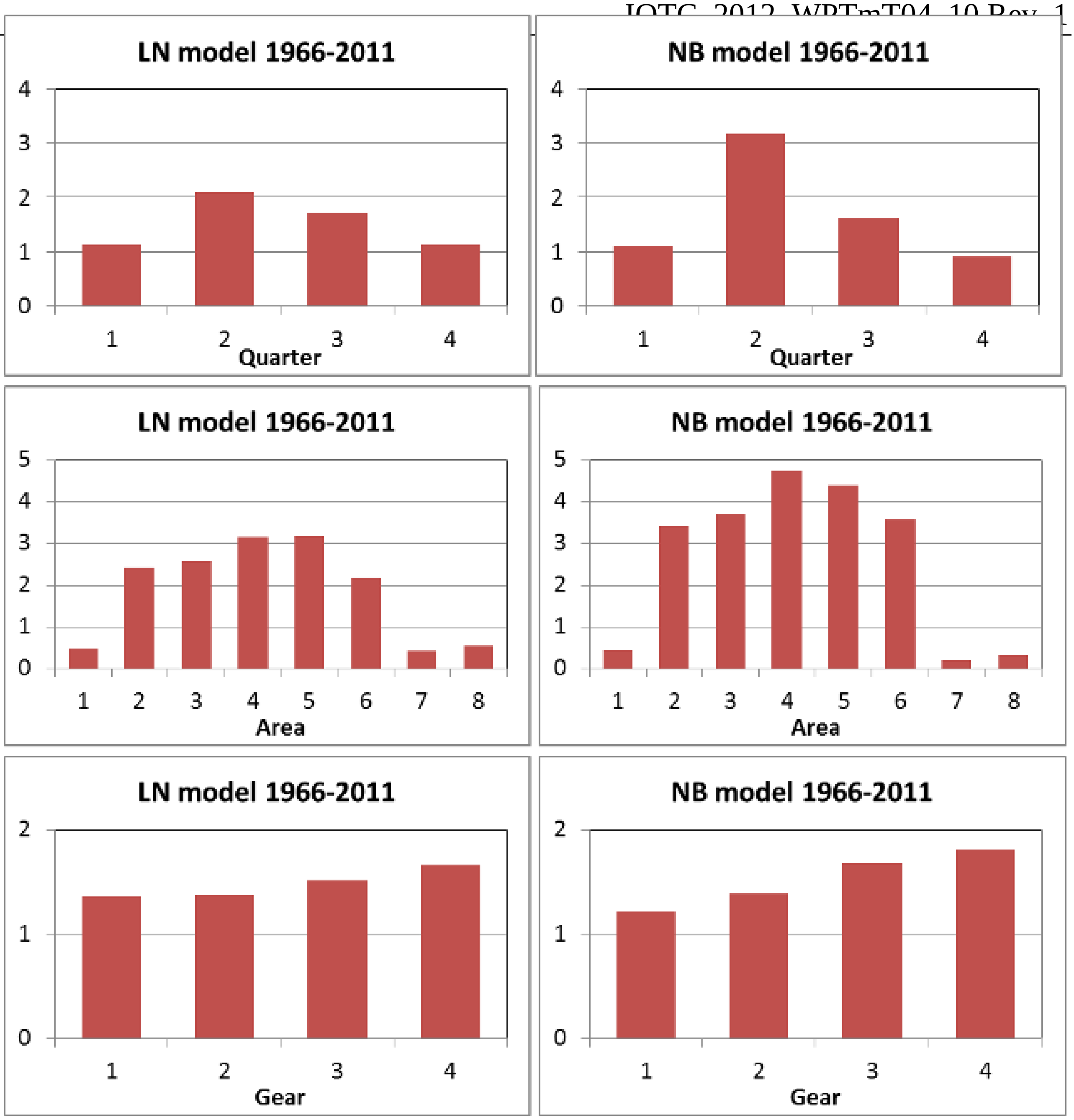


Fig. 6. Relative effects of season (quarter), area and gear (number of hooks per basket) for the GLM analysis (left: LN model, right: NB model).

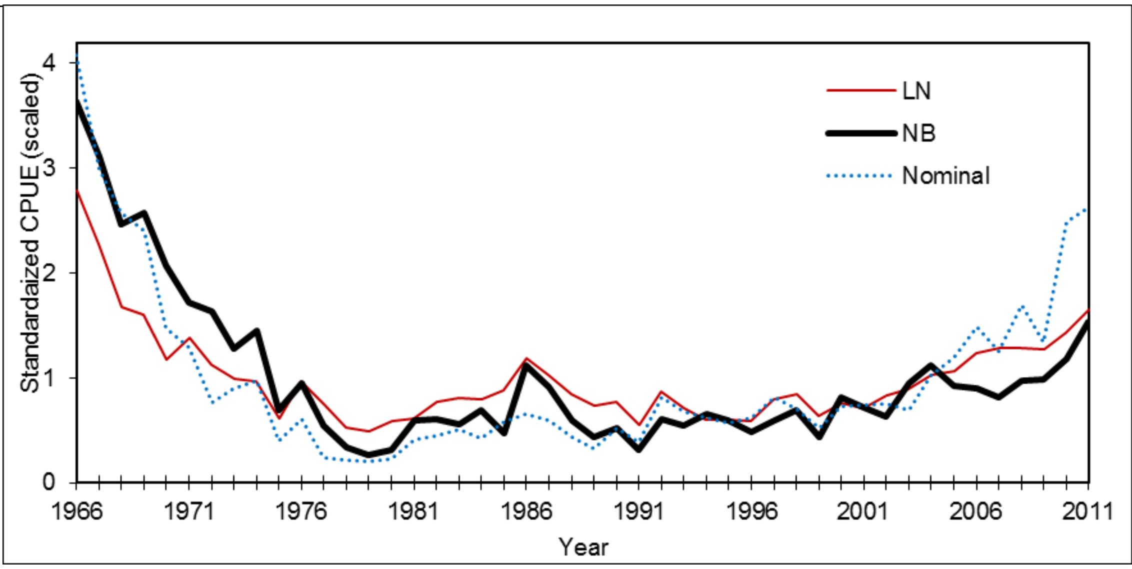


Fig. 7. Comparison of standardized CPUE (annual) for albacore in the Indian Ocean by two different models along with nominal CPUE. CPUE indices were scaled by dividing by the average.

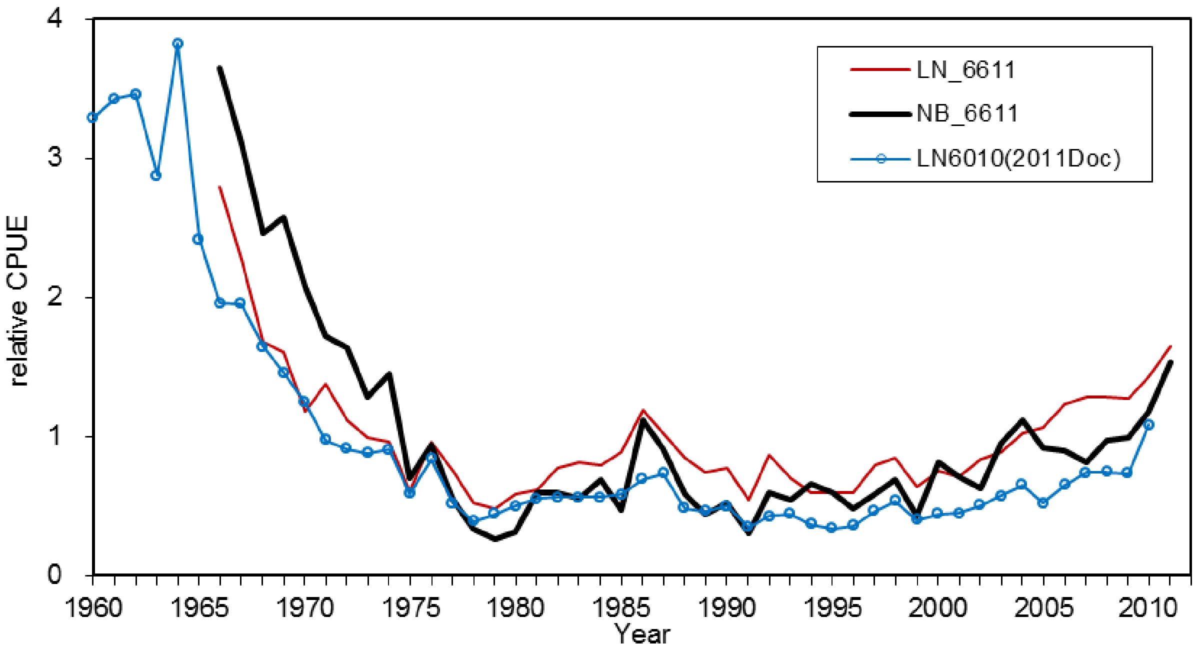


Fig. 8. Comparison of standardized CPUE (annual) with that for previous study (Matsumoto and Uosaki, 2011, LN model).

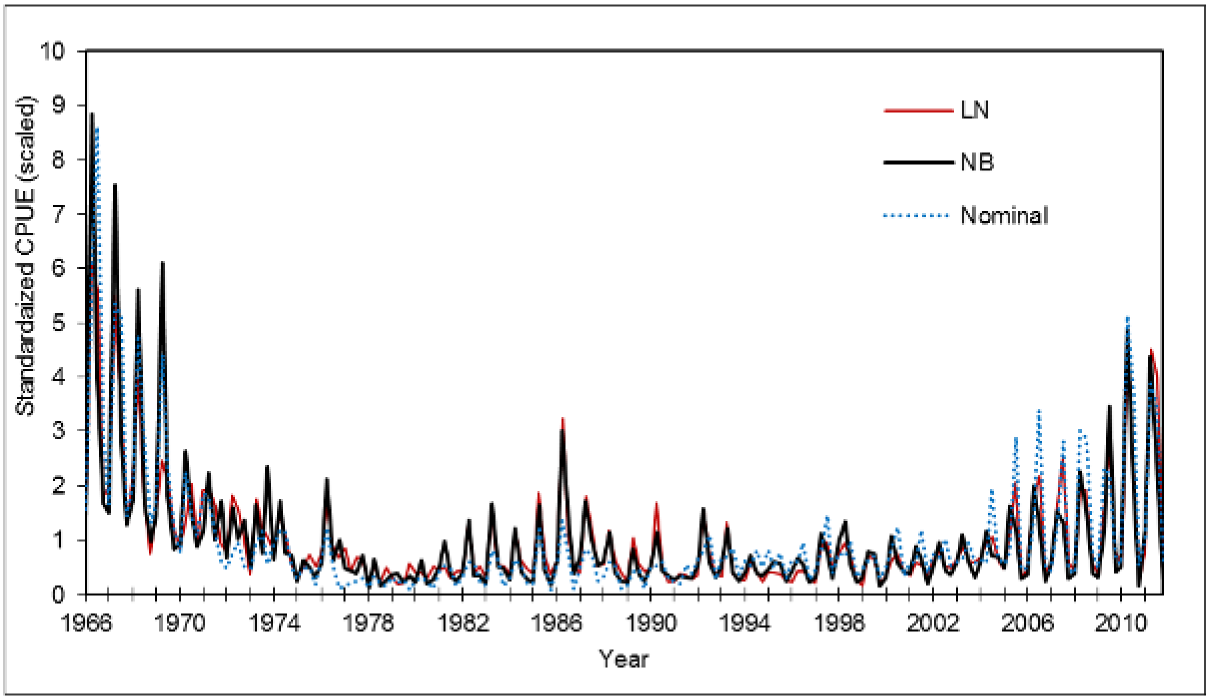


Fig. 9. Comparison of standardized CPUE (quarterly) for albacore in the Indian Ocean by two different models along with nominal CPUE. CPUE indices were scaled by dividing by the average.

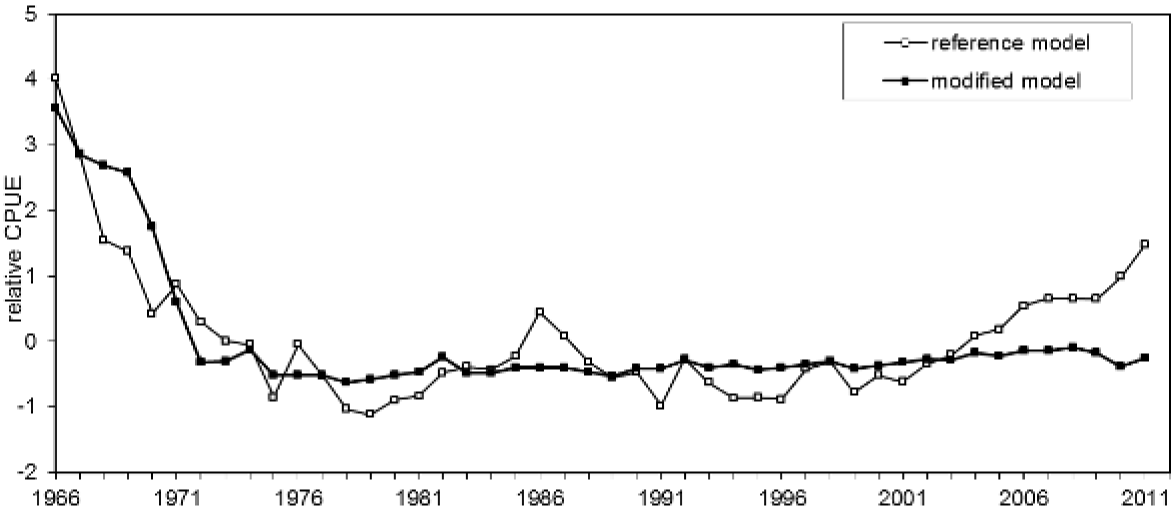
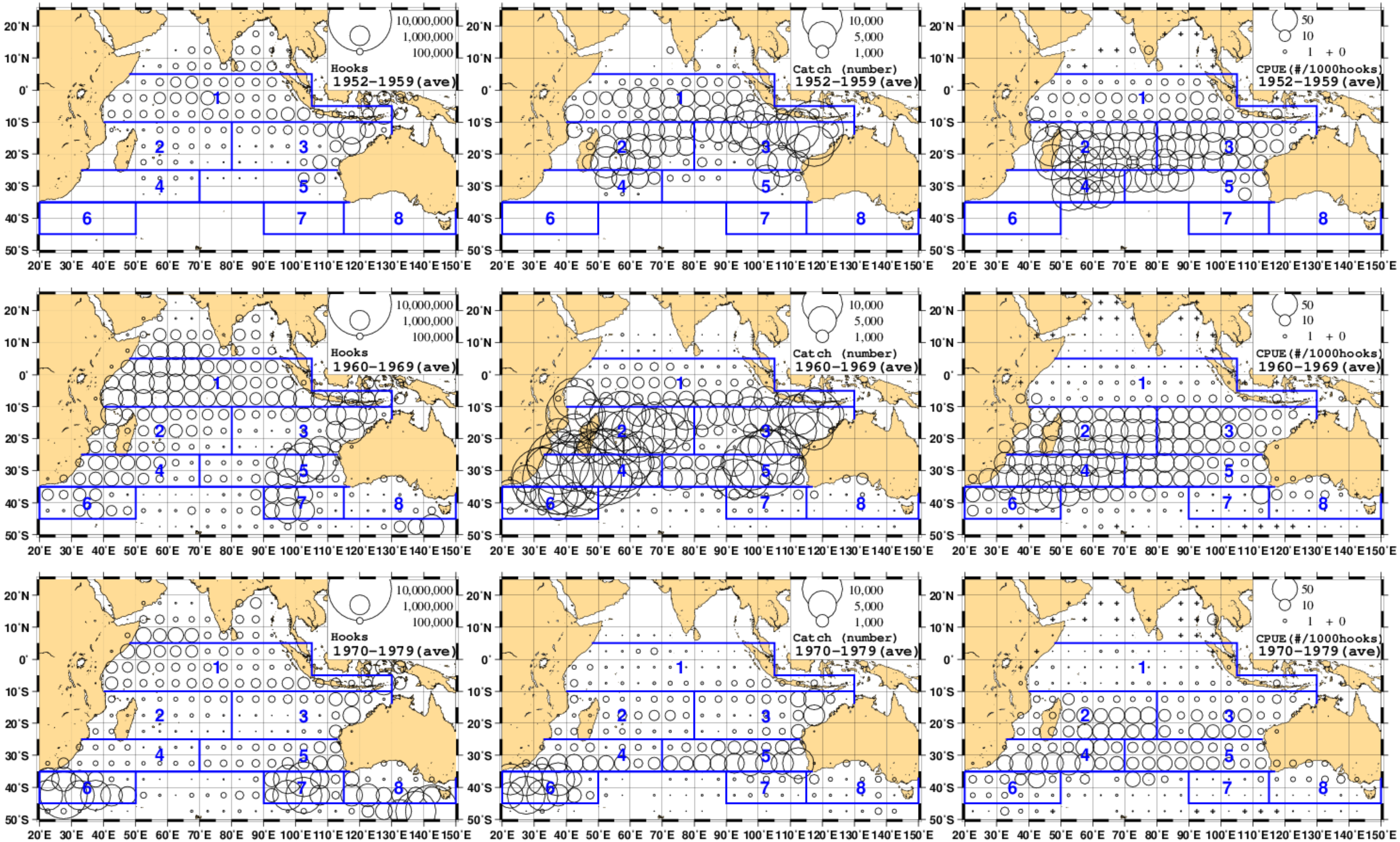
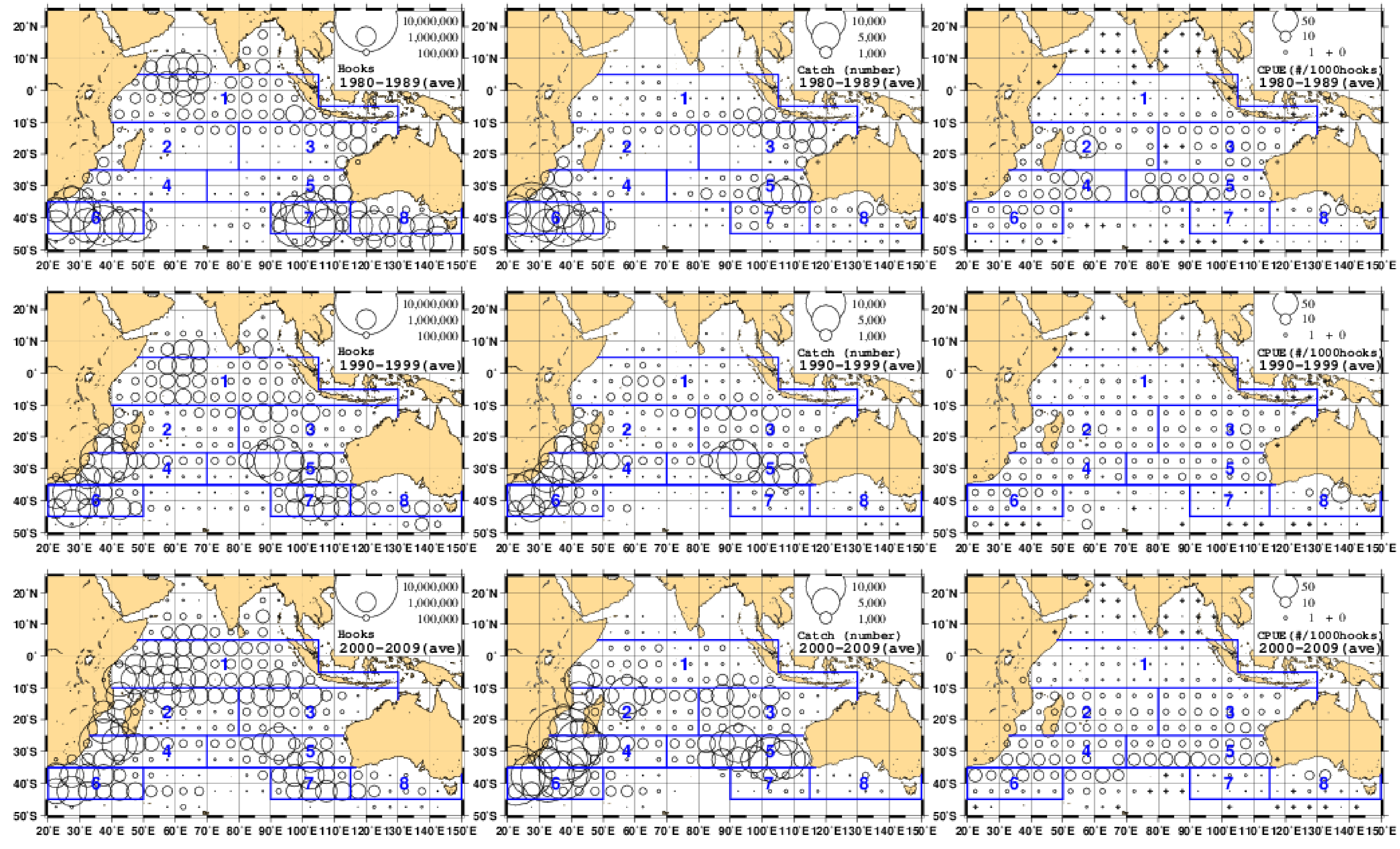


Fig. 10. Standardized CPUEs for the reference and modified models (both by NB model). The CPUE for the modified model were calculated using only from Area 2 and Area 4 where albacore is generally abundant. The CPUE for the reference model is the same as that shown in Fig. 7.



Appendix Fig. 1. The geographical distribution of the effort (number of hooks), albacore catch (number of fish) and CPUE (number of fish/1000hooks) for each decadal period.



Appendix Fig. 1. The geographical distribution of the effort (number of hooks), albacore catch (number of fish) and CPUE (number of fish/1000hooks) for each decadal period. (continued)