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Albacore *(Thunnus alalunga)* CPUE Trend from Indian Core Albacore Areas based on Taiwanese longline catch and effort statistics dating from 1980 to 2013
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Liang-Kang Lee[1], Chih-Cheng Hsu[2] and Feng-Chen Chang[3]

SUMMARY

Because of disharmonious CPUE trends, using generalized linear models without the effect of fishing gears interventions, were observed during recent assessments on Indian Ocean albacore, an attempt of identification the 'Core albacore Area' was recommended to rectify this problem. This study was thus to propose the 'Core albacore Area' and to standardize its corresponding albacore abundance indices based on Taiwanese longline fisheries data series.

Two areas were proposed by Taiwan as the core albacore area, namely South area 2a (S15°-45°, E55°-100°) and South area 2b (S20°-40°, E20°-70°) respectively. For Taiwanese longline fishery, both proposed core areas do have own characteristics and represented meaning. South area 2a is always the most dominate fishing ground of albacore by Taiwanese longline fishery. Although South area 2b is also an important fishing ground of albacore, it reflects the shift of fishing composition since 2000. Standardized yearly and quarterly CPUE series of albacore in both areas, dating from 1980 to 2013, based on Taiwanese longline catch and effort statistics by using Generalized Liner Model (GLM) procedure were carried out in present study.

In South area 2a, the standardized yearly CPUE series showed a decline trend from early 1980s to early 1990s, after that there were two times increase sharply in 1990s, then leveled off since 1999 up to 2013. The standardized quarterly CPUE series showed a similar trend as those of obtained in the yearly trend but having more fluctuations. The results of ANOVA indicated that (1) both of yearly model and quarter-series model are statistically significant (P < 0.0001); (2) the factor of subarea in both yearly and quarter-series model is non significant, it may be because albacore is the most dominant targeting species in this area and this area just covered little subarea 4 caused; (3) comparatively, factors of yellowfin tuna and bigeye tuna play the important roles in explanation of its variation to the total.

In South area 2b, the standardized yearly CPUE series indicated that it appeared a decline trend from early 1980s to early 1990s, then leveled off since early 1990s up to 2013 and a periodic up and down was presented as a cycle of 4-7 years. The standardized quarterly CPUE series showed a similar trend as those of obtained in the yearly trend but having more fluctuations. The results of ANOVA indicated that (1) both of yearly model and quarter-series model are statistically significant (P < 0.0001); (2) factors subarea and bycatch effect of OTHER have the most important effect; (3) the factor of quarter is non significant.

1 Dept. of Fisheries production and Management, National Kaoshiung Marine University, Kaohsiung, Taiwan; E-mail: leelk@mail.nkmu.edu.tw;
2 Dept. of Fisheries production and Management, National Kaoshiung Marine University, Kaohsiung, Taiwan; E-mail: hsucc.nkmu@gmail.com;
3 Overseas Fisheries Development Council, Taipei, Taiwan; E-mail: fengchen@ofdc.org.tw

INTRODUCTION

In the Indian Ocean, albacore is one of the main target species of commercial tuna fishery and has a long history of scientific research. Albacore in the Indian Ocean has, for the last four decades, been mainly exploited by Taiwan, Japan, and Korea. Taiwanese catch of Indian albacore increased steadily from the 1960's to average around 10,000 tons by the mid-1970s. Between 1998 and 2002 catches ranged between 21,500 tons to 26,900 tons, comprising about 60% of the total Indian albacore catch. In the recent decade, the catch of Indian albacore by Taiwanese longliners fluctuated between 10,000 tons to 18,000 tons. Fig. 1 showed the yearly fluctuations of albacore catch and catch composition of main species made by Taiwanese longline fisheries, 1980-2013. It is clear that catch rate of albacore was decreased, yet bigeye and yellowfin tunas were increased greatly after 1985. However, the total catch rate of these three main species was less than 50% after 2006.

Taiwanese longliners in the Indian composed mainly of two types of fishing gears, i.e., regular longliner and deep longliner. The regular longliner, which commenced since 1960s and is also called traditional longliner, is mainly targeting on albacore. Since mid-1980s, another type of longliner or so called deep longliner, which equipped with –70 degree centigrade or more freezing capability, emerged and mainly targeting on bigeye and yellowfin tunas. Unfortunately, it was not until mid-1990s when the logbook reporting system was able to distinguish their major identity by the addition of "the number of hooks per basket" used in new reporting logbook. Nevertheless, historic task2 data series compiled by Taiwanese fisheries managerial sector and reported to the IOTC thus became one of the important data sources to investigate the long-term abundance fluctuation of this resource.

For the Indian albacore caught by Taiwanese longline fishery, CPUE standardization using the General Linear Model (GLM) had been carried out for 1980-2010 (Chang *et al*., 2011) and for 1980-2011 (Lee *et al.*, 2012). The previous studies on CPUE standardization of Taiwanese longline were almost analyzed from whole area of the Indian Ocean. However, because of the conflict of CPUE trends between Taiwanese and Japanese longline at the recent assessment of Indian Ocean albacore, 'core area' approach was recommended (IOTC, 2012). The main purposes of this study were thus to propose the core albacore area and to standardize its corresponding albacore abundance indices using Taiwanese 1980-2013 task2 data series, by Generalized Linear Models.

MATERIALS AND METHODS

The task2 data, aggregated by month and by 5° statistical block from 1980 to 2013, were compiled and provided by Overseas Fisheries Development Council of Taiwan. However, the data in 2013 are still preliminary.

In order to find the appropriate area as the core albacore area for Taiwanese longline fishery, figures of the average distribution of effort, albacore catch, albacore CPUE, amount of catch by species and proportion of catch by species for each decadal period by Taiwanese longline fishery were used to examine.

GLM with normal error structure (Robson, 1966; Gavaris, 1980; Kimura, 1981) was used in present study to standardize yearly and quarterly CPUE series of albacore in core area. Factors used in the standardization are year, quarter, subarea, effects of bycatch, which includes bigeye tuna, yellowfin tuna and others (catch fishes except albacore, bigeye tuna and yellowfin tuna) and interaction on quarter and subarea. Nominal CPUE was defined as catch in number per 1,000 hooks. Nominal CPUE values of those bycatch species were calculated and coded by quantile. GLM models constructed in present study for yearly and quarterly standardizations are as follows:

Yearly generalized linear model with normal error structure:

$$\mathbf{Ln(CPUE_{\mathit{ijklmno}}+const)=\mu+YEAR_{\mathit{i}}+QUARTER_{\mathit{j}}+SUBAREA_{\mathit{k}}+CODEBET_{\mathit{l}}+CODEYFT_{\mathit{m}}+CODEOTHER_{\mathit{n}}+QUARTER*SUBAREA_{\mathit{0}}+\xi_{\mathit{ijklmno}}}$$

where

Ln: natural logarithm;

$CPUE_{ijklmno}$: nominal albacore CPUE (catch in number per 1000 hooks) in year i, quarter j, subarea k, bycatch of BET_l, YFT_m, $OTHER_n$, and $QUARTER*SUBAREA_0$;

μ: intercept, or overall mean for correction;

const: constant (10% of the overall mean albacore nominal CPUE);

$YEAR_i$: main effect of year i;

$QUARTER_j$: effect of quarter j;

$SUBAREA_k$: effect of subarea k;

$CODEBET_l$: effect of bycatch (bigeye tuna);

$CODEYFT_m$: effect of bycatch (yellowfin tuna);

$CODEOTHER_n$: effect of bycatch (other fishes);

$QUARTER*SUBAREA_0$: effect of interaction on quarter and subarea;

$\xi_{ijkl\,mno}$: error with distribution character of $N(0,\sigma^2)$.

Quarterly generalized linear model with normal error structure:

$$\mathbf{Ln(CPUE_{\mathit{iklmnop}}+const)=\mu+QUARTER\text{-}SERIES_{\mathit{i}}+SUBAREA_{\mathit{k}}+CODEBET_{\mathit{l}}+CODEYFT_{\mathit{m}}+CODEOTHER_{\mathit{n}}+QUARTER*SUBAREA_{\mathit{0}}+YEAR*QUARTER_{\mathit{p}}+\xi_{\mathit{iklmnop}}}$$

where

Ln: natural logarithm;

$CPUE_{iklmno}$: nominal albacore CPUE (catch in number per 1,000 hooks) in quarter-series i, subarea k, bycatch of BET_l, YFT_m, $OTHER_n$, and $QUARTER*SUBAREA_0$;

μ: intercept, or overall mean for correction;

const: constant (10% of the overall mean albacore nominal CPUE);

$QUARTER\text{-}SERIES_i$: main effect of quarter-series i;

$SUBAREA_k$: effect of subarea k;

$CODEBET_l$: effect of bycatch (bigeye tuna);

$CODEYFT_m$:effect of bycatch (yellowfin tuna);

$CODEOTHER_n$: effect of bycatch ((other fishes);

$QUARTER*SUBAREA_0$: effect of interaction on quarter and subarea;

YEAR* $QUARTER_p$: effect of interaction on year and quarter;

$\xi_{iklmnop}$: error with distribution character of $N(0,\sigma^2)$.

Fig. 2 showing the 4 subareas of the Indian Ocean those were obtained based on the results of cluster analysis on Taiwanese longline catch statistics.

SAS Ver. 9.3. Statistical package was used to obtain solution.

RESULTS AND DISCUSSION

Based on Fig. 3 ~Fig.7, two areas were proposed (Fig. 8) as the core albacore area, namely South area 2a (S15°-45°, E55°-100°) and South area 2b (S20°-40°, E20°-70°) respectively. We can see from these figures, South area 2a located in the south central Indian Ocean is always the most dominate fishing ground of albacore by Taiwanese longline fishery. South area 2b located in the southwest of Indian Ocean, although it is also an important fishing ground of albacore, it reflects the shift of fishing composition since 2000.

Standardization in South area 2a:
A constant of 1.6853, which was obtained by averaging all Taiwanese longliners' nominal albacore CPUE reported from 1980 to 2013 in South area 2a and divided by 10, was determined and added to each nominal albacore CPUE for the purpose of avoiding zero albacore catch rate problem (ICCAT, 1996).

Nominal abundance of bigeye tuna, yellowfin tuna and OTHER will also be included as factors of bycatch into the model and the value input is using discrete quantile level. The discrete quantile values used for grouping nominal CPUEs were: (1) 0~0.164, 0.164~0.698, 0.698~1.664, and greater than 1.664 for bigeye tuna; (2) 0~0.031, 0.031~0.313, 0.313~0.853, and greater than 0.853 for yellowfin tuna; and (3) 0~0.190, 0.190~0.641, 0.641~1.700, and greater than 1.700 for OTHER, accordingly.

In this area, because of missing of QUARTER*SUBAREA interaction, leading to standardized CPUE can't be calculated, GLM models for yearly and quarterly standardizations were thus modified as **Ln(CPUE+const)=μ+YEAR+QUARTER+SUBAREA+CODEBET+CODEYFT+CODEOTHER+ξ** and **Ln(CPUE+const)=μ+QUARTER-SERIES+SUBAREA+CODEBET+CODEYFT+CODEOTHER+YEAR*QUARTER + ξ**, respectively.

The nominal yearly CPUE trend and its respective standardized yearly CPUE series thus obtained were tabulated in Table 1, and plotted in Fig. 9. The standardized yearly CPUE series showed a decline trend from early 1980s to early 1990s, after that there were two times increase sharply in 1990s, then leveled off since 1999 up to 2013. The big rise of CPUE in 1997 and 1998 whether with El Nino/Southern Oscillation related, need for further verification. The nominal quarterly CPUE trend and its respective standardized quarterly CPUE series thus obtained were tabulated in Table 3, and plotted in Fig. 10. The standardized quarterly CPUE series showed a similar trend as those of obtained in the yearly trend but having more fluctuations.

The ANOVA tables, as shown in Table 2 and 5, which were obtained by SAS solver, indicated that (1) both yearly model and quarter-series model are statistically significant ($P < 0.0001$); (2) the factor of subarea in both yearly and quarter-series model is non significant, it may be because albacore is the most dominant targeting species in this area and this area just covered little subarea 4 caused; (3) comparatively, factors of yellowfin tuna and bigeye tuna play the important roles in explanation of its variation to the total.

Standardization in South area 2b:
A constant of 1.1550, which was obtained by averaging all Taiwanese longliners' nominal albacore CPUE reported from 1980 to 2013 in South area 2b and divided by 10, was determined and added to each nominal albacore CPUE for the purpose of avoiding zero albacore catch rate problem (ICCAT,

1996).

Nominal abundance of bigeye tuna, yellowfin tuna and OTHER will also be included as factors of bycatch into the model and the value input is using discrete quantile level. The discrete quantile values used for grouping nominal CPUEs were: (1) 0~0.181, 0.181~0.670, 0.670~1.629, and greater than 1.629 for bigeye tuna; (2) 0~0.086, 0.086~0.349, 0.349~0.887, and greater than 0.887 for yellowfin tuna; and (3) 0~0.274, 0.274~1.129, 1.129~4.243, and greater than 4.243 for OTHER, accordingly.

The nominal yearly CPUE trend and its respective standardized yearly CPUE series thus obtained were tabulated in Table 1, and plotted in Fig. 9. The standardized yearly CPUE series indicated that it appeared a decline trend from early 1980s to early 1990s, then leveled off since early 1990s up to 2013 and a periodic up and down was presented as a cycle of 4-7 years. The nominal quarterly CPUE trend and its respective standardized quarterly CPUE series thus obtained were tabulated in Table 4, and plotted in Fig. 10. The standardized quarterly CPUE series showed a similar trend as those of obtained in the yearly trend but having more fluctuations.

The ANOVA tables, as shown in Table 2 and 5, which were obtained by SAS solver, indicated that (1) both of yearly model and quarter-series model are statistically significant ($P < 0.0001$); (2) factors subarea and bycatch effect of OTHER have the most important effect.; (3) the factor of quarter is non significant.

Both South area 2a and South area 2b are the main fishing grounds of albacore for Taiwanese longline fishery, especially South area 2a. For Taiwanese longline fishery, both proposed core areas do have own characteristics and represented meaning. South area 2a is always the most dominate fishing ground of albacore by Taiwanese longline fishery. Although South area 2b is also an important fishing ground of albacore, it reflects the shift of fishing composition since 2000. Which proposed area could be the appropriate core area? Perhaps through analysis, comparison and discussion by assessment models would have the results.

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Table 1 Yearly nominal and standardized CPUE trends of albacore in South area 2a and South area 2b based on Taiwanese longline fishery data set from 1980-2013 using GLM procedure.

South area 2a (S15-45°,E55-100°)			South area 2b (S20-40°, E20-70°)		
Year	Nominal CPUE	STD-CPUE	Year	Nominal CPUE	STD-CPUE
1980	18.865	15.979	1980	29.336	9.573
1981	25.875	23.073	1981	32.221	11.393
1982	27.279	23.569	1982	28.555	10.214
1983	22.757	17.326	1983	24.067	6.569
1984	20.048	14.068	1984	24.926	7.482
1985	22.634	15.350	1985	22.802	6.641
1986	36.033	25.010	1986	27.112	9.489
1987	23.658	19.558	1987	25.073	9.785
1988	23.766	18.111	1988	22.360	8.637
1989	12.740	9.865	1989	9.574	2.485
1990	6.680	4.066	1990	13.172	3.267
1991	13.985	10.185	1991	7.614	3.124
1992	20.853	10.981	1992	3.424	1.178
1993	18.323	15.304	1993	11.303	5.827
1994	14.148	10.267	1994	10.066	6.802
1995	13.576	7.795	1995	5.716	3.194
1996	20.089	13.864	1996	11.087	3.394
1997	29.266	24.730	1997	14.117	6.080
1998	31.699	23.809	1998	18.191	5.525
1999	12.759	8.933	1999	7.764	3.455
2000	18.319	10.314	2000	9.486	3.278
2001	12.955	9.030	2001	11.771	3.872
2002	10.457	8.572	2002	11.241	5.278
2003	11.606	8.560	2003	14.354	5.051
2004	9.114	9.356	2004	9.432	5.279
2005	9.898	8.150	2005	7.324	3.754
2006	9.791	8.015	2006	2.804	2.058
2007	12.324	8.646	2007	3.188	2.858
2008	16.198	10.690	2008	4.596	4.647
2009	13.052	8.728	2009	4.658	5.368
2010	14.817	10.250	2010	3.809	4.106
2011	12.071	6.884	2011	3.856	4.968
2012	16.383	9.785	2012	3.605	5.022
2013	17.774	12.840	2013	3.195	2.873

Table 2 Analysis of variance of standardized albacore in South area 2a and South area 2b yearly CPUE using Taiwanese longline fishery data set from 1980 to 2013 by GLM procedure.

South area 2a (S15-45° ,E55-100°)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	46	1134.339066	24.659545	49.24	<.0001
Error	5113	2560.792701	0.50084		
Corrected Total	5159	3695.131768			
R-Square	Coeff Var	Root MSE	lalb Mean		
0.306982	27.58646	0.7077	2.56539		
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	33	509.8964089	15.4514063	30.85	<.0001
season	3	55.7181792	18.5727264	37.08	<.0001
subarea	1	0.2100454	0.2100454	0.42	0.5173
CODEBET	3	101.6197296	33.8732432	67.63	<.0001
CODEYFT	3	145.8423114	48.6141038	97.07	<.0001
CODEOTHER	3	8.1427427	2.7142476	5.42	0.001

South area 2b (S20-40°, E20-70°)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	49	2460.216614	50.208502	63.54	<.0001
Error	4246	3354.98847	0.790153		
Corrected Total	4295	5815.205084			
R-Square	Coeff Var	Root MSE	lalb Mean		
0.423066	42.73106	0.888905	2.080232		
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	33	446.3903737	13.526981	17.12	<.0001
season	3	4.2643476	1.4214492	1.8	0.1451
subarea	1	133.2763223	133.2763223	168.67	<.0001
CODEBET	3	122.9799566	40.9933189	51.88	<.0001
CODEYFT	3	51.3059831	17.1019944	21.64	<.0001
CODEOTHER	3	326.5838196	108.8612732	137.77	<.0001
season*subarea	3	8.7227162	2.9075721	3.68	0.0116

Table 3 Quarterly nominal and standardized CPUE trends of albacore in South area 2a based on Taiwanese longline fishery data set from 1980-2013 using GLM procedure.

South area 2a (S15-45°,E55-100°)															
Year	Q	Nominal CPUE	STD CPUE	Year	Q	Nominal CPUE	STD CPUE	Year	Q	Nominal CPUE	STD CPUE	Year	Q	Nominal CPUE	STD CPUE
1980	1	16.001	12.391	1989	1	12.268	10.510	1998	1	28.563	23.718	2007	1	9.350	9.057
1980	2	23.012	18.286	1989	2	11.286	9.689	1998	2	36.664	33.572	2007	2	15.873	15.213
1980	3	21.740	17.712	1989	3	13.539	12.165	1998	3	28.465	20.321	2007	3	12.777	7.955
1980	4	17.465	18.812	1989	4	12.247	8.008	1998	4	31.298	22.178	2007	4	7.896	6.495
1981	1	23.880	21.700	1990	1	8.856	5.265	1999	1	9.487	7.956	2008	1	11.494	7.134
1981	2	30.890	27.389	1990	2	7.825	6.109	1999	2	15.341	11.870	2008	2	22.474	19.803
1981	3	31.724	28.897	1990	3	5.139	3.662	1999	3	12.011	9.590	2008	3	12.486	8.825
1981	4	18.577	18.604	1990	4	5.502	2.660	1999	4	11.580	6.726	2008	4	10.464	6.963
1982	1	30.310	24.105	1991	1	9.909	6.787	2000	1	13.202	7.099	2009	1	12.528	8.524
1982	2	32.082	28.915	1991	2	19.705	14.213	2000	2	24.732	16.282	2009	2	14.140	12.284
1982	3	27.608	24.251	1991	3	11.624	10.472	2000	3	16.316	10.990	2009	3	12.442	7.082
1982	4	16.715	20.308	1991	4	10.434	9.008	2000	4	10.479	6.038	2009	4	15.090	10.507
1983	1	25.073	17.547	1992	1	11.012	11.878	2001	1	10.665	6.755	2010	1	20.474	10.683
1983	2	27.062	20.613	1992	2	21.945	9.996	2001	2	15.682	7.457	2010	2	17.228	15.358
1983	3	22.454	17.494	1992	3	19.880	10.328	2001	3	12.037	9.845	2010	3	12.293	7.477
1983	4	14.509	16.011	1992	4	33.899	41.961	2001	4	12.260	13.191	2010	4	7.948	8.760
1984	1	20.349	12.294	1993	1	23.606	22.694	2002	1	7.261	7.281	2011	1	11.754	5.245
1984	2	25.014	16.757	1993	2	21.567	18.893	2002	2	13.235	10.069	2011	2	13.681	10.747
1984	3	23.843	18.982	1993	3	17.643	15.002	2002	3	9.610	8.750	2011	3	9.962	7.651
1984	4	10.115	11.202	1993	4	13.834	11.676	2002	4	9.029	8.823	2011	4	2.972	1.873
1985	1	23.713	11.754	1994	1	14.528	10.059	2003	1	9.964	8.438	2012	1	14.710	4.096
1985	2	30.976	22.043	1994	2	18.372	14.521	2003	2	14.009	10.064	2012	2	24.971	19.604
1985	3	22.410	18.774	1994	3	10.264	6.919	2003	3	9.933	7.562	2012	3	12.555	8.624
1985	4	13.548	15.033	1994	4	13.590	12.367	2003	4	17.022	9.795	2012	4	16.214	17.200
1986	1	39.643	24.876	1995	1	9.484	8.832	2004	1	14.406	10.565	2013	1	3.940	7.796
1986	2	44.095	38.370	1995	2	16.578	8.196	2004	2	14.040	12.749	2013	2	19.672	16.141
1986	3	32.558	24.830	1995	3	11.664	5.600	2004	3	5.647	6.928	2013	3	18.084	15.302
1986	4	21.119	18.290	1995	4	14.608	14.148	2004	4	9.585	9.454				
1987	1	27.872	25.134	1996	1	27.457	18.413	2005	1	11.242	8.417				
1987	2	25.009	24.067	1996	2	26.112	14.120	2005	2	12.912	9.526				
1987	3	23.688	15.920	1996	3	15.053	9.606	2005	3	8.347	7.588				
1987	4	18.999	18.805	1996	4	20.136	17.616	2005	4	8.841	7.674				
1988	1	24.319	19.635	1997	1	24.310	19.183	2006	1	10.627	8.371				
1988	2	27.767	20.900	1997	2	41.188	37.767	2006	2	12.623	9.668				
1988	3	23.384	19.509	1997	3	22.030	18.522	2006	3	7.832	7.202				
1988	4	12.983	13.653	1997	4	31.644	31.670	2006	4	10.690	7.549				

Table 4 Quarterly nominal and standardized CPUE trends of albacore in South area 2b based on Taiwanese longline fishery data set from 1980-2013 using GLM procedure.

South area 2b (S20-40˚, E20-70˚)

Year	Q	Nominal CPUE	STD CPUE	Year	Q	Nominal CPUE	STD CPUE	Year	Q	Nominal CPUE	STD CPUE	Year	Q	Nominal CPUE	STD CPUE
1980	1	28.148	7.400	1989	1	8.386	2.508	1998	1	17.840	6.355	2007	1	0.590	1.230
1980	2	34.975	11.371	1989	2	10.350	2.540	1998	2	21.869	5.899	2007	2	1.323	1.733
1980	3	29.200	8.948	1989	3	9.068	2.490	1998	3	14.698	3.535	2007	3	5.186	3.263
1980	4	18.903	7.871	1989	4	4.120	1.117	1998	4	37.821	13.096	2007	4	5.173	3.618
1981	1	25.927	12.859	1990	1	10.224	1.413	1999	1	6.021	2.514	2008	1	6.964	3.987
1981	2	36.010	11.874	1990	2	14.545	3.961	1999	2	8.052	3.166	2008	2	5.362	5.955
1981	3	38.860	12.272	1990	3	12.886	2.663	1999	3	8.169	3.445	2008	3	2.173	2.543
1981	4	17.663	6.585	1990	4	11.621	3.513	1999	4	7.226	3.330	2008	4	5.933	6.520
1982	1	28.988	10.466	1991	1	6.500	2.420	2000	1	6.120	3.233	2009	1	4.752	6.832
1982	2	35.240	11.639	1991	2	11.174	5.493	2000	2	8.995	3.258	2009	2	2.335	4.539
1982	3	28.188	8.680	1991	3	7.110	2.041	2000	3	8.337	2.526	2009	3	6.424	5.616
1982	4	17.310	7.595	1991	4	4.976	3.142	2000	4	16.146	2.694	2009	4	5.712	4.205
1983	1	16.494	5.705	1992	1	0.727	0.640	2001	1	6.163	3.013	2010	1	4.809	4.066
1983	2	32.801	7.588	1992	2	4.140	0.891	2001	2	13.678	3.483	2010	2	3.537	3.603
1983	3	25.648	5.393	1992	3	3.656	1.559	2001	3	10.711	3.372	2010	3	1.999	2.798
1983	4	15.348	6.280	1992	4	0.607	0.000	2001	4	13.322	3.577	2010	4	7.766	5.029
1984	1	20.256	5.841	1993	1	17.696	10.495	2002	1	9.166	4.891	2011	1	5.999	4.703
1984	2	31.031	8.251	1993	2	18.036	3.817	2002	2	13.555	5.995	2011	2	3.152	5.027
1984	3	25.838	7.733	1993	3	10.196	6.001	2002	3	10.383	4.510	2011	3	2.426	3.105
1984	4	13.900	5.320	1993	4	11.605	4.795	2002	4	8.907	3.409	2011	4	7.255	6.909
1985	1	15.821	4.611	1994	1	13.071	4.058	2003	1	7.596	2.070	2012	1	2.931	4.034
1985	2	29.770	7.103	1994	2	15.942	8.474	2003	2	13.934	4.181	2012	2	1.630	3.382
1985	3	27.621	8.946	1994	3	7.389	5.144	2003	3	13.718	5.134	2012	3	3.523	3.989
1985	4	17.108	6.356	1994	4	9.636	7.158	2003	4	20.997	7.214	2012	4	8.516	8.690
1986	1	20.387	6.653	1995	1	14.906	7.395	2004	1	11.049	5.334	2013	1	2.874	2.738
1986	2	33.246	12.545	1995	2	7.468	2.880	2004	2	15.017	5.991	2013	2	2.962	1.943
1986	3	32.929	9.820	1995	3	3.581	2.072	2004	3	6.588	4.624	2013	3	4.071	3.677
1986	4	21.566	8.645	1995	4	4.532	1.639	2004	4	8.287	3.694				
1987	1	23.310	10.561	1996	1	11.004	2.615	2005	1	5.675	2.927				
1987	2	27.717	9.860	1996	2	12.683	2.687	2005	2	6.941	2.611				
1987	3	25.045	8.228	1996	3	9.440	2.314	2005	3	6.302	4.139				
1987	4	21.340	8.853	1996	4	18.492	5.361	2005	4	10.044	3.707				
1988	1	23.794	10.404	1997	1	23.353	13.876	2006	1	5.406	2.636				
1988	2	21.944	8.612	1997	2	19.639	6.387	2006	2	2.851	1.936				
1988	3	23.701	6.980	1997	3	9.294	2.948	2006	3	2.756	1.496				
1988	4	14.245	6.381	1997	4	19.612	3.869	2006	4	0.798	1.295				

Table 5 Analysis of variance of standardized albacore in South area 2a and South area 2b quarterly CPUE using Taiwanese longline fishery data set from 1980 to 2013 by GLM procedure.

South area 2a (S15-45˚ ,E55-100˚) by Quarter

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	144	1298.70335	9.018773	18.87	<.0001
Error	5015	2396.428418	0.477852		
Corrected Total	5159	3695.131768			
R-Square	Coeff Var	Root MSE	lalb Mean		
0.351463	26.94595	0.691268	2.56539		
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	33	477.1889341	14.4602707	30.26	<.0001
season	3	55.4290979	18.476366	38.67	<.0001
subarea	1	0.3469847	0.3469847	0.73	0.3942
CODEBET	3	90.1566159	30.0522053	62.89	<.0001
CODEYFT	3	125.901345	41.967115	87.82	<.0001
CODEOTHER	3	9.3241241	3.1080414	6.5	0.0002
Year*season	98	164.3642835	1.6771866	3.51	<.0001

South area 2b (S20-40˚, E20-70˚) by Quarter

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	147	2649.479467	18.02367	23.62	<.0001
Error	4148	3165.725617	0.763193		
Corrected Total	4295	5815.205084			
R-Square	Coeff Var	Root MSE	lalb Mean		
0.455612	41.99576	0.873609	2.080232		
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	33	420.9820941	12.7570332	16.72	<.0001
season	3	2.3040342	0.7680114	1.01	0.3888
subarea	1	121.505106	121.505106	159.21	<.0001
CODEBET	3	106.5822989	35.527433	46.55	<.0001
CODEYFT	3	33.3849341	11.1283114	14.58	<.0001
CODEOTHER	3	319.2394364	106.4131455	139.43	<.0001
season*subarea	3	8.364039	2.788013	3.65	0.012
Year*season	98	189.2628527	1.9312536	2.53	<.0001

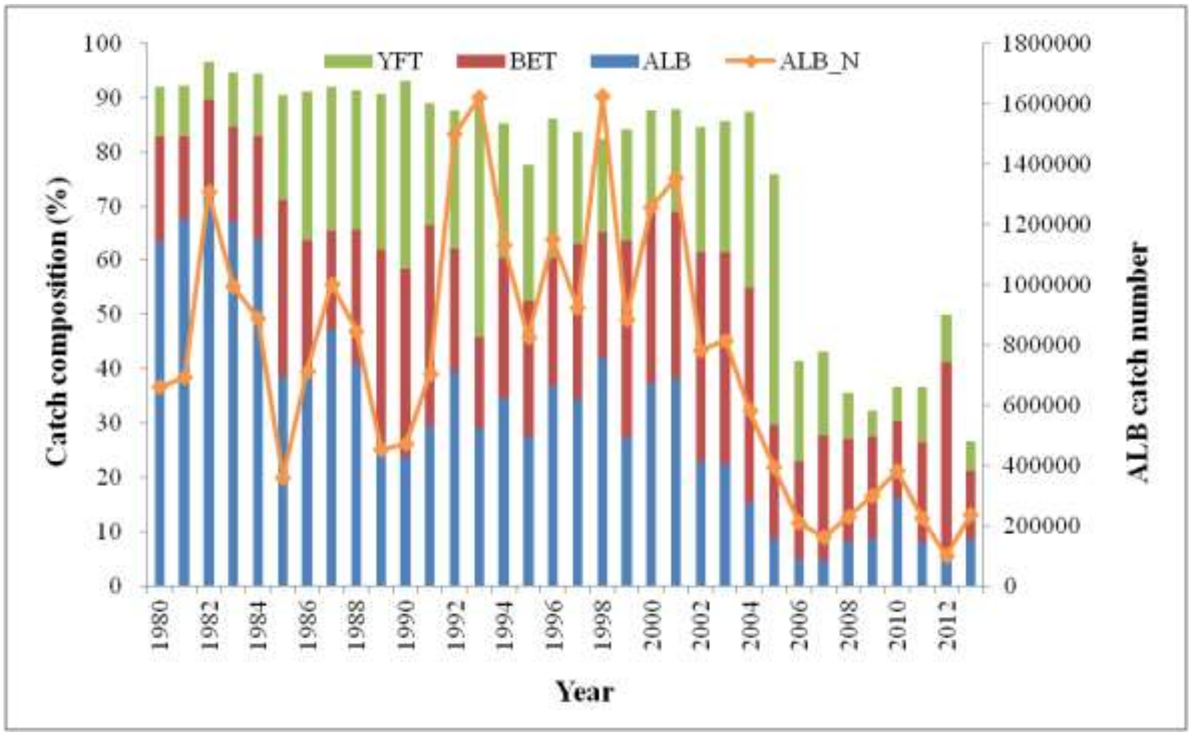


Fig. 1 Yearly fluctuations of albacore catch and catch composition of main species made by Taiwanese longline fisheries, 1980-2013.

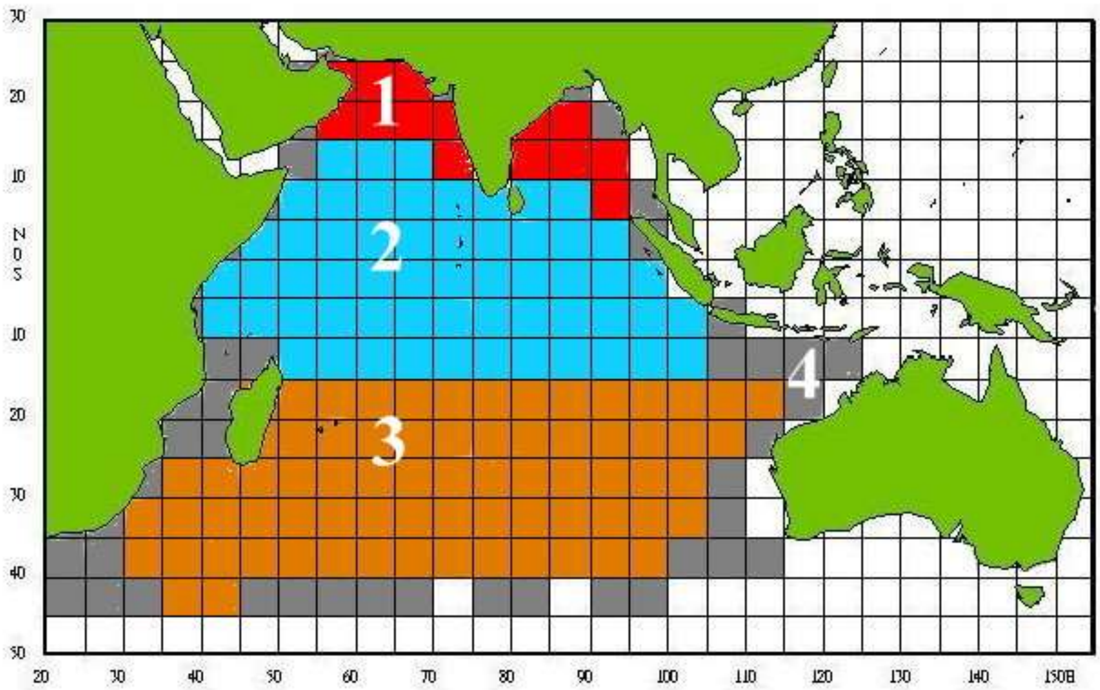


Fig. 2 Subarea delineation of Indian albacore for Taiwanese longline fishery.

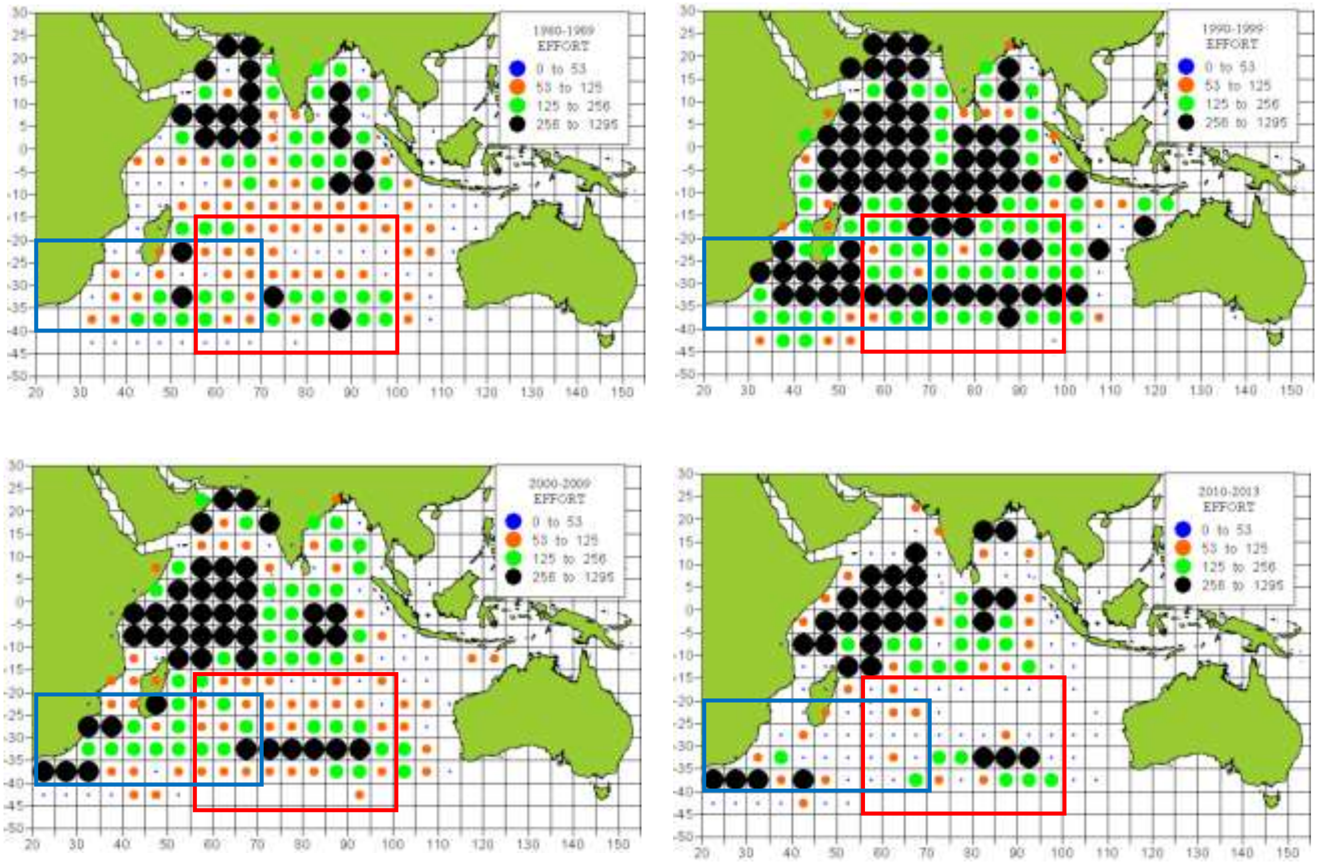


Fig. 3 The average distribution of effort (number of hooks) for each decadal period by Taiwanese longline fishery.

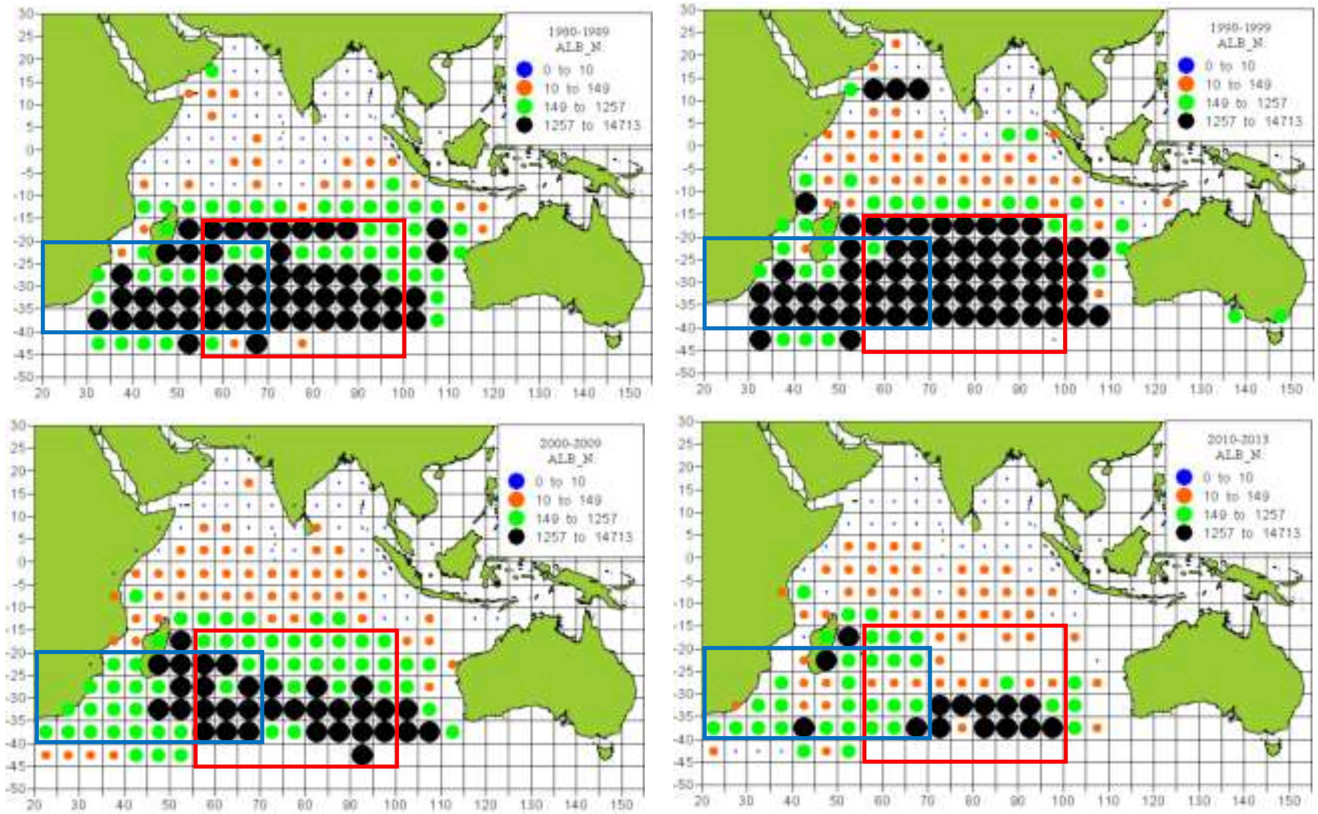


Fig. 4 The average distribution of albacore catch (number of fish) for each decadal period by Taiwanese longline fishery.

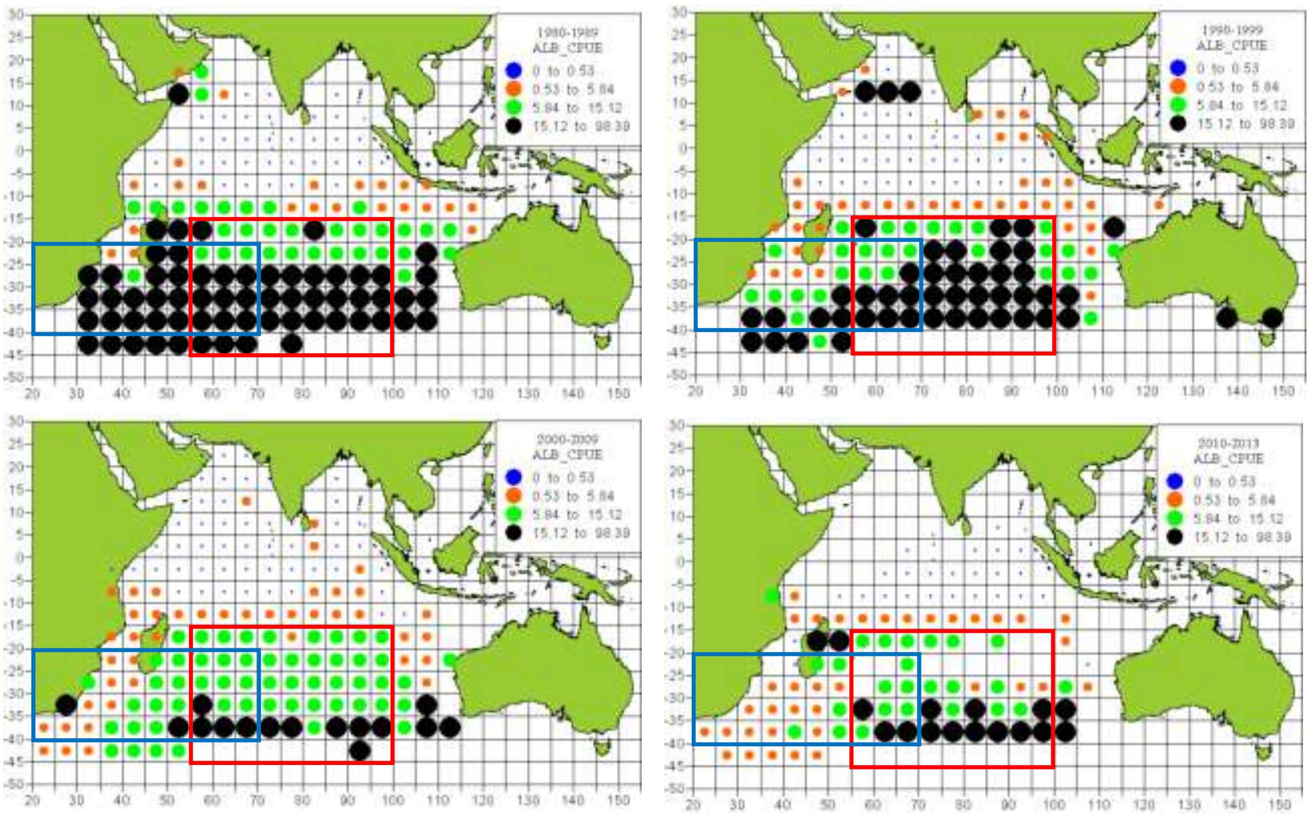


Fig. 5 The average distribution of albacore CPUE (number of fish/1000 hooks) for each decadal period by Taiwanese longline fishery.

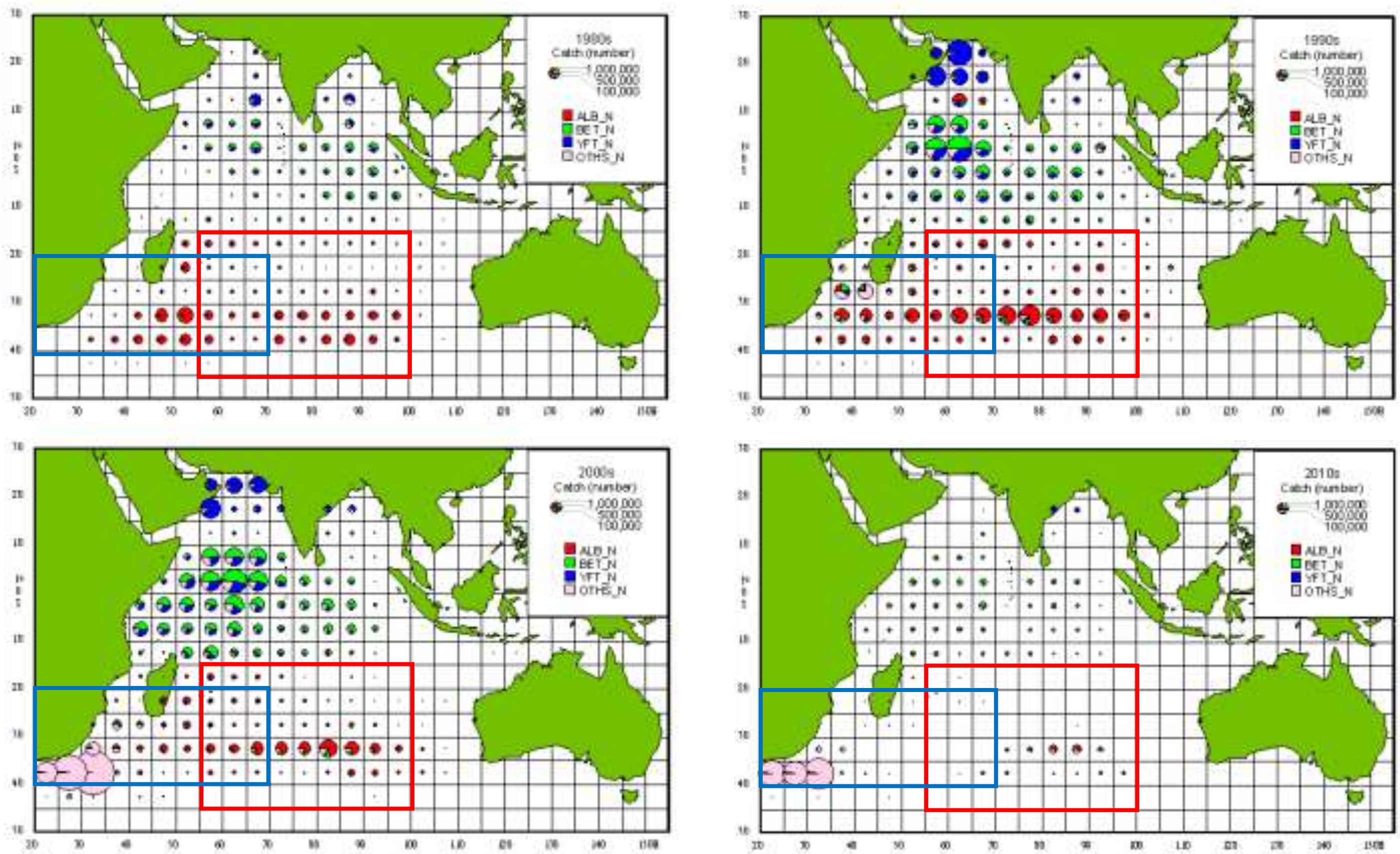


Fig. 6 The averaged distribution of amount of catch by species for each decade. Size of circle shows amount of total of catches. i.e. albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT) and others catch (OTHS).

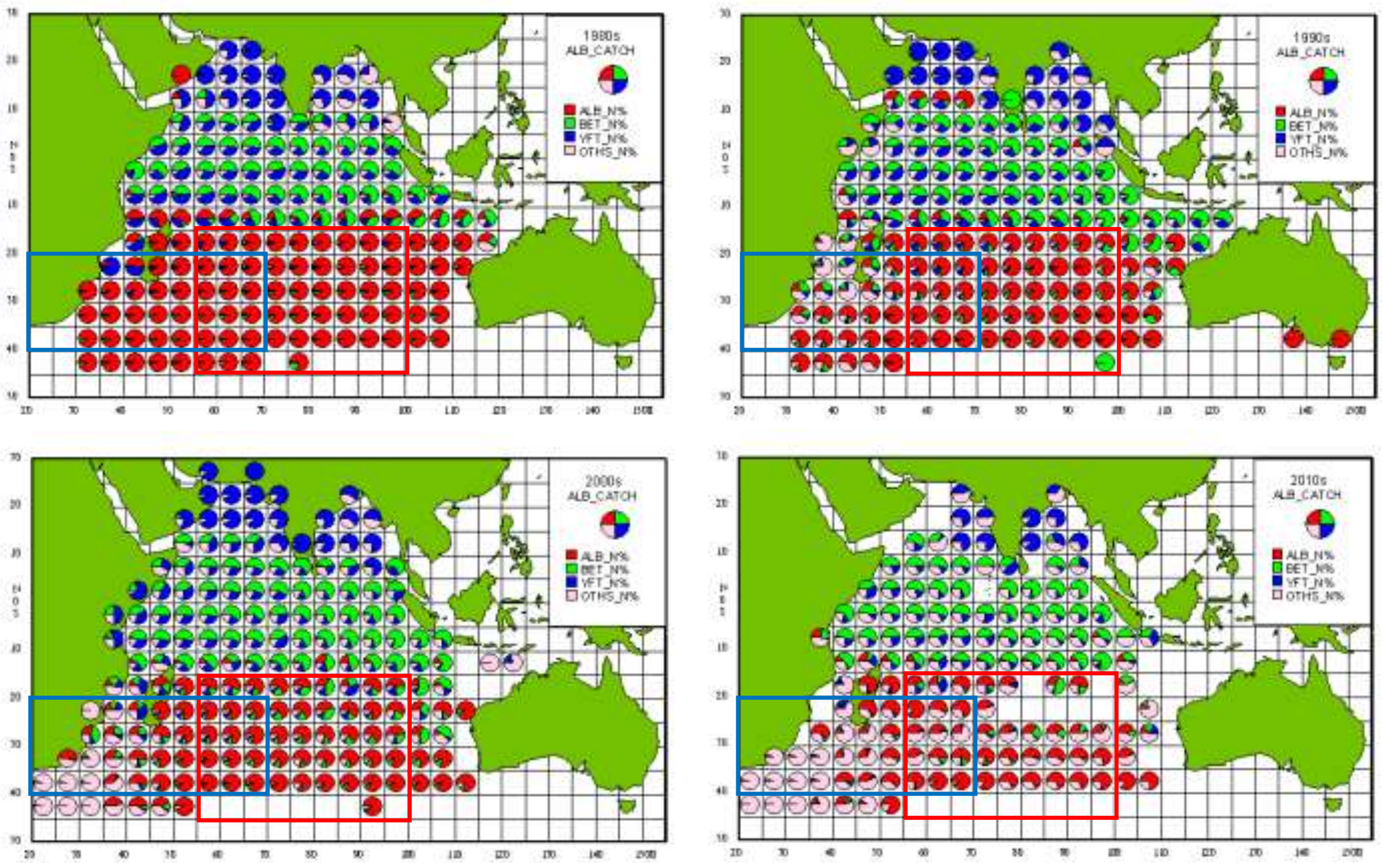


Fig. 7 The averaged distribution of proportion of catch by species for each decade. The circle shows proportion of total of catches. i.e. albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT) and others catch (OTHS).

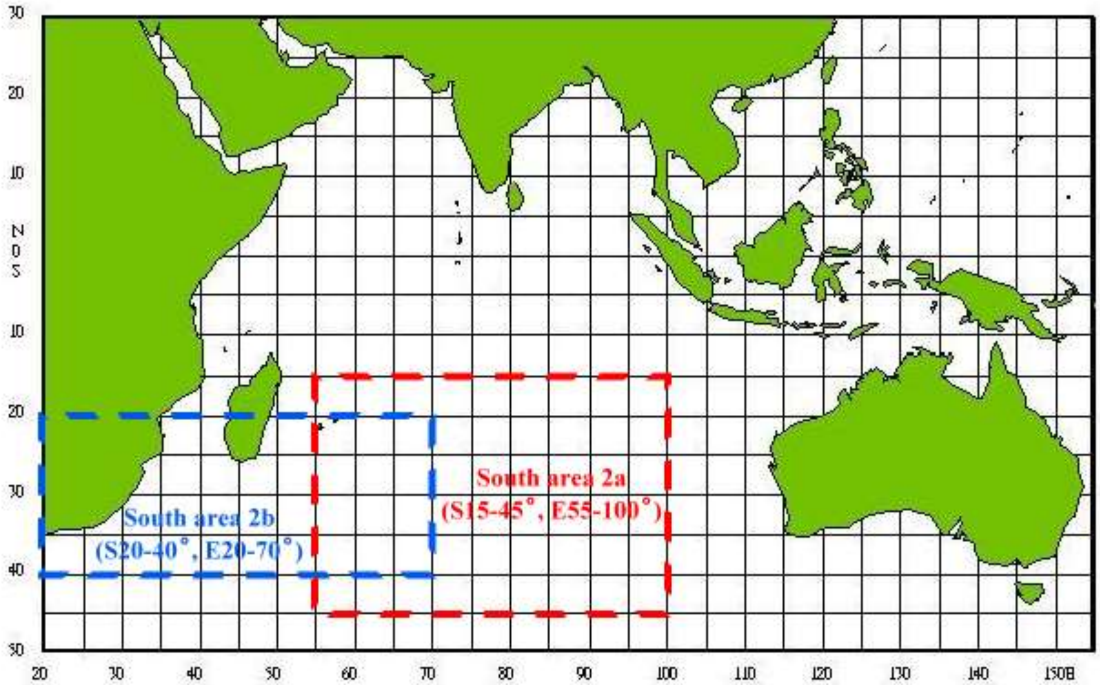
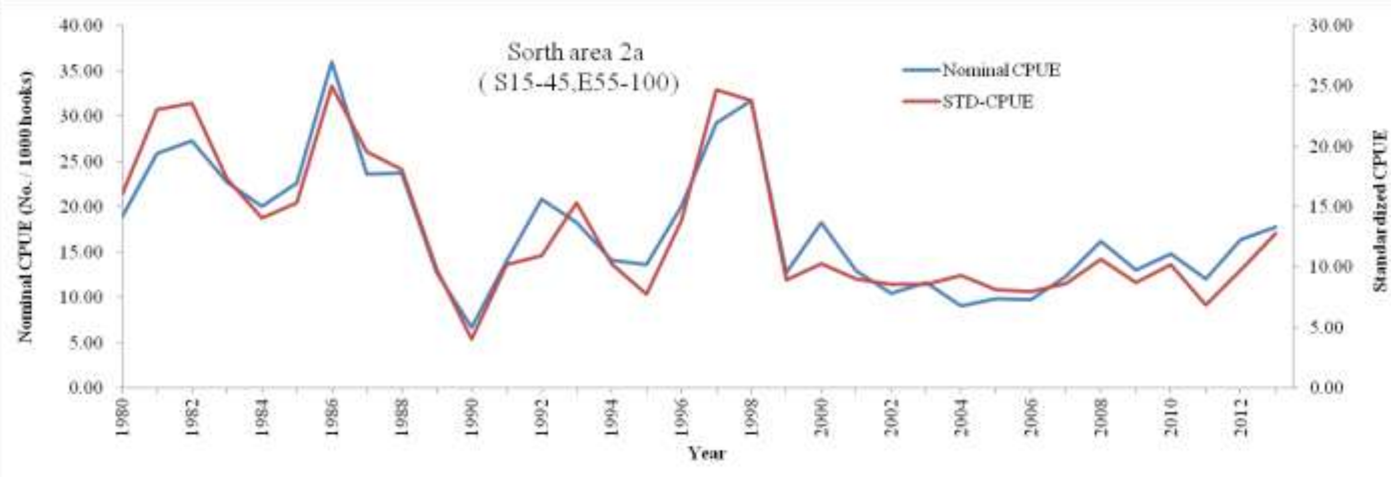


Fig. 8 The proposed core albacore area by Taiwan.



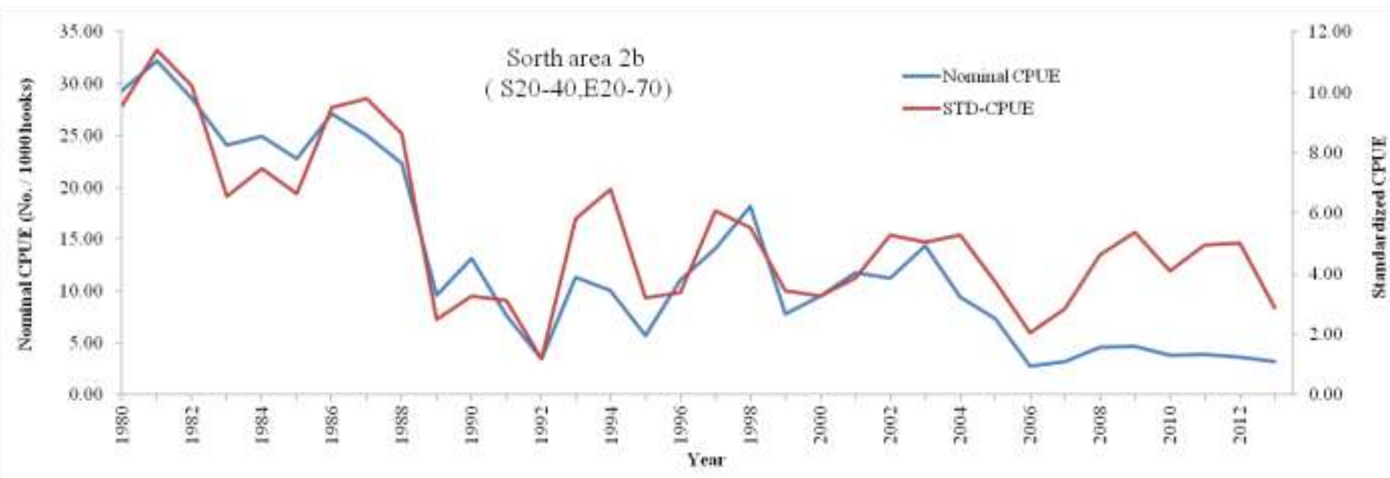
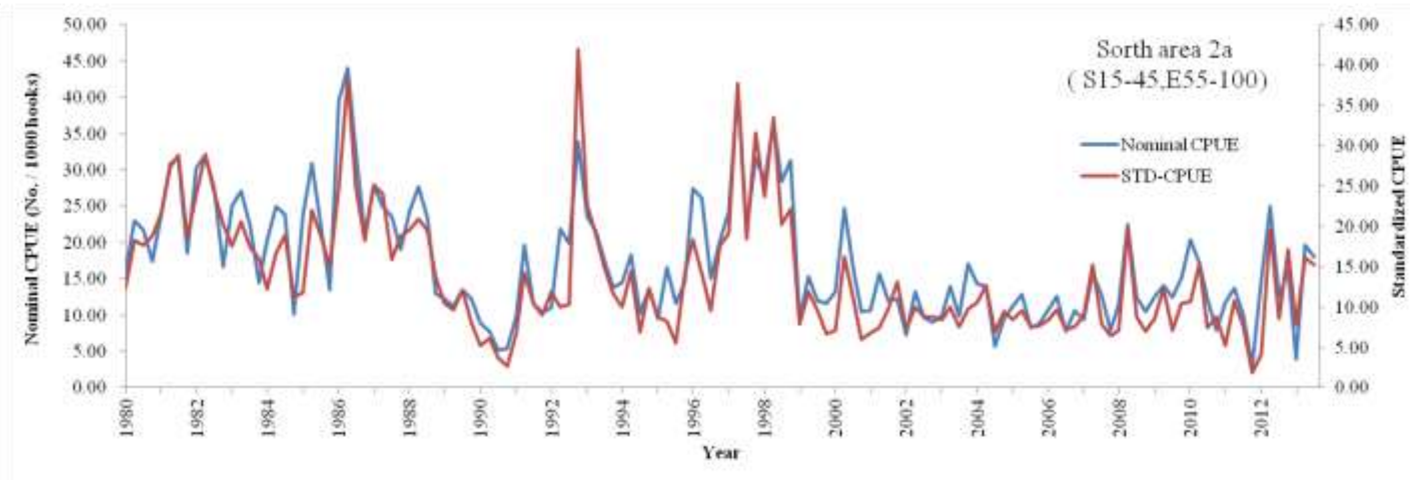


Fig. 9 Yearly nominal and standardized CPUE trends of albacore in South area 2a (top) and South area 2b (bottom) based on Taiwanese longline fishery data set from 1980 to 2013.



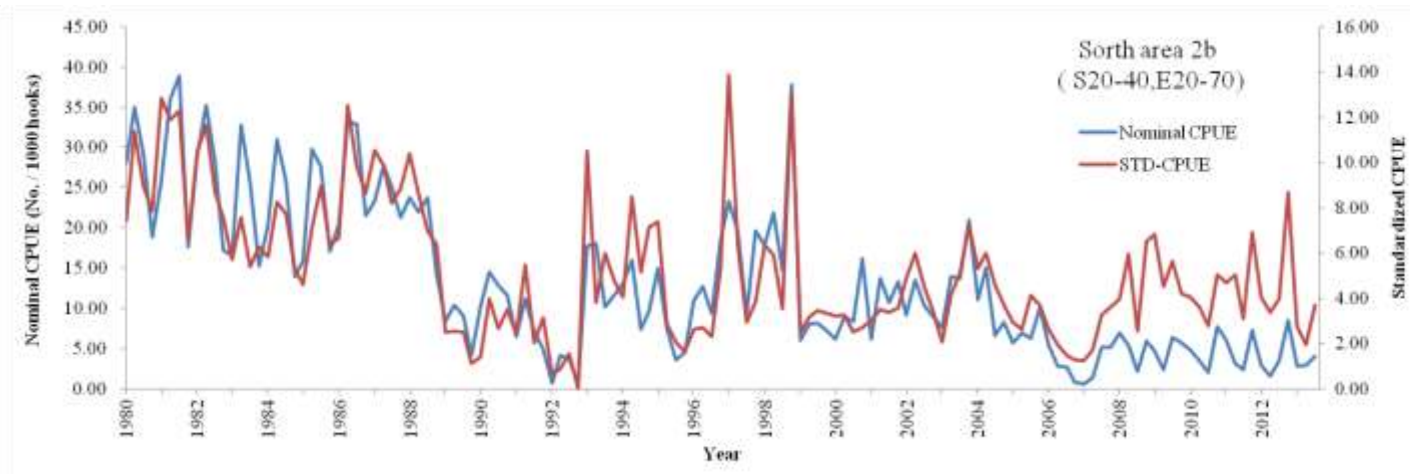


Fig. 10 Quarterly nominal and standardized CPUE trends of albacore in South area 2a (top) and South area 2b (bottom) based on Taiwanese longline fishery data set from 1980 to 2013.