Received: 13 & 16 November 2014

Preliminary analysis of Taiwanese longline fisheries based on operational catch and effort data for bigeye and yellowfin tuna in the Indian Ocean.

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Abstract

We compared nominal and standardized bigeye and yellowfin CPUE using Taiwanese longline catch and effort data, both operational and aggregated by 5x5 degree square and month, in the tropical Indian Ocean between 10N-15S (core area) from 1979 to 2012. Nominal and standardized bigeye CPUE for both data types showed quite similar trends. The standardized bigeye CPUE trend from operational data kept at nearly the same level from 1970 to 2012. In the case of yellowfin, CPUE trends of both data types showed similar trends but with small differences in amplitude; overall they were relatively stable until 2005, then decreased to less than half in 2009 from the 2003-2005 level.

Historical change in the fishing efficiency of the Taiwanese longline fishery was estimated for bigeye and yellowfin by including Vessel ID in the standardization using operational data. The estimated fishing efficiency for bigeye across all core areas increased from 0.9 to 1.1 during 1979 ~ 2012. When areas were viewed separately, in the west core area efficiency increased continuously from 0.8 in 1979 to 1.1 in 1989 and then remained stable. In the east core area efficiency was estimated to have remained stable throughout the 33 years. In the southern area there was a continuous increasing trend, from 0.7 to 1.4 during the 33 years analyzed. On the other hand, fishing efficiency for yellowfin tuna estimated in core areas showed no clear trends, varying between 0.7 and 1.0 from 1979 to 1993 and then remaining at a similar level of about 1.1 (in the case of west core) or remaining stable for the 33 years analyzed (east core). In the south area there were relatively high values of 1.2 in 1979 and 1989 and low value of 0.6 for 1992 and 1993, stability of around 1.0 until 1996, and then a steady increase to 1.3 in 2012.

Two types of Taiwanese operational longline data, the first with resolution of 5 degree square from 1970 to 2012 (noted as the 'long series') and the second with resolution of 1 degree square from 1995 to 2012 (noted as the short series'), were standardized and their trends compared. As well as differing in resolution, data on the number of hooks between floats (NHBF) was available in the short series. Cluster analysis was used to classify longline sets in relation to species composition of the catches. Five effort clusters were identified. Four clusters comprised ~90% of the total sets, and the catch compositions suggested targeting for either

tropical tuna (bigeye and yellowfin) or albacore. The clusters were used as a target proxy in GLMs to adjust the effectiveness of fishing effort units. NHBF was used an alternative target proxy in GLMs for operational data from 1995 to 2012. In all core areas and the south area, bigeye CPUE trends were similar between different types of data. For yellowfin tuna, quite similar trends were observed between standardized CPUEs derived from the two types of data except in the east core area. In this case the long CPUE series showed a decreasing trend from 1992 to 2012, but the short series did not.

Introduction

It has been noted that the CPUE trend of longline fishery for bigeye in the Indian Ocean is considerably different between Taiwan and Japan at WPTT and Scientific committee of IOTC (Anonymous 2013a). In Okamoto (2014), historical change in the fishing distribution of Japanese and Taiwanese longliners was compared, and it was concluded that the tropical area from 10°N to 15°S would be appropriate as core area for the both fisheries. However, standardized CPUE of both fleet applying whole strata in core area still showed large difference especially for bigeye, and this difference could not be improved by applying shared strata. In this study, similar framework analysis was conducted using Taiwanese operational data for comparison to evaluate the effect of data resolution.

Cluster analyses of operational–level, longline catch and effort data for bigeye and yellowfin tuna in the Indian Ocean were carried out to separate individual sets target different targets species. The objective was to take target factor into consideration in the following standardization of bigeye and yellowfin CPUE.

Besides, in order to address fishing efficiency issue, by applying Vessel ID in the GLM as explanatory variable using methods developed by Hoyle (2009), and Hoyle et al. (2010), historical change in the fishing efficiency for bigeye and yellowfin catch was estimated by area.

Materials and methods

Data preparation, cleaning and characterization

Data were prepared, validated, and cleaned in order to provide datasets suitable for investigating estimating indices of abundance and vessel effects.

ID number (CT number) was selected as the vessel identifier (Vessel ID). CT number is unique to the vessel and held throughout the vessel's working life. It was rendered anonymous by changing each CT number to an arbitrary integer (the first integer references the class level of tons). Number between floats data were available since 1995. Number of hooks between floats (NHBF) were available for almost all sets. Sets with missing values were removed, and the few sets with more than 22 NHBF were pooled into the 22 NHBF category.

'Target' data were available from 2006. There are three target type data, targeting on bigeye, albacore and both. All targets were included in the fishing power analyses, since the target field was not available before 2006, and removing other targets after 1994 might have biased the results. Hooks per set, and bigeye, yellowfin, and albacore catch in numbers were cleaned by removing outliers. After data cleaning, a standard dataset was produced that was used in subsequent analyses (Table 1). A modified dataset was used to generate indices of abundance, and this is described below

Area definition

Area definition used in this analysis was the same as that used in (OKAMOTO, 2014). The area from 10°N to 15°S was defined as “core area”, and that of west from 80E and that of east from 80E were treated as “west core” and “east core”, respectively. South Indian Ocean from 15°S to 35°S was defined as “south area”.

Longline catch and effort data used in this study

1) Cluster analysis to identify alternative fishing strategies.

   Daily set-by-set catch and effort data with 5 degree by 5 degree resolution from the logbooks of Taiwanese longline fishery from 1979-2012 were provided by Overseas Fisheries Development Council (OFDC). For this analysis, year, month, date, bigeye, yellowfin, albacore, bluefin tuna, southern blue tuna, swordfish, billfish group (white marlin, blue marlin, black marlin), shark, and other tuna catch in number included in this data were used.

   Cluster analysis, which can separate effort target at different species (He et al., 1997) was adopted to identify alternative fishing strategies. The purpose of this study were to categorize individual fishing sets using cluster analysis based on similarity of catch composition, examine the spatial distribution of effort and operational information to indicate differences in fishing strategies among clusters and provide target proxy in the following standardizing bigeye and yellowfin CPUE use.

2) Data resolution and target proxy analyses:

   Two types of Taiwanese longline non-aggregated operational data with resolution of 5 degree square from 1970 to 2012 (noted as long series) and with resolution of 1 degree square from 1995 to 2012 (noted as short series with NHBF information is available) were used. For this analyses, year, month, the number of hooks used, bigeye, yellowfin catch in number and classified cluster in long series data set were used. As the NHBF information is available since 1995, extra NHBF information in short series were used.

3) Fishing efficiency analysis:

   Daily set-by-set catch and effort data with 5 degree by 5 degree resolution from the logbooks of Taiwanese longline fishery from 1979-2012 were provided by Overseas Fisheries Development Council (OFDC). For this analysis, Vessel ID, year, month, the number of hooks used in each set, bigeye and yellowfin catch in number included in this data were used.

Environmental factors

As environmental factors, which are available from Japanese Scientist (Okamoto-san) for the analyzed period from 1979 to 2012, SST (Sea Surface Temperature) was applied.

CPUE standardization

CPUEs based on the number of catch was used.

The model used for GLM analyses (CPUE-LogNormal error structured model) for each analysis was as follows. All explanatory variables were applied as class variable.

1) Alternative target proxy analyses in core area:

Long series (for operational data from 1979 to 2012)

Log [CPUE +const] = μ + year +quarter + CLUSTER+LT5LN5 + error

where

Log: natural logarithm,

CPUE: catch in number of bigeye per 1000 hooks,

const: 10% of overall mean of CPUE,

μ: overall mean (i.e. intercept),

year: effect of year,

quarter: effect of season,

LT5LN5: effect of each latitude 5 degree and longitude 5 degree square,

CLUSTER: Classified cluster of catch composition by cluster analysis,

Short series (for operational data from 1995 to 2012, CLUSTER was applied as target proxy, denoted as short1 series)

Log [CPUE +const] = μ + year +quarter +CLUSTER+ LT5LN5 + SST + error

where

SST: effect of sea surface temperature (Round off to nearest integral number; 27.6 → 28).

Short series (for operational data from 1995 to 2012, NHBF was applied as target proxy, denoted as short2 series)

Log [CPUE +const] = μ + year +quarter +NHBF+ LT5LN5 + SST + error

where

NHBF: effect of gear type (the number of hooks between floats),,

2) Fishing efficiency analysis:

Log [CPUE +const] = μ + year + quarter + CLUSTER + Vessel ID + lt5ln5 + error (a)

Log [CPUE +const] = μ + year + quarter + CLUSTER + + lt5ln5 + error (b)

Where

Vessel ID: effect of identifier of each vessel (ID number of boat was used as vessel ID),

Historical trend of fishing efficiency was estimated by dividing CPUE derived from (b) by that derived from (a).

3) Comparisons with aggregated data analyses

The implications of using aggregated data to estimate indices of abundance were examined by comparing the results from the operational data GLM with the equivalent analysis when the same data had been aggregated.

Results and Discussions

1) Custer analysis to identify alternative fishing strategies

   Five clusters of longline set were produced by the cluster analysis. Three clusters (1, 2,4) of sets caught high percentages of bigeye tuna (Table 2). Cluster 1 had the high percentages of bigeye tuna but also a high percentage of swordfish. Cluster 4 caught high percentage of yellowfin tuna. Cluster 5 caught high percentage of albacore tuna.

   Spatial distribution of effort and bigeye and yellowfin CPUE for clusters was shown in Figures x and x. Cluster 1 and 2 had intensive effort distribution from 10N to 10S. Effort in Cluster 5 was largely concentrated from 10S to 40S. Obviously, effort in Cluster 2 target on bigeye tuna and effort in Cluster 4 target on yellowfin tuna.

   75% of individual sets target on tropical tuna constitute a major sector of the fishery and 20% of individual sets target on albacore constitute a minor sector of the fishery (Table 3). Comparison of fishing strategies among clusters indicated that regarding of NHBF, Cluster1, 2 and 4 (tropical tuna) sets were most different from Cluster 5 (albacore) sets. Compare with figure x and figure x, some information was revealed for the historical dynamic of fishing strategies from a view of NHBF.

   Time series of nominal CPUE for bigeye and yellowfin tuna were compared for different clusters in different regions (Figure 5 and Figure 6). Overall, clustering revealed different fishing strategies and then to separate effort targeted at different species.

2) Comparisons with aggregated data analyses in core area

   Compare nominal and standardized bigeye and yellowfin CPUE using Taiwanese longline catch and effort operational data and data aggregated by 5x5 degree and month in the tropical Indian Ocean ranged 10N-15S (core area) defined by Okamoto (2014) from 1979 to 2012. The analyses on aggregated was analyzed and documented by Okamoto (2014). The comparison was made standardized CPUE using all strata in which Taiwanese and Japanese fleets made operation or using shared strata in which both fleets made operation.

   For both of all and shared core area analyses, nominal of standardized bigeye CPUE of both resolutions showed quite similar trends, however standardized bigeye CPUE trend by operational data kept in the nearly same level from 1970 to 2012 (Figure 7 and Figure 8). In the case of yellowfin, CPUE trends of both resolutions showed basically similar trend but with little difference in amplitude, overall relatively stable until 2005 and kept decreasing to less than half in 2009 from 2003-2005 level (Figure 7 and Figure 8).

3) Alternative target proxy analyses

In order to know the effect of alternative target proxy on the CPUE trend, Three cases of Taiwanese longline data, non-aggregated operational data with resolution of 5 degree square from 1970 to 2012 (noted as long series) and with resolution of 1 degree square from 1995 to 2012 (noted as short1 series with CLUSTER as target proxy in GLM and short2 series with NHBF as target proxy in GLM) were applied for standardization and their trends were compared. In all core areas and south area, bigeye CPUE trends were basically similar among three series. As for yellowfin tuna also, quite similar trend was observed between standardized CPUEs derived from three series except east core area. Long CPUE series showed decreasing trend from 1992 to 2012, however, short series didn’t reveal the phenomenon.

Fig. 9 and Fig 11 shows the standardized bigeye CPUE derived from three series for core areas (all, west and east) and south area. In all cases of areas and data, effect of all explanatory variables included in the full model were significant (Table 4). Distribution of standardized residuals were not largely different from normal distributions in core areas and south area for both species (Appendix Fig. 1 and 2). In all core areas (all, west and east) and south area, bigeye CPUE trends were basically similar among three series.

As for yellowfin tuna also, quite similar trend was observed between standardized CPUEs derived from each of three series as shown in Fig. 10 and Fig. 12. As the case of bigeye, effect of all explanatory variables included in the full model were significant in all area (Table 5). The performance of CPUE standardization may not be measured by R square value, and application of operational data into standardization would have more benefit than using aggregated data. Nevertheless the resulted CPUE standardized might not be so improved by using operational data as far as the same explanatory variables are applied in the GLM model.

4) Fishing efficiency analysis

By dividing CPUE standardized applying model excluding vessel ID by CPUE standardized applying model including vessel ID, historical change in fishing efficiency was estimated for bigeye and yellowfin tuna in each area. As the effects of all explanatory variables included in the full model were significant in all cases for both of bigeye and yellowfin tunas (Table 8 and 9), the full model was adopted as the final model. Distribution of standardized residuals were not largely different from normal distributions in core areas and south area for both species (Appendix Fig. 5 and 6).

Approximately 800 unique vessels have reported fishing since 1979 (Figure 13). Historical change in fishing efficiency of Taiwanese longline fishery was estimated for bigeye and yellowfin by applying Vessel ID for the standardization using operational data. Estimated fishing efficiency for bigeye in the core areas increased slightly from 0.9 to 1.1 during 1979 ~ 2012, it increased continuously from0.8 in 1979 to 1.1in 1989 and then kept stable after that (in the case of west core) or kept at the similar lever around 1.0 level (in the case of east core) through the 33 years, whereas that in south area it showed continuous increasing trend, from 0.7 to 1.4 during 33 years analyzed (Figure 14). On the other hand, fishing efficiency for yellowfin tuna estimated in core areas showed no obvious trend, vibrated between 0.7 and 1.0 from 1979 to 1993 and then kept at the similar level around 1.1 (in the case of west core) or kept around 1.0 level (east core) during 33 years analyzed, whereas in the south area there were relative high value 1.2 at 1979 and 1989 and low value 0.6 at 1992 before 1993, and kept stable around 1.0 until 1996 then increased continuously to 1.3 in 2012 slightly (Figure 15).

Table 1. Number of available records by variable in the operational data

Year	No. of ops	Cruise start date	Cruise end date	op start date	Op end date
1979	16,056	15,996	16,056	0	0
1980	21,021	20,682	21,021	0	0
1981	16,969	16,835	16,969	0	0
1982	23,110	23,110	23,110	0	0
1983	22,048	22,048	22,048	0	0
1984	17,551	17,551	17,551	0	0
1985	13,531	13,531	13,531	0	0
1986	13,257	13,257	13,257	0	0
1987	14,431	14,431	14,431	0	0
1988	12,497	12,497	12,497	0	0
1989	9,045	9,045	9,045	0	0
1990	7,181	7,181	7,181	0	0
1991	5,738	5,738	5,738	0	0
1992	3,499	3,499	3,499	0	0
1993	17,869	17,869	17,869	0	0
1994	20,315	7,726	7,726	1,359	2,021
1995	19,341	19,341	19,196	19,077	19,341
1996	24,492	24,402	24,492	24,492	24,492
1997	25,503	23,137	25,503	25,503	25,503
1998	24,041	23,653	24,041	24,041	24,041
1999	29,608	29,037	29,608	29,563	29,608
2000	31,664	30,489	31,569	31,593	31,569
2001	40,636	39,073	40,486	40,486	40,486
2002	42,017	41,522	42,017	42,017	42,017
2003	69,329	68,205	65,718	69,329	69,329
2004	80,508	77,186	76,430	80,508	80,508
2005	72,204	68,983	63,761	72,204	72,204
2006	51,798	47,281	47,784	51,798	51,798
2007	44,016	36,749	37,705	44,016	44,016
2008	31,809	24,716	25,335	31,809	31,809
2009	40,097	31,527	31,265	40,097	40,097

Year	No. of ops	Cruise start date	Cruise end date	op start date	Op end date
2010	29,856	26,057	23,609	29,801	29,801
2011	22,544	19,182	17,000	22,544	22,544
2012	21,697	16,085	15,698	21,697	21,697

Table 1. Number of available records by variable in the operational data (continued)

Year	No. of ops	Set type	Lat & long in 1 degree	NHBF	After cleaning
1979	16,056	0	0	0	12,758
1980	21,021	0	0	0	16,889
1981	16,969	0	0	0	13,561
1982	23,110	0	0	0	17,786
1983	22,048	0	0	0	17,129
1984	17,551	0	0	0	14,339
1985	13,531	0	0	0	11,888
1986	13,257	0	0	0	10,491
1987	14,431	0	0	0	11,018
1988	12,497	0	0	0	10,434
1989	9,045	0	0	0	7,099
1990	7,181	0	0	0	5,787
1991	5,738	0	0	0	4,993
1992	3,499	0	0	0	2,907
1993	17,869	0	0	0	11,662
1994	20,315	0	20,315	0	15,635
1995	19,341	0	12,051	7,116	15,319
1996	24,492	0	18,408	10,884	18,760
1997	25,503	0	20,565	9,495	20,255
1998	24,041	0	19,785	10,022	20,482
1999	29,608	0	24,603	14,198	26,090
2000	31,664	0	26,723	16,022	27,429
2001	40,636	0	37,853	32,575	36,308
2002	42,017	0	38,204	40,768	37,475
2003	69,329	0	53,455	69,183	37,338
2004	80,508	0	76,388	80,402	70,125
2005	72,204	0	70,135	72,204	57,497
2006	51,798	51,798	50,987	51,798	38,910
2007	44,016	44,016	43,506	44,016	32,622
2008	31,809	31,809	31,176	31,809	23,602
2009	40,097	40,097	39,355	40,097	30,773

Year	No. of ops	Set type	Lat & long in 1 degree	NHBF	After cleaning
2010	29,856	29,856	29,756	29,856	23,342
2011	22,544	22,544	22,544	22,544	17,701
2012	21,697	21,697	21,696	21,697	14,723

Table 2. Mean percentages of catches for tuna and tuna-like species and billfish groups within five clusters of sets from the Taiwanese longline fishery (1979 – 2012)

Species groups	Cluster				
	1	2	3	4	5
Bigeye tuna	32.9	70.6	3.5	21.1	5.8
Yellowfin tuna	14.1	15.3	1.7	62.9	2.8
Albacore	5.2	1.5	3.8	1.2	85.7
Bluefin tuna	0.2	0.1	0.0	0.1	0.1
Southern Bluefin tuna	0.6	0.1	0.0	0.1	1.0
Swordfish	24.8	4.5	1.1	4.7	1.1
Shark	5.9	1.3	1.6	1.6	0.6
Billfish group	7.7	3.1	0.4	5.3	0.6
Other fishes	8.6	3.5	87.9	3.2	2.4

Table 3. Mean percentages of catches for tuna and tuna-like species and billfish groups within five clusters of sets from the Taiwanese longline fishery (1979 – 2012)

	Cluster				
	1	2	3	4	5
Primary catch	Bigeye-Swordfish	Bigeye	Other fishes	Yellowfin-Bigeye	Albacore
No. of sets	97,221	310,984	34,525	140,835	149,562
Hooks per set	3,032(365)	3,019(310)	3,362(548)	3,078(399)	2,998(687)
NHBF	15(3)	15(2)	14(3)	15(3)	11(2)

Table 4 Anova table of GLM for bigeye CPUE standardization without Vessel ID as an explanatory factor using operational catch and effort data of Taiwanese longline fisheries for all strata in core, core east, and core west and south fishing areas in the Indian ocean for 1979 – 2012.

Core: 15N-15S **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	116	150937.782	1301.188	3106.780	<.0001	0.410793
						CV =
Year	33	6408.490	194.197	463.670	<.0001	41.02871
Quarter	3	854.109	284.703	679.770	<.0001	
LT5LN5	76	22843.213	300.569	717.650	<.0001	
CLUSTER	4	87684.021	21921.005	52339.700	<.0001	

Core: 15N-15S **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	107	88940.171	831.217	1945.060	<.0001	0.382728
						CV =
Year	17	4392.214	258.366	604.580	<.0001	40.68062
Quarter	3	554.024	184.675	432.140	<.0001	
LT5LN5	74	12177.983	164.567	385.090	<.0001	
CLUSTER	4	54672.378	13668.095	31983.500	<.0001	
SST	9	51.380	5.709	13.360	<.0001	

Core: 15N-15S **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	118	34962.396	296.292	503.750	<.0001	0.150451
						CV =
Year	17	8070.401	474.729	807.120	<.0001	47.72553
Quarter	3	802.450	267.483	454.770	<.0001	
LT5LN5	74	17053.955	230.459	391.820	<.0001	
NHBF	15	694.604	46.307	78.730	<.0001	
SST	9	73.531	8.170	13.890	<.0001	

Core East **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	69	65858.99	954.478	2615.090	<.0001	0.58526
						CV =
Year	33	1601.350	48.526	132.950	<.0001	40.5158
Quarter	3	78.337	26.112	71.540	<.0001	
LT5LN5	29	12260.554	422.778	1158.330	<.0001	
CLUSTER	4	20558.590	5139.648	14081.600	<.0001	

Core East **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	57	30008.107	526.458	1412.640	<.0001	0.592427
						CV =
Year	17	445.023	26.178	70.240	<.0001	40.98266
Quarter	3	23.388	7.796	20.920	<.0001	
LT5LN5	27	4296.606	159.134	427.000	<.0001	
CLUSTER	4	8367.541	2091.885	5613.160	<.0001	
SST	6	53.962	8.994	24.130	<.0001	

Core East **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	68	21942.692	322.687	622.500	<.0001	0.433198
						CV =
Year	17	826.980	48.646	93.840	<.0001	48.3344
Quarter	3	223.290	74.430	143.580	<.0001	
LT5LN5	27	8125.177	300.932	580.530	<.0001	
NHBF	15	302.127	20.142	38.860	<.0001	
SST	6	140.233	23.372	45.090	<.0001	

Table 5 Anova table of GLM for bigeye CPUE standardization without Vessel ID as an explanatory factor using operational catch and effort data of Taiwanese longline fisheries for shared strata in core, core east, and core west and south fishing areas in the Indian ocean for 1979 – 2012.

Core West — **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	86	89375.83	1039.254	2347.900	<.0001	R-Square= 0.341704
						CV =
Year	33	6260.752	189.720	428.620	<.0001	41.74294
Quarter	3	982.113	327.371	739.600	<.0001	
LT5LN5	46	4505.338	97.942	221.270	<.0001	
CLUSTER	4	67974.813	16993.703	38392.500	<.0001	

South: 15S-35S — **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	106	76922.61	725.685	788.390	<.0001	R-Square= 0.344321
						CV =
Year	33	3122.608	94.625	102.800	<.0001	1262.346
Quarter	3	2059.799	686.600	745.920	<.0001	
LT5LN5	66	8200.027	124.243	134.980	<.0001	
CLUSTER	4	32454.449	8113.612	8814.640	<.0001	

Core West — **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	79	60403.867	764.606	1762.810	<.0001	R-Square= 0.331974
						CV =
Year	17	4587.451	269.850	622.140	<.0001	40.41931
Quarter	3	547.424	182.475	420.700	<.0001	
LT5LN5	46	2482.008	53.957	124.400	<.0001	
CLUSTER	4	46334.970	11583.743	26706.600	<.0001	
SST	9	56.222	6.247	14.400	<.0001	

South: 15S-35S — **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	108	34317.014	317.750	363.480	<.0001	R-Square= 0.324504
						CV =
Year	17	1714.829	100.872	115.390	<.0001	513.9669
Quarter	3	375.678	125.226	143.250	<.0001	
LT5LN5	65	2828.042	43.508	49.770	<.0001	
CLUSTER	4	20407.439	5101.860	5836.110	<.0001	
SST	19	161.505	8.500	9.720	<.0001	

Core West — **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	90	14637.388	162.638	272.390	<.0001	R-Square= 0.080446
						CV =
Year	17	7743.463	455.498	762.880	<.0001	47.42303
Quarter	3	705.937	235.312	394.110	<.0001	
LT5LN5	46	4254.800	92.496	154.910	<.0001	
NHBF	15	568.491	37.899	63.470	<.0001	
SST	9	79.689	8.854	14.830	<.0001	

South: 15S-35S — **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	120	18015.375	150.128	139.81	<.0001	R-Square= 0.170355
						CV =
Year	17	4963.683	291.981	271.900	<.0001	569.6419
Quarter	3	794.954	264.985	246.760	<.0001	
LT5LN5	65	3240.150	49.848	46.420	<.0001	
NHBF	16	4105.799	256.612	238.970	<.0001	
SST	19	255.928	13.470	12.540	<.0001	

Table 6 Anova table of GLM for yellowfin CPUE standardization without Vessel ID as an explanatory factor using operational catch and effort data of Taiwanese longline fisheries for all strata in core, core east, and core west and south fishing areas in the Indian ocean for 1979 – 2012.

Core: 15N-15S **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	116	242333.54	2089.082	3107.690	<.0001	0.410864
						CV =
Year	33	19777.190	599.309	891.520	<.0001	40.3134
Quarter	3	379.327	126.443	188.090	<.0001	
LT5LN5	76	12916.463	169.954	252.820	<.0001	
CLUSTER	4	152522.632	38130.658	56722.700	<.0001	

Core: 15N-15S **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	107	174123.108	1627.319	2296.180	<.0001	0.42262
						CV =
Year	17	13857.887	815.170	1150.220	<.0001	151.1072
Quarter	3	82.142	27.381	38.630	<.0001	
LT5LN5	74	10234.126	138.299	195.140	<.0001	
CLUSTER	4	100512.958	25128.240	35456.500	<.0001	
SST	9	264.698	29.411	41.500	<.0001	

Core: 15N-15S **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	118	78456.726	664.888	669.070	<.0001	0.190425
						CV =
Year	17	31148.746	1832.279	1843.810	<.0001	178.9328
Quarter	3	295.840	98.613	99.230	<.0001	
LT5LN5	74	25820.081	348.920	351.120	<.0001	
NHBF	15	4846.576	323.105	325.140	<.0001	
SST	9	483.690	53.743	54.080	<.0001	

Core East **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	69	62487.04	905.609	1389.600	<.0001	0.428525
						CV =
Year	33	5895.493	178.651	274.130	<.0001	185.6627
Quarter	3	719.065	239.688	367.790	<.0001	
LT5LN5	29	3674.660	126.712	194.430	<.0001	
CLUSTER	4	25032.073	6258.018	9602.560	<.0001	

Core East **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	57	29939.451	525.254	655.310	<.0001	0.402729
						CV =
Year	17	1880.076	110.593	137.980	<.0001	-3389.842
Quarter	3	400.003	133.334	166.350	<.0001	
LT5LN5	27	2866.709	106.174	132.460	<.0001	
CLUSTER	4	8942.295	2235.574	2789.100	<.0001	
SST	6	77.747	12.958	16.170	<.0001	

Core East **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	68	21535.679	316.701	332.170	<.0001	0.289686
						CV =
Year	17	2773.833	163.167	171.140	<.0001	-3697.106
Quarter	3	437.650	145.883	153.010	<.0001	
LT5LN5	27	9324.388	345.348	362.220	<.0001	
NHBF	15	538.523	35.902	37.660	<.0001	
SST	6	116.008	19.335	20.280	<.0001	

Table 7 Anova table of GLM for yellowfin CPUE standardization without Vessel ID as an explanatory factor using operational catch and effort data of Taiwanese longline fisheries for shared strata in core, core east, and core west and south fishing areas in the Indian ocean for 1979 – 2012.

Core West **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	86	180282.41	2096.307	3104.990	<.0001	0.407038
						CV =
Year	33	15693.195	475.551	704.370	<.0001	112.5892
Quarter	3	294.416	98.139	145.360	<.0001	
LT5LN5	46	5271.473	114.597	169.740	<.0001	
CLUSTER	4	123826.589	30956.647	45852.000	<.0001	

Core West **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	79	136247.971	1724.658	2465.950	<.0001	0.410087
						CV =
Year	17	12883.227	757.837	1083.570	<.0001	127.0169
Quarter	3	180.236	60.079	85.900	<.0001	
LT5LN5	46	4078.347	88.660	126.770	<.0001	
CLUSTER	4	89341.896	22335.474	31935.700	<.0001	
SST	9	216.704	24.078	34.430	<.0001	

Core West **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	90	51559.747	572.886	571.950	<.0001	0.155187
						CV =
Year	17	29856.564	1756.268	1753.410	<.0001	152.0044
Quarter	3	705.918	235.306	234.920	<.0001	
LT5LN5	46	8248.568	179.317	179.020	<.0001	
NHBF	15	4653.672	310.245	309.740	<.0001	
SST	9	437.663	48.629	48.550	<.0001	

South: 15S-35S **Long: 1979-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	106	94616.67	892.610	673.060	<.0001	0.309544
						CV =
Year	33	4893.746	148.295	111.820	<.0001	-135.5049
Quarter	3	1132.226	377.409	284.580	<.0001	
LT5LN5	66	17497.921	265.120	199.910	<.0001	
CLUSTER	4	30818.989	7704.747	5809.640	<.0001	

South: 15S-35S **Short1: 1995-2012 (cluster)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	108	48640.496	450.375	323.700	<.0001	0.29963
						CV =
Year	17	4627.706	272.218	195.650	<.0001	-117.3345
Quarter	3	498.220	166.073	119.360	<.0001	
LT5LN5	65	9158.984	140.907	101.270	<.0001	
CLUSTER	4	14257.740	3564.435	2561.870	<.0001	
SST	19	145.814	7.674	5.520	<.0001	

South: 15S-35S **Short2: 1995-2012 (NHF)**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	120	35957.186	299.643	193.720	<.0001	0.2215
						CV =
Year	17	6137.863	361.051	233.420	<.0001	-123.7152
Quarter	3	423.010	141.003	91.160	<.0001	
LT5LN5	65	13803.807	212.366	137.300	<.0001	
NHBF	16	1574.430	98.402	63.620	<.0001	
SST	19	184.899	9.732	6.290	<.0001	

Table 8. Anova table of GLM for bigeye CPUE standardization with vessel ID included in model using operational catch and effort data of Taiwanese longline fisheries for core, core east, and core west and south fishing areas in the Indian ocean for 1979 – 2012.

Core **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
						R-Square=
Model	763	164254.878	215.275	546.720	<.0001	0.446584
						CV =
Year	33	6233.334	188.889	479.710	<.0001	39.78583
Quarter	3	776.366	258.789	657.230	<.0001	
LT5LN5	76	18000.429	236.848	601.510	<.0001	
CLUSTER	4	77584.039	19396.010	49258.800	<.0001	
Call sign	647	13025.718	20.132	51.130	<.0001	

Core East **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
						R-Square=
Model	603	69350.0861	115.0084	339.04	<.0001	0.615913
						CV =
Year	33	932.84931	28.26816	83.33	<.0001	39.06328
Quarter	3	62.25577	20.75192	61.18	<.0001	
LT5LN5	29	9103.99208	313.93076	925.46	<.0001	
CLUSTER	4	16471.12576	4117.78144	12139.2	<.0001	
Call sign	534	3379.91093	6.32942	18.66	<.0001	

Core West **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
						R-Square=
Model	665	98970.247	148.827	369.930	<.0001	0.387442
						CV =
Year	33	5734.924	173.786	431.970	<.0001	39.52474
Quarter	3	851.015	283.672	705.100	<.0001	
LT5LN5	46	2892.987	62.891	156.320	<.0001	
CLUSTER	4	59551.704	14887.926	37005.900	<.0001	
Call sign	579	11605.671	20.044	49.820	<.0001	

South **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
						R-Square=
Model	733	91657.55	125.044	150.420	<.0001	0.41007
						CV =
Year	33	3265.941	98.968	119.050	<.0001	1206.463
Quarter	3	1584.495	528.165	635.330	<.0001	
LT5LN5	66	6599.995	100.000	120.290	<.0001	
CLUSTER	4	20856.474	5214.119	6272.080	<.0001	
Call sign	627	14679.348	23.412	28.160	<.0001	

Table 9 Anova table of GLM for Yellowfin CPUE standardization with vessel ID included in model using operational catch and effort data of Taiwanese longline fisheries for core, core east, and core west and south fishing areas in the Indian ocean for 1979 – 2012.

Core **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	763	269051.960	352.624	549.840	<.0001	0.447992
						CV =
Year	33	14896.981	451.424	703.900	<.0001	123.0908
Quarter	3	275.886	91.962	143.390	<.0001	
LT5LN5	76	10952.639	144.114	224.710	<.0001	
CLUSTER	4	133940.568	33485.142	52212.900	<.0001	
Call sign	647	22660.208	35.024	54.610	<.0001	

Core East **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	603	69705.5378	115.5979	193.3	<.0001	0.477599
						CV =
Year	33	2057.08664	62.33596	104.24	<.0001	177.7043
Quarter	3	520.16388	173.38796	289.93	<.0001	
LT5LN5	29	2329.27911	80.31997	134.31	<.0001	
CLUSTER	4	21744.71414	5436.17854	9090.12	<.0001	
Call sign	534	6882.18386	12.88798	21.55	<.0001	

Core West **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	665	199416.636	299.875	477.940	<.0001	0.449694
						CV =
Year	33	13238.099	401.155	639.360	<.0001	108.5323
Quarter	3	288.936	96.312	153.500	<.0001	
LT5LN5	46	4811.815	104.605	166.720	<.0001	
CLUSTER	4	104281.809	26070.452	41551.100	<.0001	
Call sign	579	18848.722	32.554	51.880	<.0001	

South **1979-2012 with call sign**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	733	116148.30	158.456	132.530	<.0001	0.379823
						CV =
Year	33	3726.148	112.914	94.440	<.0001	-128.6016
Quarter	3	1024.174	341.392	285.530	<.0001	
LT5LN5	66	12405.174	187.957	157.200	<.0001	
CLUSTER	4	19833.086	4958.271	4146.900	<.0001	
Call sign	627	21541.785	34.357	28.730	<.0001	

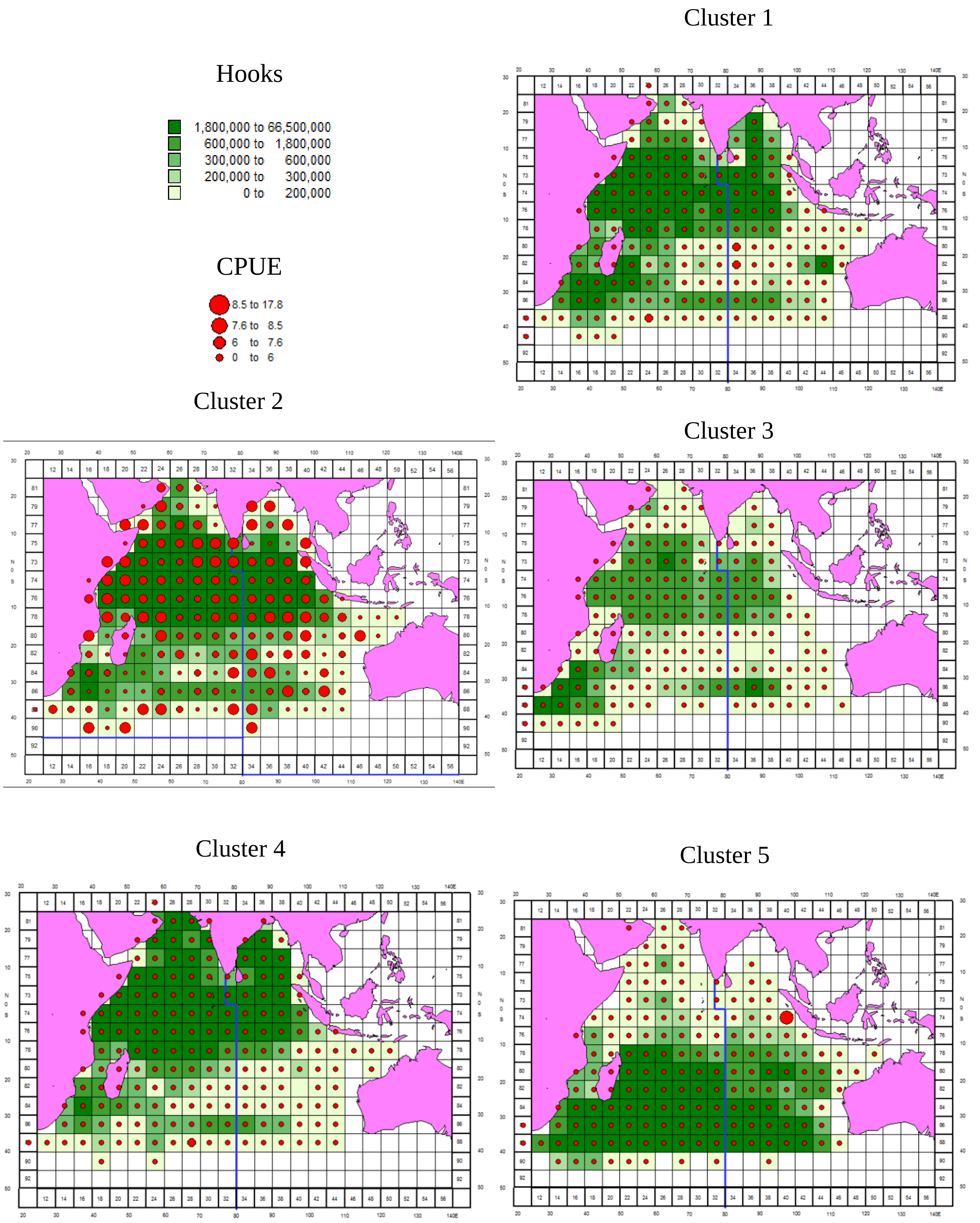


Figure 1. Spatial distribution of fishing effort and bigeye CPUE for five clusters of sets in the Taiwanese longline fishery (1979 – 2012).

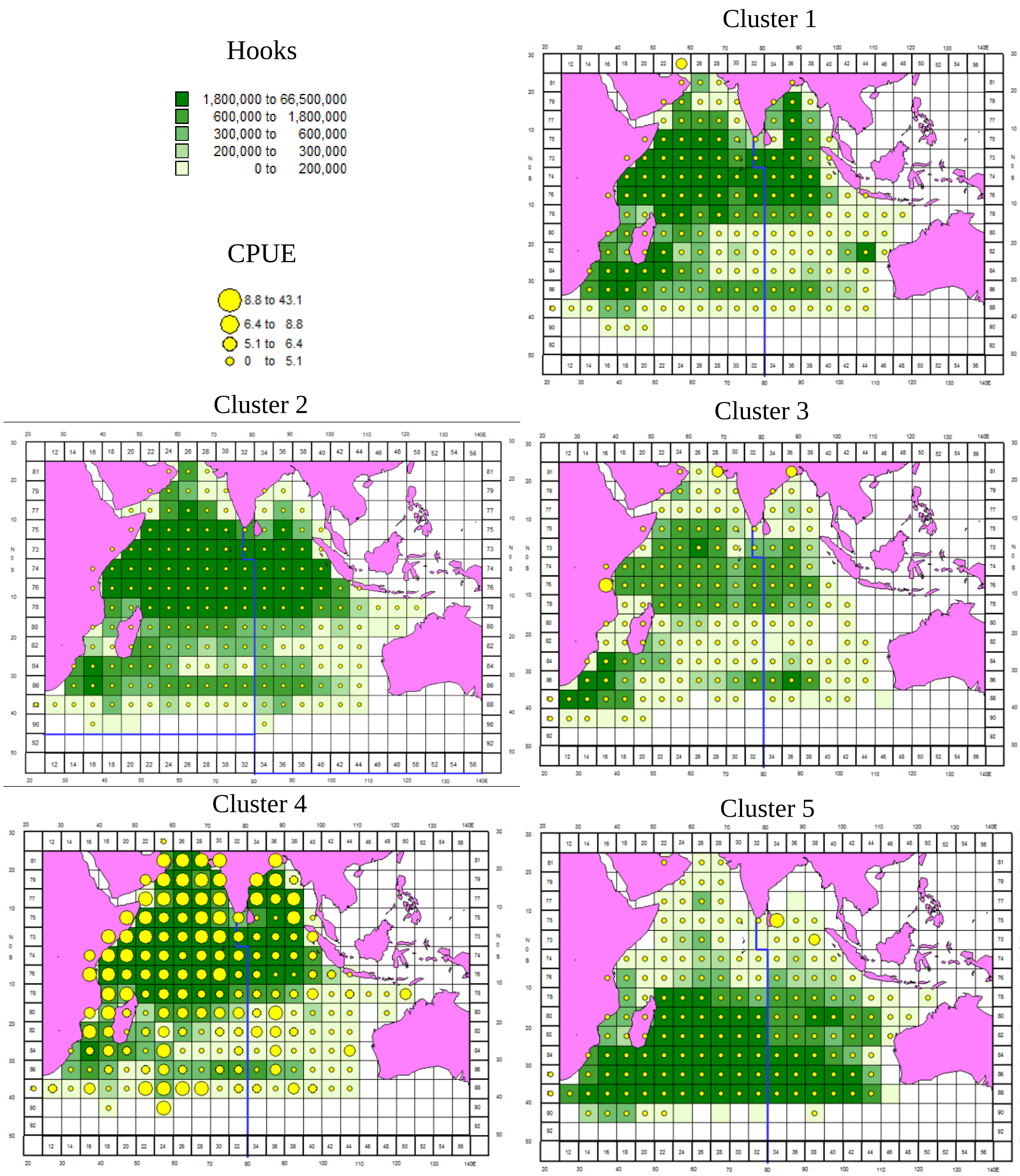


Figure 2. Spatial distribution of fishing effort and Yellowfin CPUE for five clusters of sets in the Taiwanese longline fishery (1979 – 2012).

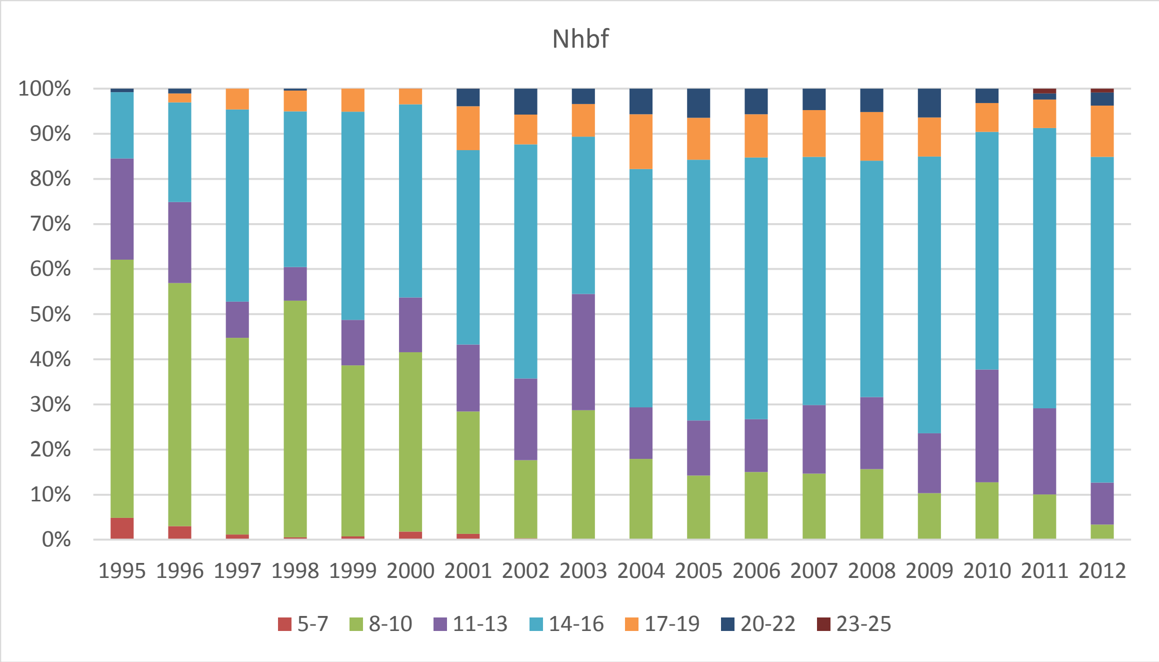
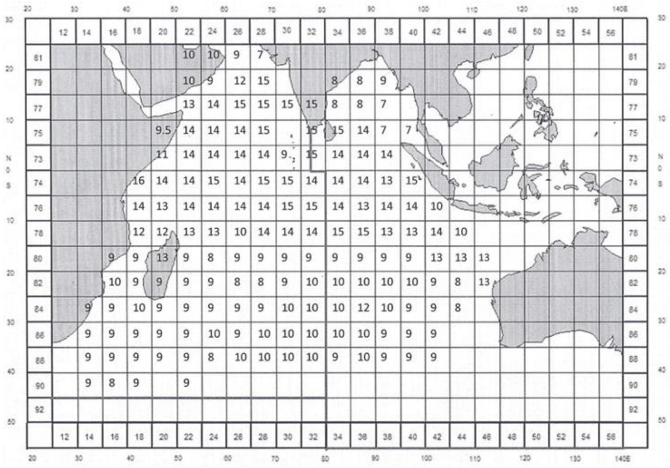
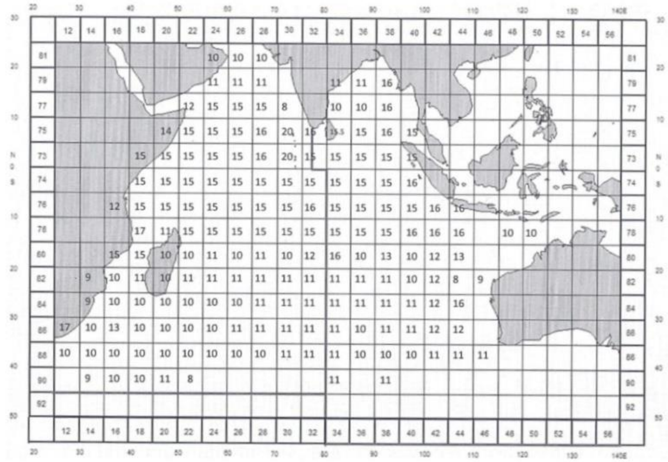


Figure 3. The temporal dynamic of the proportion of various NHBF from 1995 to 2012

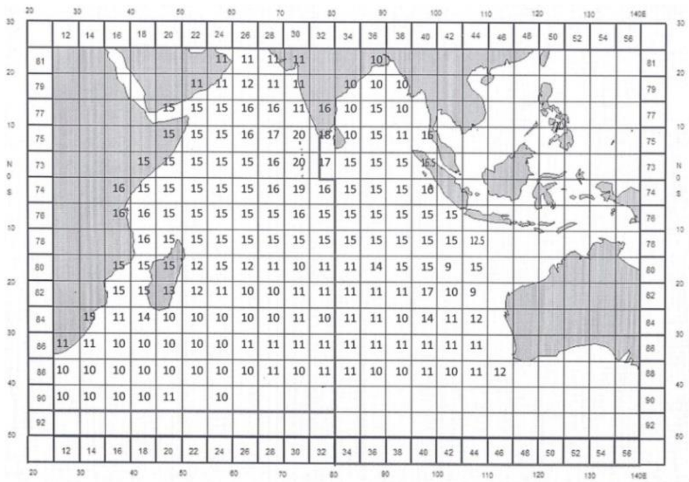
1995 – 1998



1999 – 2003



2004– 2008



2009-2012

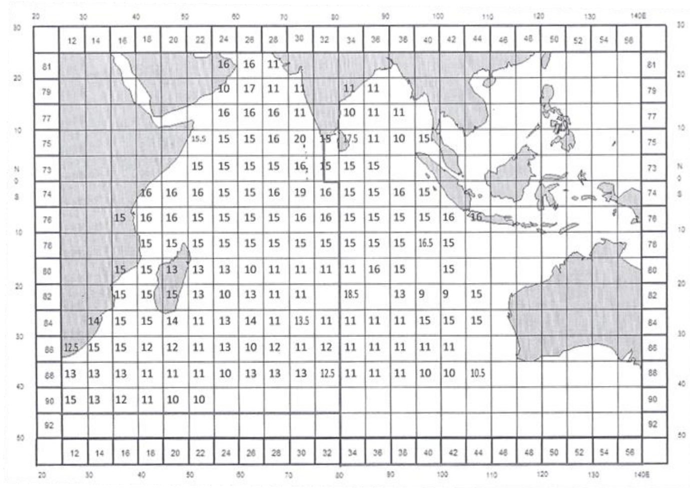


Figure 4. Median NHBF by 5 degree square for four different 8-year period (1995 – 1998, 1999 – 2003, 2004– 2008, and 2009-2012).

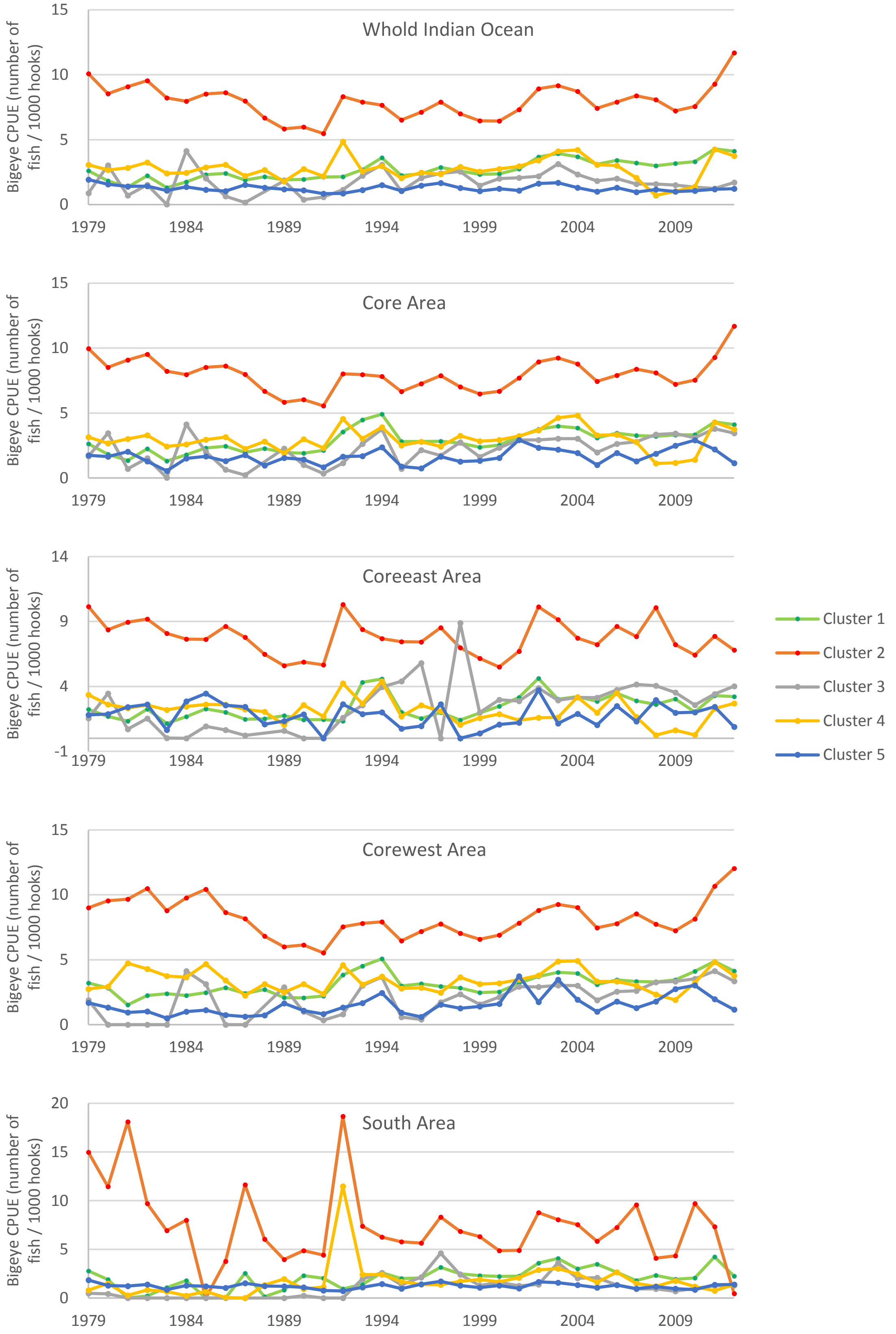


Figure 5. Mean CPUE of bigeye tuna for different clusters of sets in the Taiwanese longline fishery.

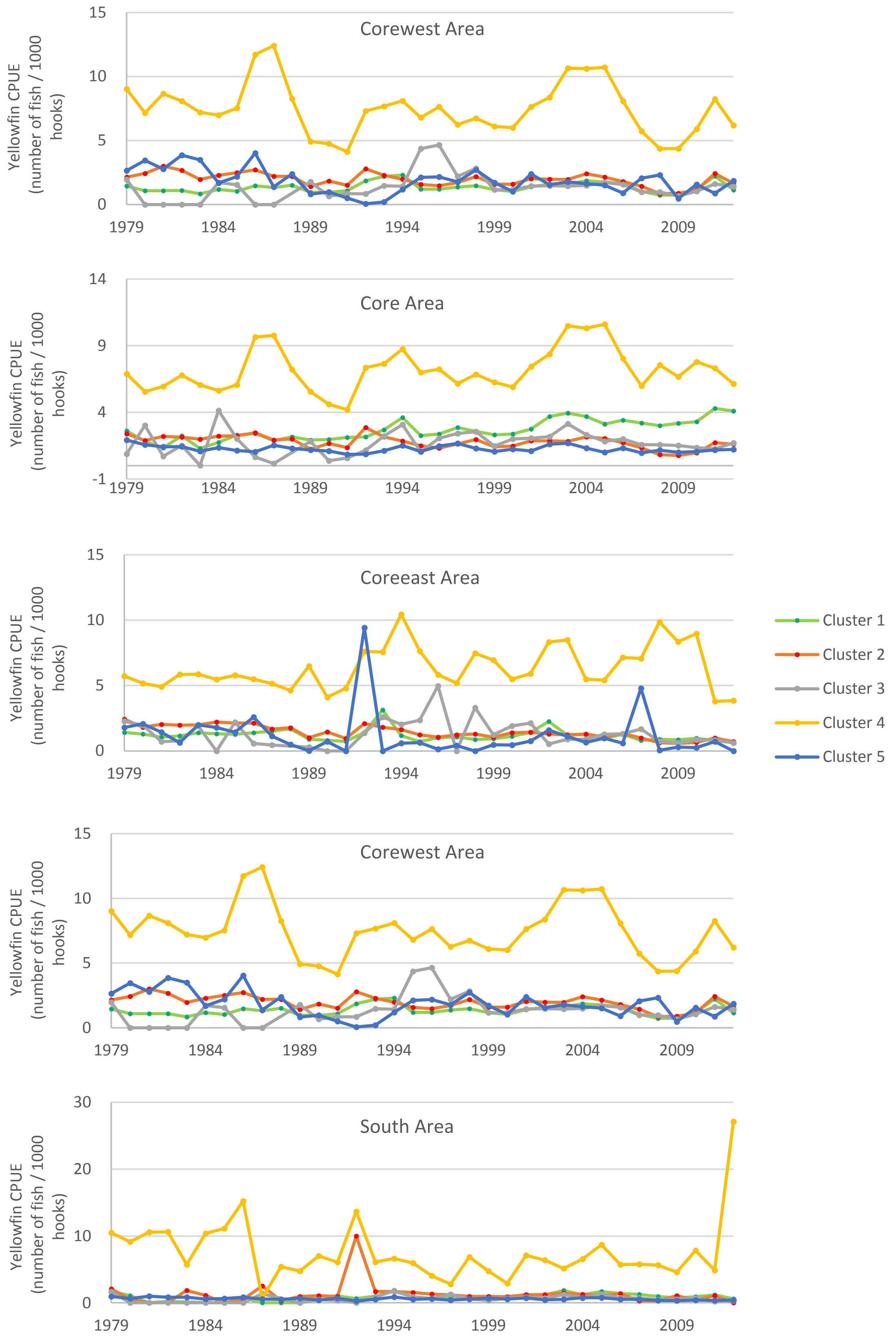


Figure 6. Mean CPUE of yellowfin tuna for different clusters of sets in the Taiwanese longline fishery.

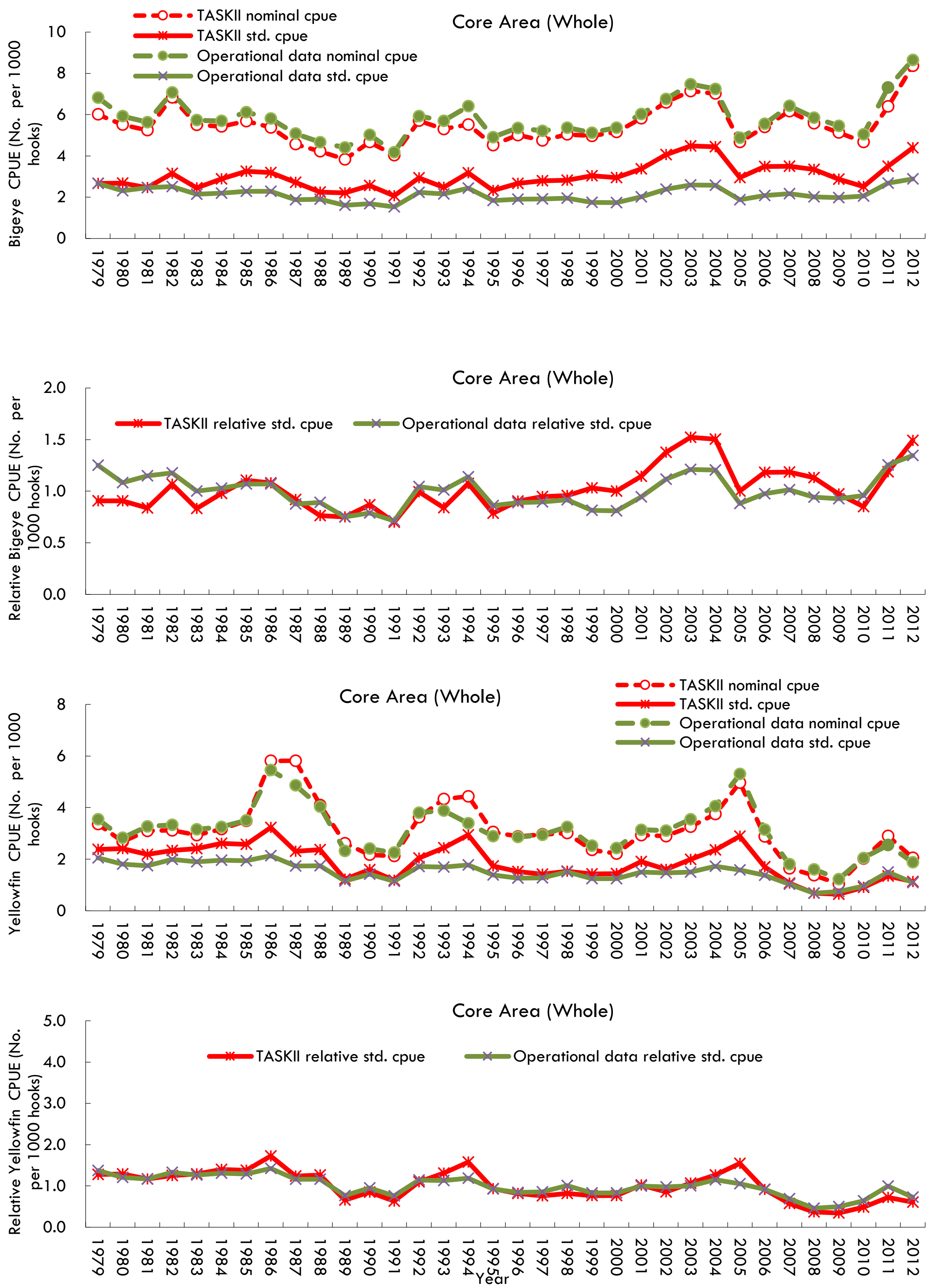


Figure 7. Nominal and Standardized bigeye and yellowfin CPUE derived from all strata in core areas for Taiwanese TaskII data and operational data in real and relative.

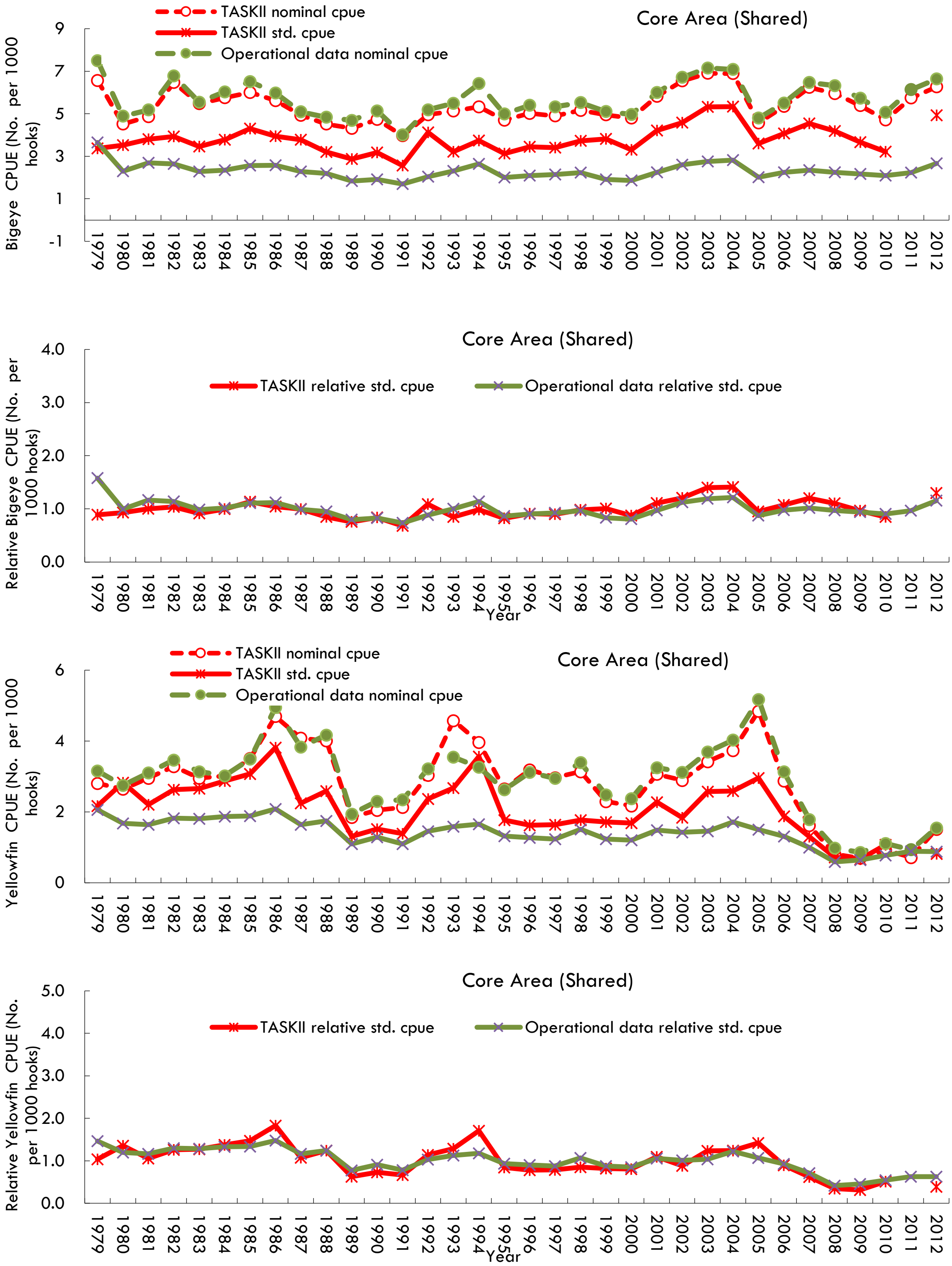


Figure 8. Nominal and Standardized bigeye and yellowfin CPUE derived from shared strata in core areas for Taiwanese TaskII data and operational data in real and relative.

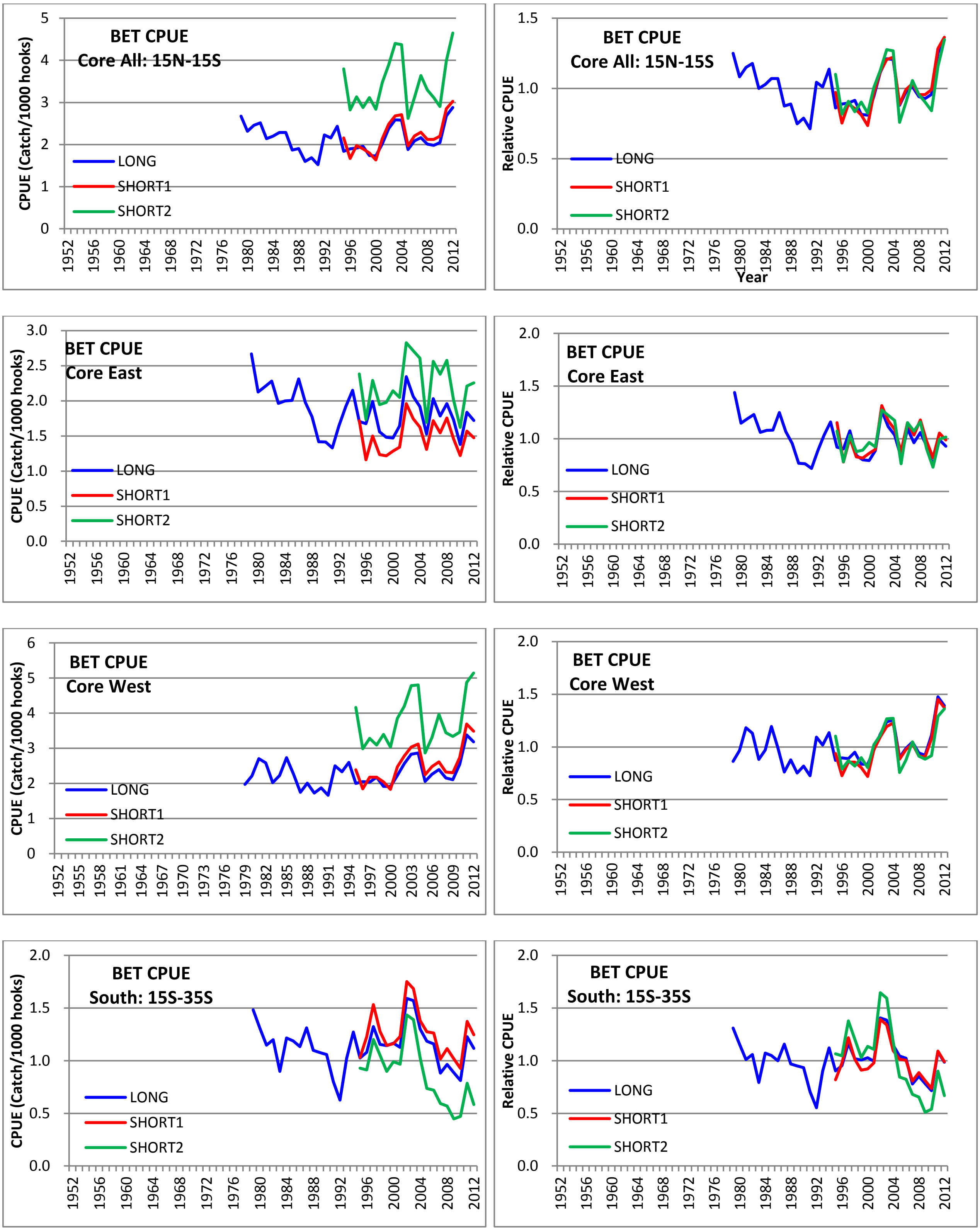


Figure 9. Standardized Bigeye CPUE of Taiwanese longline fishery from 1979 to 2012 using operational data without applying vessel ID as explanatory variable in the model for all strata in core (a), core east (b) core west (c) areas and south area. CPUE in real (left), and relative (right) scale.

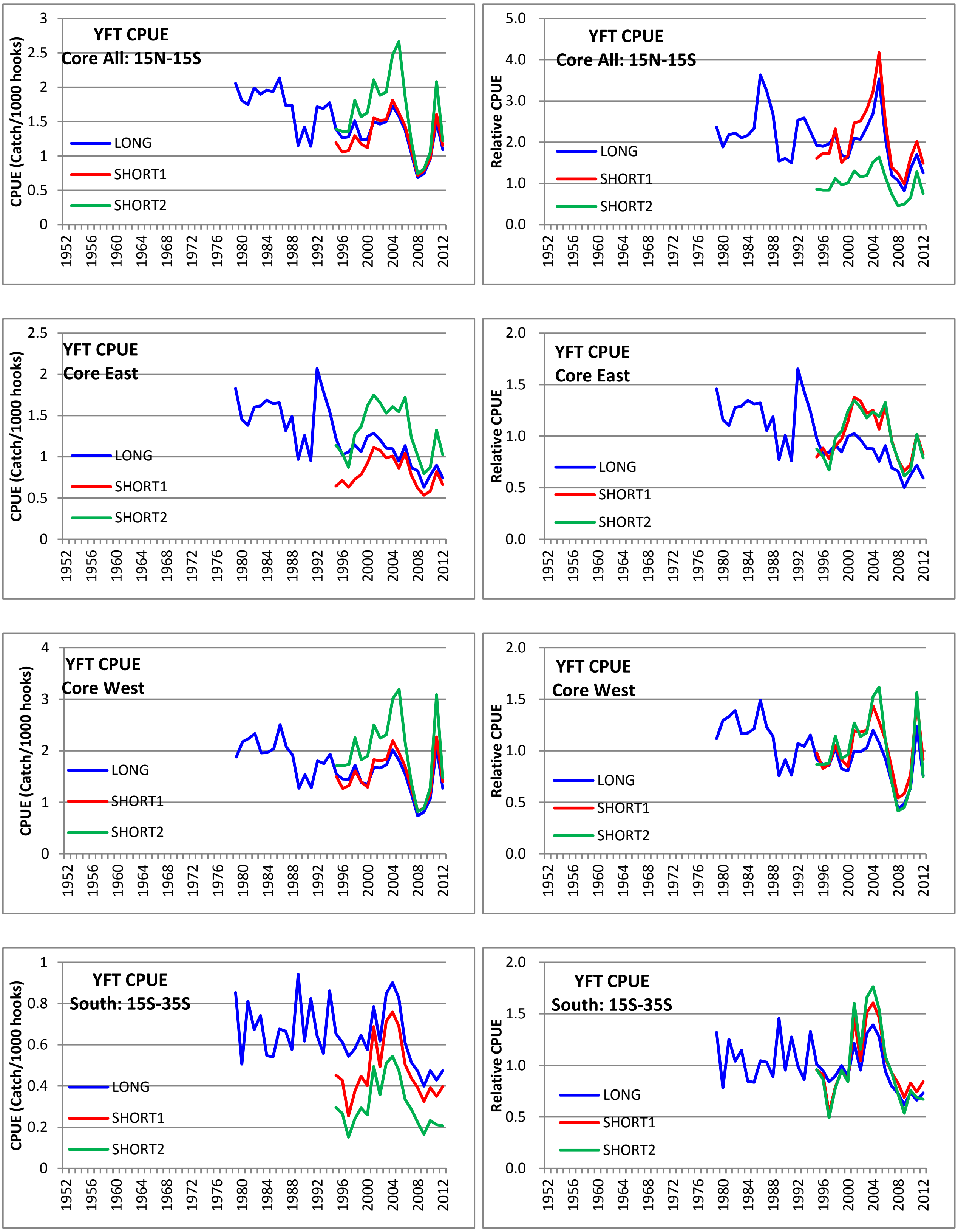


Figure 10. Standardized Yellowfin CPUE of Taiwanese longline fishery from 1979 to 2012 using operational data without applying vessel ID as explanatory variable in the model for all strata in core (a), core east (b) core west (c) areas and south area. CPUE in real (left), and relative (right) scale.

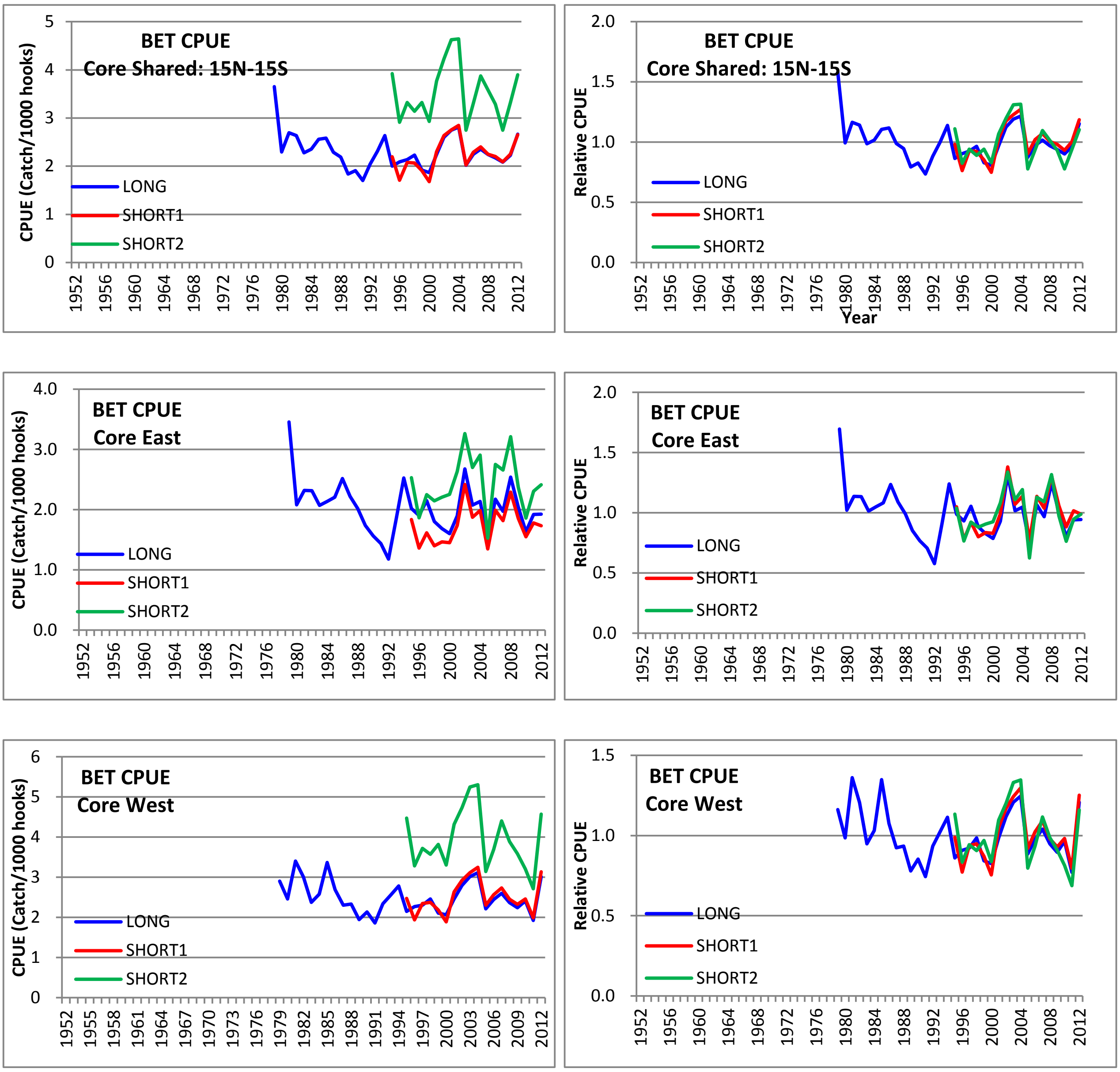


Figure 11. Standardized Bigeye CPUE of Taiwanese longline fishery from 1979 to 2012 using operational data without applying vessel ID as explanatory variable in the model for shared strata in core (a), core east (b) core west (c) areas and south area. CPUE in real (left), and relative (right) scale.

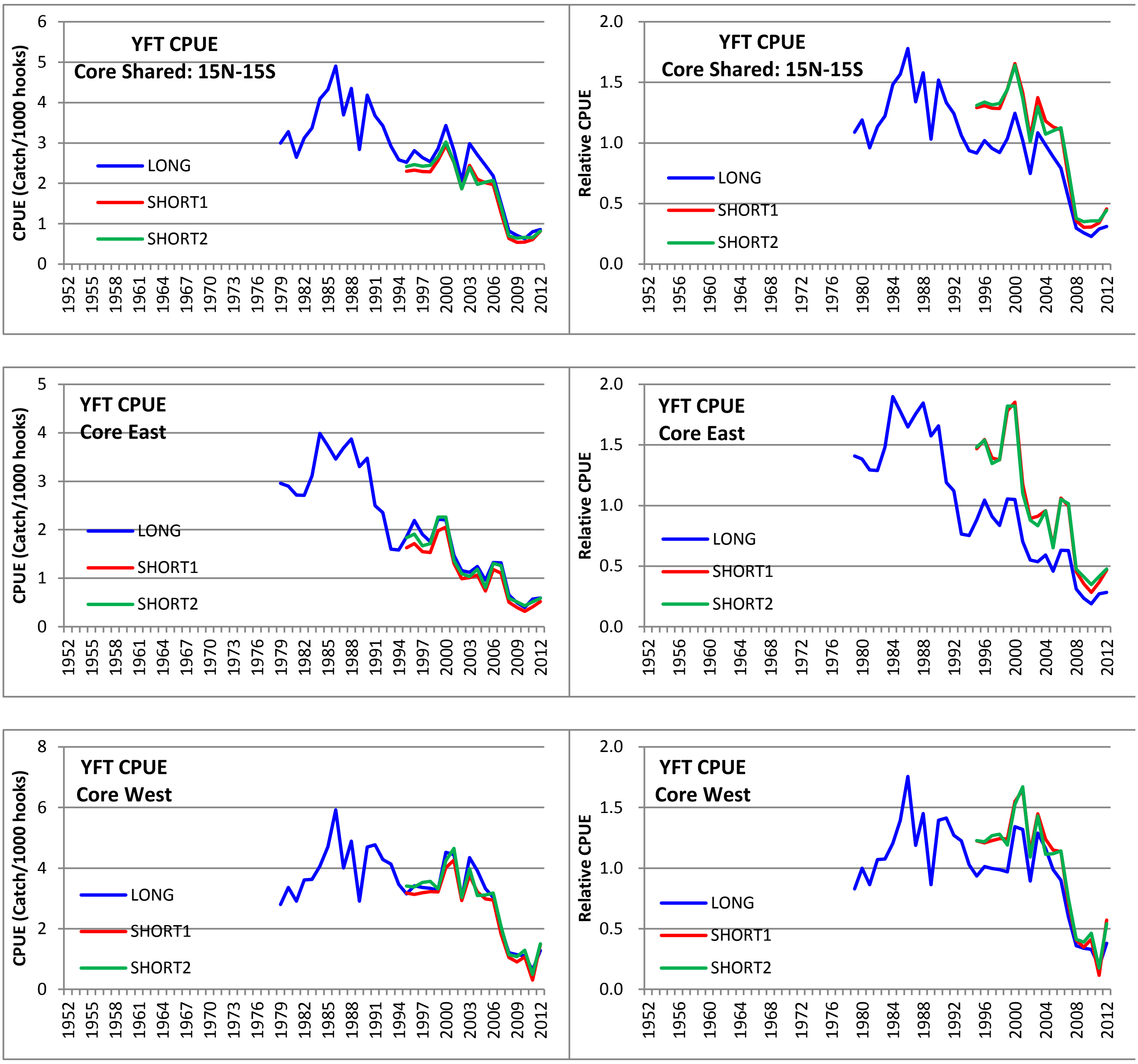


Figure 12. Standardized Yellowfin CPUE of Taiwanese longline fishery from 1979 to 2012 using operational data without applying vessel ID as explanatory variable in the model for shared strata in core (a), core east (b) core west (c) areas and south area. CPUE in real (left), and relative (right) scale.

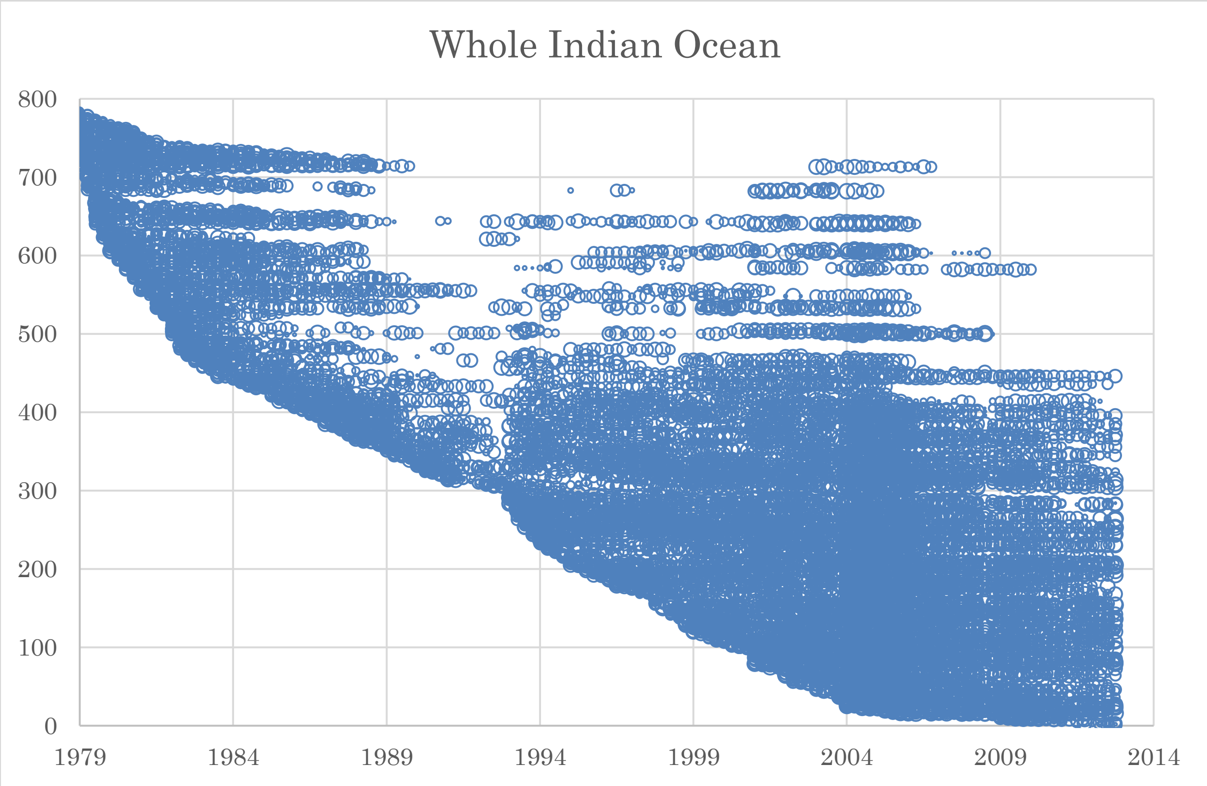


Figure 13. Logbook entry presence and absence by vessel and quarter for vessels included in the full fishing power analysis Vessels are sorted by (a) year of first logsheet and (b) year of last logsheet. Circle area is proportional to the number of sets.

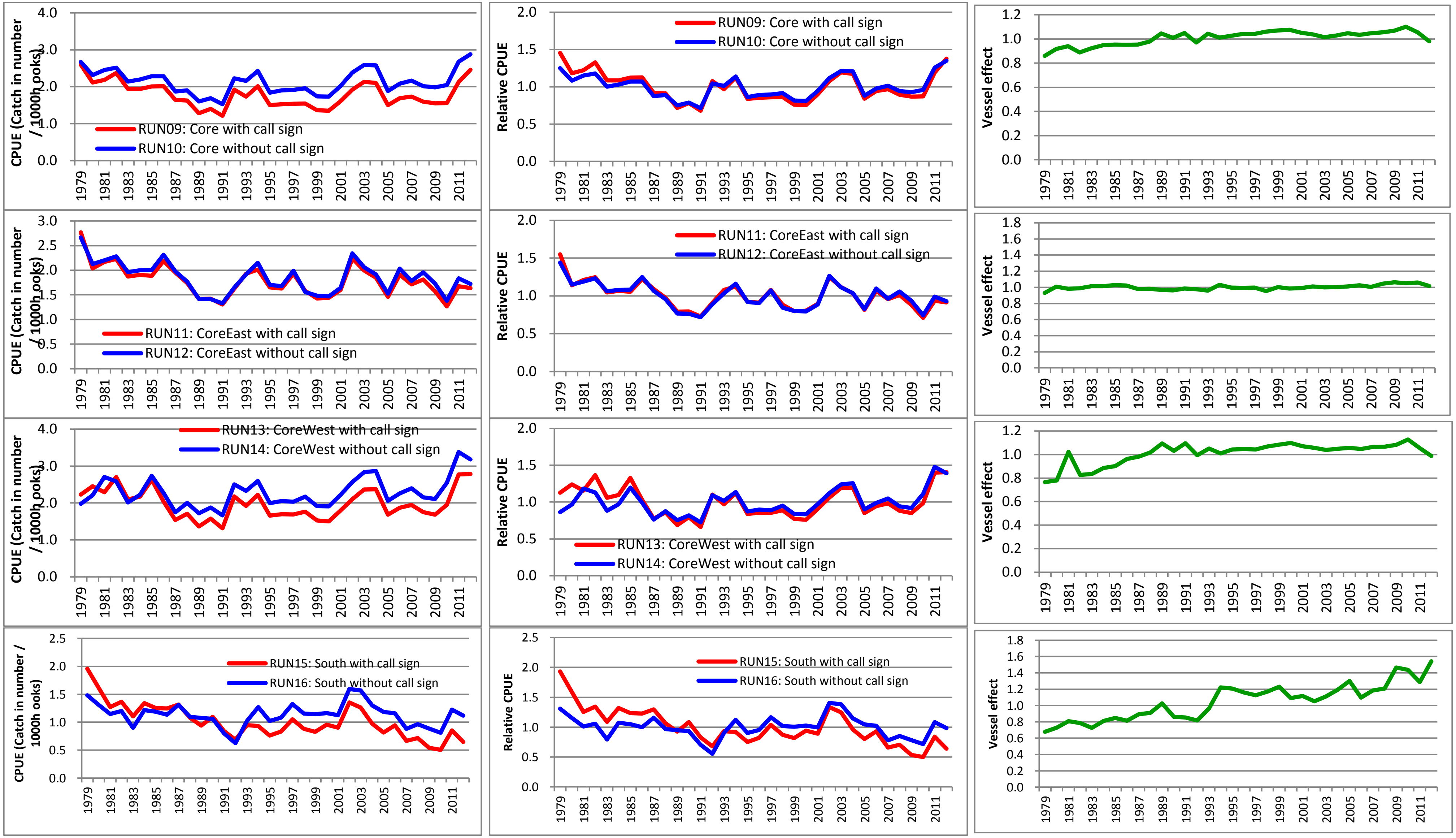
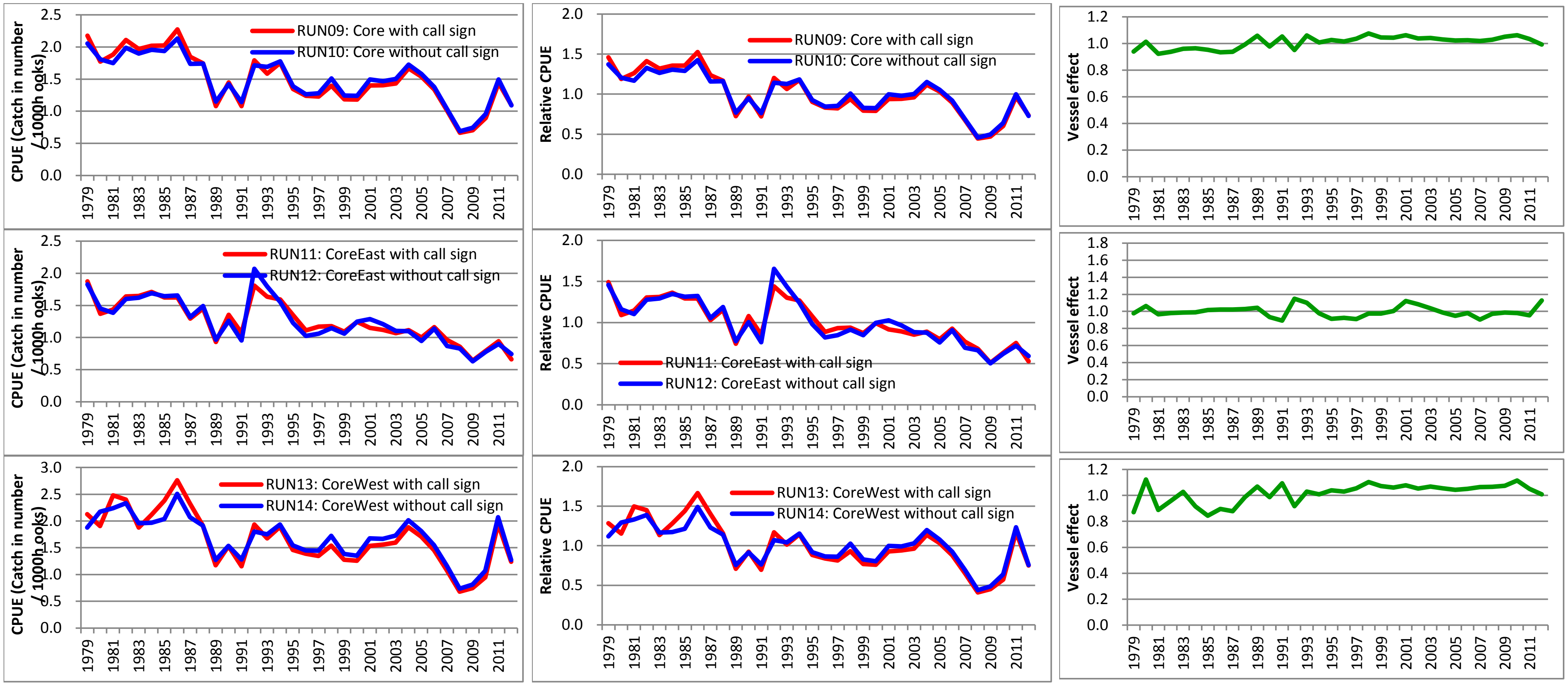
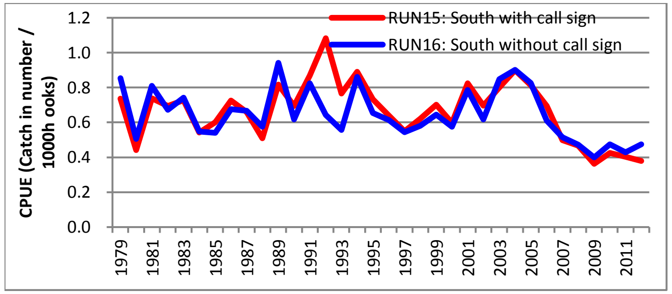
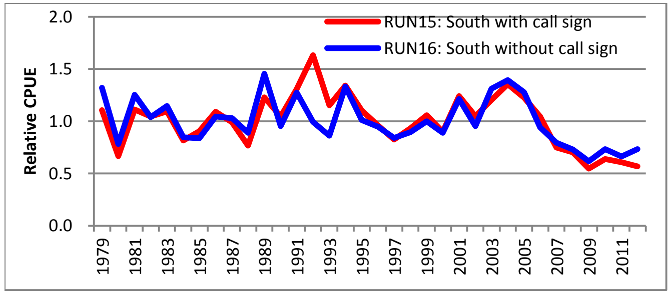


Figure 14. Standardized Bigeye CPUE of Taiwanese longline fishery from 1979 to 2012 using operational data with (red) and without (blue) applying vessel ID as explanatory

variable in the model in core (a), core east (b) and core west (c). CPUE in real scale (left), CPUE in relative scale (middle) and ratio of relative CPUEs standardized with and without Vessel ID.







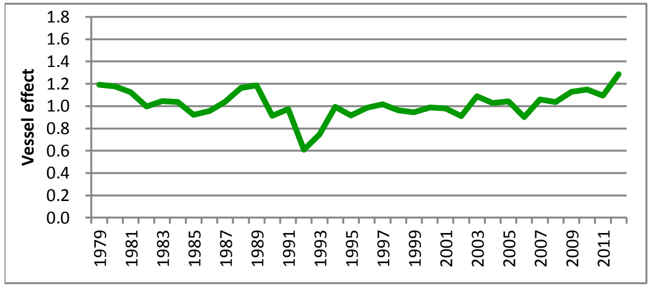


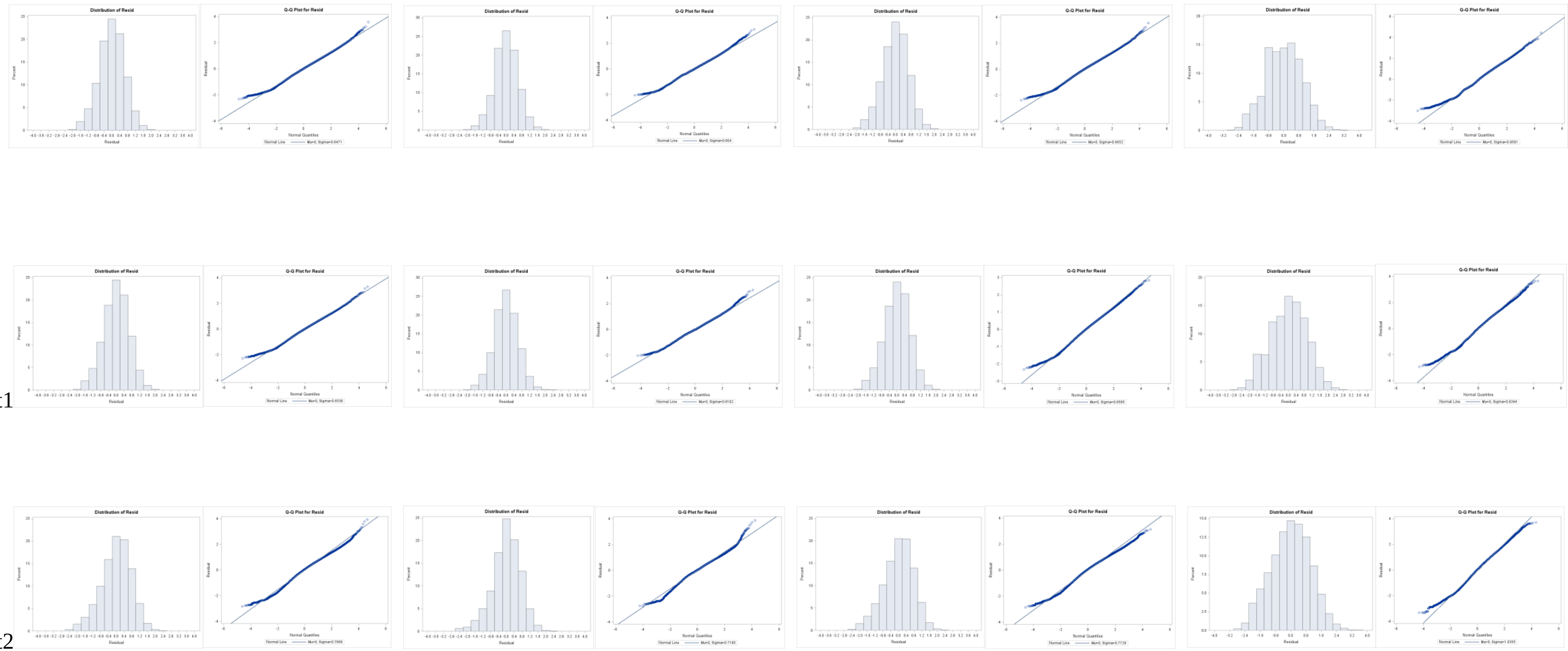
Figure 15. Standardized Yellowfin CPUE of Taiwanese longline fishery from 1979 to 2012 using operational data with (red) and without (blue) applying vessel ID as explanatory variable in the model in core (a), core east (b) and core west (c). CPUE in real scale (left), CPUE in relative scale (middle) and ratio of relative CPUEs standardized with and without Vessel ID.

core core east core west south

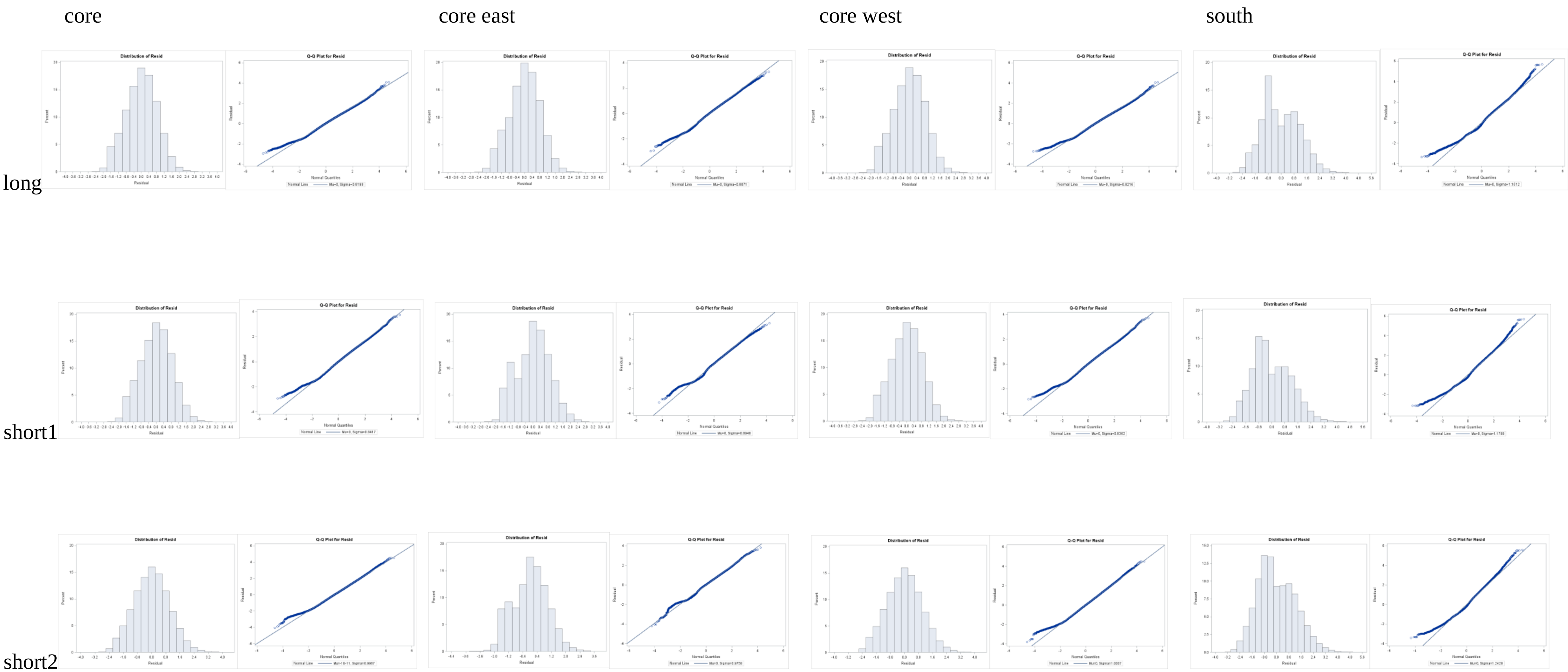
long

short1

short2



Appendix Fig. 1 (All strata) Standardized residuals of standardization of bigeye CPUE of Taiwanese longline fishery using long, short1 and short2 data without applying vessel ID (call sign) as explanatory variable in the model for all, east and west core areas and south area expressed as histogram and QQ plot.



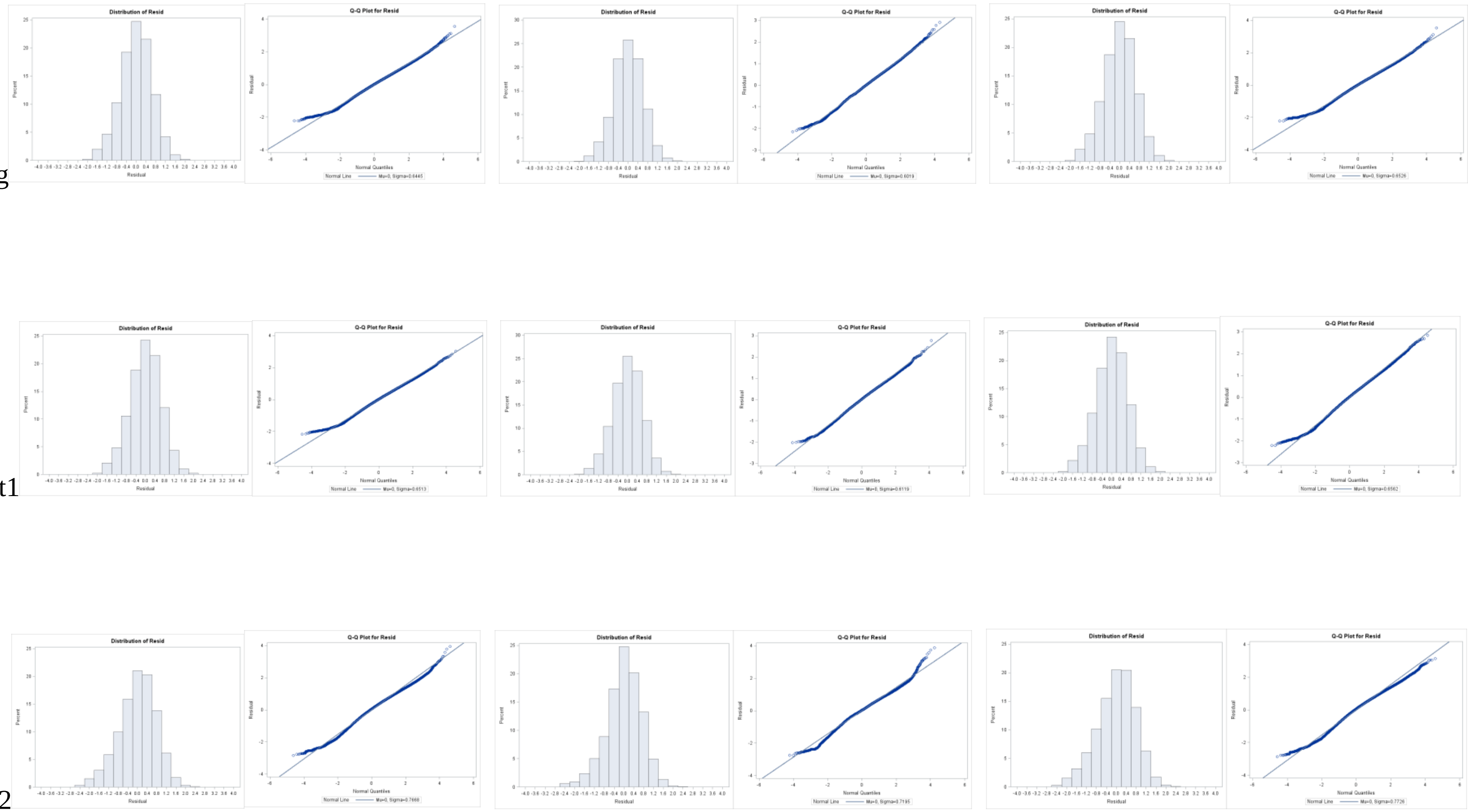
Appendix Fig. 2 (All strata) Standardized residuals of standardization of yellowfin CPUE of Taiwanese longline fishery using long, short1 and short2 data without applying vessel ID (call sign) as explanatory variable in the model for all, east and west core areas and south area expressed as histogram and QQ plot.

core | core east | core west

long

short1

short2



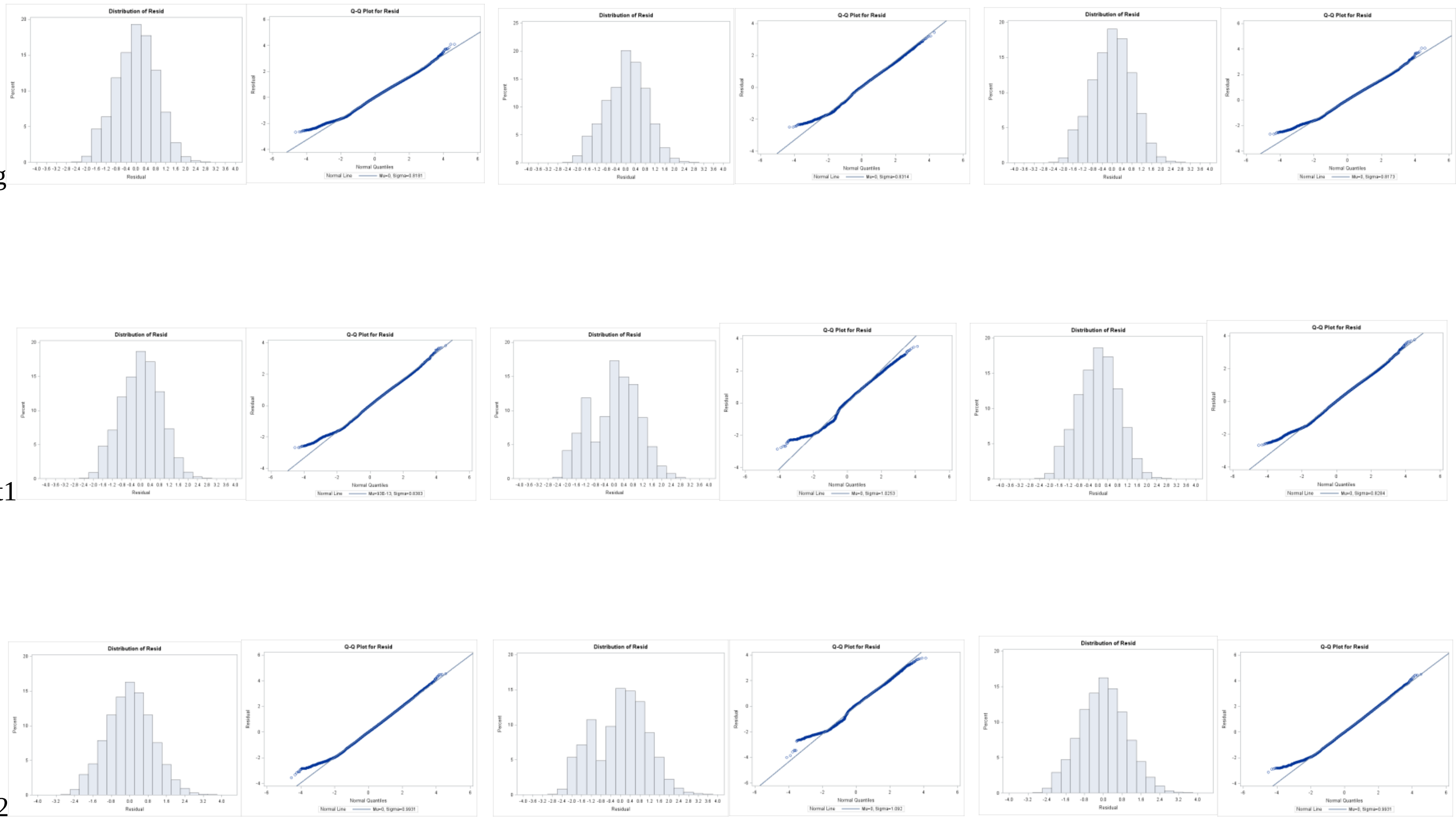
Appendix Fig. 3 (Shared strata) Standardized residuals of standardization of bigeye CPUE of Taiwanese longline fishery using long, short1 and short2 data without applying vessel ID (call sign) as explanatory variable in the model for all, east and west core areas and south area expressed as histogram and QQ plot.

core core east core west

long

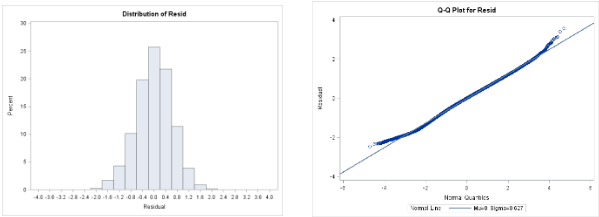
short1

short2

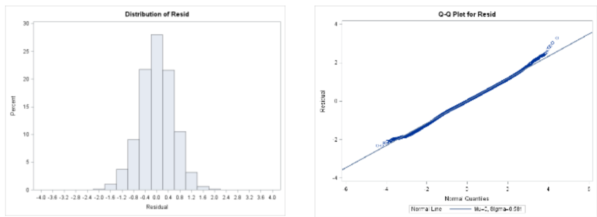


Appendix Fig. 4 (Shared strata) Standardized residuals of standardization of yellowfin CPUE of Taiwanese longline fishery using long, short1 and short2 data without applying vessel ID (call sign) as explanatory variable in the model for all, east Appendix Fig. 3 Standardized residuals of standardization of bigeye CPUE of Taiwanese longline fishery using operational data with and without applying vessel ID (call sign) as explanatory variable in the model for all, east and west core areas and south area expressed as histogram and QQ plot.

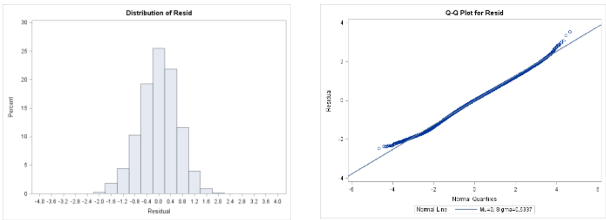
core



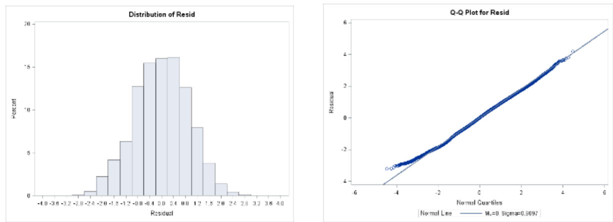
core east



core west

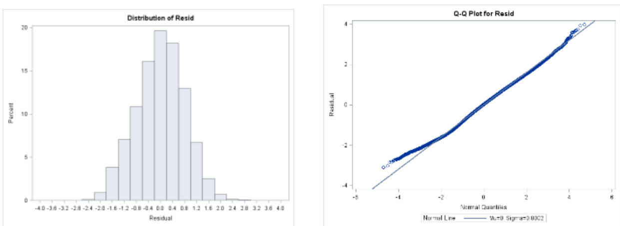


south

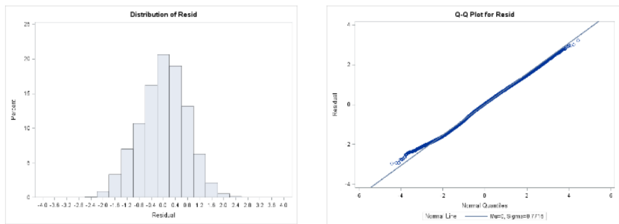


Appendix Fig. 5 Standardized residuals of standardization of bigeye CPUE of Taiwanese longline fishery using operational data with applying vessel ID (call sign) as explanatory variable in the model for all, east and west core areas and south area expressed as histogram and QQ plot.

core



core east



core west

south

Appendix Fig. 6 Standardized residuals of standardization of yellowfin CPUE of Taiwanese longline fishery using operational data with applying vessel ID (call sign) as explanatory variable in the model for all, east and west core areas and south area expressed as histogram and QQ plot