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CPUE of bigeye and yellowfin tuna caught by Japanese longliner in the Indian Ocean standardized by GLM considering several aspects of area, catchability and data resolution.

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Abstract

Using Japanese and Taiwan-China longline catch and effort data aggregated by 5x5 degree and month, bigeye and yellowfin CPUE in the tropical Indian Ocean from 10N-15S (core area) were standardized from 1967 to 2012. Bigeye CPUE of both fleets showed quite similar trends until 1976, after which Taiwan-China CPUE did not show a clear trend but continued at a similar level. Japanese CPUE increased suddenly in the mid-1970s, remained at a high level until 1991, and then decreased steadily to about half the level of the mid-1980s by 2002. In the case of yellowfin, the CPUE trends of both fleets showed generally similar trends, with a large decline before 1979, relatively stability until 2005, and sudden decreases to less than half the 2003-2005 level by 2008. For both species and both fleets, large differences were not observed between standardized CPUE derived from all strata and that from strata shared by both fleets.

Historical changes in fishing efficiency of the Japanese longline fishery were estimated for bigeye and yellowfin by including the Vessel ID in the standardization using operational data. Fishing efficiency for bigeye tuna estimated in core areas showed a continuously increasing trend, from 0.8 to 1.6 (in the case of the west core) or from 0.7 to 1.4 (east core) during 33 years analyzed (about 2.1-2.4% per year), whereas efficiency in the south area has been almost at the same level throughout. In contrast, estimated fishing efficiency for yellowfin in the core area increased until the late 1980s after which it steadily decreased from 1.16 to 0.7 through the remained 24 years (about -2% per year). Efficiency in the south area remained at the same level throughout the period, apart from increasing trends observed in the early 1980s and after around 2004.

Three types of Japanese longline data: non-aggregated operational data; L1 data aggregated by 1 degree latitude and 1 degree longitude, month and NHF; and L5 data aggregated by 5 degree latitude and 5 degree longitude, month and NHF were standardized for each species and region, and their trends compared. In all core areas and the south area, both bigeye and yellowfin CPUE trends were similar between different data resolutions.

Introduction

It has been pointed out that the CPUE trend of longline fishery for bigeye in the Indian Ocean is considerably different between Japan (JPN) and Taiwan China (TWN-CHN) at WPTT and Scientific committee of IOTC (Anonymous 2013a). In the CPUE Workshop held in San Sebastian in October 2013, it was suggested as the strong recommendation that the approaches to possibly pursue are the following: i) Assess filtering approaches on data and whether they have an effect, ii) examine spatial resolution on fleets operating and whether this is the primary reason for differences, and iii) examine fleet efficiencies by area, iv) use operational data for the standardization, and v) have a meeting amongst all operational level data across all fleets to assess an approach where we may look at catch rates across the broad areas (Anonymous 2013b). And it was also suggested to assess how core area standardization works, and operational level data is useful if we want to quantify fishing fleet efficiency using fleet dynamic covariates, and more applications could be developed using the methods developed by Hoyle (2009), and Hoyle et al. (2010) and preliminarily presented by author at the CPUE workshop.

In Okamoto (2014), historical change in the fishing distribution of Japanese and Taiwan China 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. Therefore, it was suggested that the difference of fishing ground should not be the main reason of their different trend of CPUE. In order to tackle further on the above issues, the following analyses were conducted for bigeye and yellowfin tunas in this study.

Core area analyses: core area analyses of Okamoto (2014) were updated using the latest data up to 2012 with some modification of model (addition of two explanatory variables, SST and 5 degree square).

Fishing efficiency analysis: By applying Vessel ID (call sign) in the GLM as explanatory variable, historical change in the fishing efficiency for bigeye and yellowfin catch was estimated by area.

Data resolution analyses: Three different resolutions of data, that is, operational data, L1 data (aggregated by month and 1 degree square) and L5 data (aggregated by month and 5 degree square), were separately applied for standardization and their trends are compared.

Materials and methods

Area definition

Area definition used in this analysis was shown in Fig. 1 which is the same as that used in Matsumoto et al. (2013) for applying into stock assessment of bigeye tuna in the Indian Ocean using Multifan-CL. 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) Comparison of Japanese and Chinese Taipei CPUE in core area:

Japanese and Taiwan China longline catch of bifeye and yellowfin and effort data from 1967 to 2012 aggregated by month and 5 degree square kept in IOTC as public domain data. As the core area, tropical area from 10°N to 15°S was used.

All data: All Japanese (or all Taiwan-China) data from strata in which 5000 or more Japanese (or Taiwan-China) hooks are included.

Shared data: Data from strata in which 5000 or more Japanese hooks and 5000 or more Taiwan-China hooks are included.

2) Fishing efficiency analysis:

Operational data kept in National Research Institute of Far Seas Fisheries data base from 1979 to 2013 was used. This data set is Japanese longline catch and effort data by each operation which is not aggregated by strata. For this analysis, year, month, the number of hooks used in each set, bigeye and yellowfin catch in number, the number of hooks between float (NHF), call sign included in this data were used.

3) Data resolution analyses:

Operational data from 1952 to 2012 was used. For this analyses, year, month, the number of hooks used, bigeye and yellowfin catch in number, NHF in this data set were used. As the NHF information is available since 1975, NHF before this period was assumed to be 5. L1 and L5 data were re-compiled from operational data by aggregating effort and catch by year, month 1 degree x 1 degree or 5degree x 5 degree, and NHF.

Environmental factors

As environmental factors, which are available for the analyzed period from 1952 to 2012, SST (Sea Surface Temperature) was applied. The original SST data, whose resolution is 1-degree latitude and 1-degree longitude by month from 1946 to 2012, was downloaded from

NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA).

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. Variable selection was conducted by a backwards stepwise F-test with a criterion of P = 0.05. In the cases in which the factor was not significant as main factor but was significant as interaction with another factor, the main factor was kept in the model. All explanatory variables were applied as class variable.

1) Comparison of Japanese and Chinese Taipei CPUE in core area:

Log [CPUE +const] = μ + year +quarter + LT5LN5 + SST + 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,
SST: effect of sea surface temperature (Round off to nearest integral number; 27.6 → 28).

2) Fishing efficiency analysis:

Log [CPUE +const] = μ + year + quarter + NHF + Vseesl ID + lt5ln5 + SST + error (a)
Log [CPUE +const] = μ + year + quarter + NHF + + lt5ln5 + SST + error (b)

Where

NHF: effect of gear type (the number of hooks between floats),
Vessel ID: effect of identifier of each vessel (call sign was used as vessel ID),

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

3) Data resolution analyses:

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

Results and discussion

1) Comparison of Japanese and Chinese Taipei CPUE in core area

Standardized CPUE of JPN and TWN-CHN longline for yellowfin and bigeye tunas in core area (10N-15S) as defined by Okamoto (2014) was updated to 2012. CPUE was standardized using all strata in which one or both fleets made operation or using shared strata in which both fleets made operation. As the effects of all explanatory variables included in the full model shown in materials and methods section were significant in all cases for both of bigeye and yellowfin tunas (Table 1 and 2), the full model was adopted as the final model for both species. Distribution of residual in each model did not show large difference from normal distribution (Appendix Fig. 1 and 2).

For both species and both fleets (TWN-CHN and JPN), large difference was not observed between standardized CPUE derived from all strata and that from shared strata as shown in Figs. 2 for bigeye and Fig. 3 for yellowfin.

As for the bigeye (Fig.2), CPUE of both fleets showed quite similar trends until 1976 after which TWN-CHN CPUE did not show a clear trend but continued at a similar level with some fluctuation although the level after 2000 is somewhat higher than before it. JPN CPUE increased suddenly in the mid-1970s, remained at a high level until 1991 and then decreased steadily to about half the level of the mid-1980s by 2002. The high JPN CPUE level from middle 1970s would have been derived from shift of target species from yellowfin to bigeye accompanied with the change in longline gear configuration (Suzuki et al., 1977). Since the continuous declining trend in JPN CPUE from late 1980s to early 2000 is supposed to reflect the declining trend of bigeye stock, TWN-CHN CPUE does not show this declining trend. Fig. 2-c shows historical change in the ratio between CPUE of both fleet (TWN-CPUE/JPN-CPUE) in real scale CPUE (left) and relative scale CPUE (right). This ratio derived from all strata and that shared strata of core area didn't show remarkable difference.

In the case of yellowfin (Fig. 3-a and 3-b), the CPUE trends of both fleets showed generally similar trends, with a large decline before 1979, relatively stability until 2005, and sudden decreases to less than half the 2—3-2005 level by 2008. As for yellowfin, historical trends of ratio between both CPUE (Fig. 3-c) was quite similar between all strata and shared strata. These results mean that the CPUE trends of both fleets didn't become closer by using shared strata than using all strata, and suggests that the difference in fishing region would not be the main reason of the difference in CPUE trends of both species between both fleets.

2) 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 were 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 3 and 4), 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. 3 and 4)

Fishing efficiency for bigeye tuna estimated in core areas (all, east and west core areas) showed a continuously increasing trend, from 0.8 to 1.6 (in the case of the west core) or from 0.7 to 1.4 (east core) during 33 years analyzed (about 2.1-2.4% per year, Fig. 4-a, -b and -c), whereas efficiency in the south area has been almost at the same level and no remarkable tread was observed throughout period (Fig. 4-d). In contrast, trend of fishing efficiency for yellowfin is quite different from that of bigeye. Estimated fishing efficiency for yellowfin in the core area increased until the late 1980s after which it steadily decreased from 1.16 to 0.7 through the remained 24 years (about -2% per year, Fig. 5-a, b and c). Efficiency in the south area remained at the same level throughout analyzed period, apart from increasing trends observed in the early 1980s and after around 2004 (Fig. 5-d).

Fishing efficiency would be changed by many factors in short or long term. As suggested in Hoyle et al. (2010), some factors, such as vessel characteristics or equipment (e.g. engine, vessel speed, well capacity, etc), may be kept throughout the life of the vessel and have consistent effects on fishing power, while other factors such as fishing techniques, targeting strategies, new technologies and vessel equipment upgrades, or changes in the crew or fishing master will affect vessels' catchability on a shorter time scale and may vary through time for an individual vessel, as well as among vessels. However vessel effects estimated by the methods in this study only account for changes in fishing power (catchability) among vessels, not changes by an individual vessel. Furthermore, one vessel has only one averaged vessel effect to cover the entire period it is included in the model, which may span decades. It means that while this method would estimate gross change in longline vessels in the area, it would not be able to detect change in catchability on a shorter time scale which may vary through time for an individual vessel. It is desired to develop better ways to consider short-term changes in individual vessels' catchability.

Since fishing efficiency, it may be expressed as catchability, is apt to be supposed to be increasing day by day. Although it might be true if fishing efficiency is changed only by innovation, actual fishing power could also be decreased by factors such as shift of target species, retirement of experienced fishing master and retreat of skillful vessel to other ocean, for example. The results of the analyses in this paper indicated that the trend of fishing efficiency for bigeye is increasing, while that of yellowfin decreasing. But, it is not easy to know what kind of factors is causing these difference in fishing efficiency by species. In the period of declining trend for yellowfin, catch of yellowfin was continuously increasing, and this trend should have been enhanced from late 1990s by concentrating their fishing effort to African coastal area where the yellowfin is abundant. As this shift of main fishing ground is supposed to have occurred to catch yellowfin more effectively, declining trend of fishing efficiency for this species would difficult to be explain by the target shift. It is also difficult to explain the reason of difference in trend of fishing efficiency between tropical (core) areas and south area for both species. It seems to be common for both species that relatively larger change and clearer trend tend to be observed in tropical areas than south area.

3) Effect of each explanatory variable

Using lsmeans from the results of GLM including Vessel ID in the model for vessel efficiency analyses, effect of each covariate was observed (Fig. 6 and 7). Effect was observed as CPUE by taking exponential of lsmean and plus 10% of overall mean of CPUE. The CPUE was expressed in relative scale in which average of CPUE in all classes is 1.0.

Quarter (Fig. 6-a): In the east core area, bigeye CPUE is high in 1st and 4th quarter while yellowfin CPUE showed opposite trend, that is, highest CPUE in 2nd quarter and lowest CPUE in 4th quarter. Both species show similar trend in west core area in which their CPUE is highest in 2nd quarter although the seasonal trend is not so clear. In the south area, since both species showed highest CPUE in 3rd quarter, that in 4th quarter is nearly highest for yellowfin and lowest for bigeye.

NHF (Number of Hooks between Float, Fig. 6-b): As for bigeye, higher CPUE was observed in larger number of NHF while the CPUE of yellowfin did not show clear trend through the range of NHF. In the tropical region, NHF most of which was around 5 or 6 until early 1970s, has increased thereafter to catch bigeye more effectively as this species has deeper habitat than former target species, yellowfin. Therefore, higher bigeye CPUE in larger NHF observed is reasonable in this context.

SST (Sea Surface Temperature, Fig. 6-c): As for bigeye, CPUE was slightly higher at 26-28°C and lowest at 31° C the highest temperature for the observed range at the east core area, while that of 27-28C is rather low and highest at 31°C at the west core area. In the case of CPUE at core area for yellowfin, CPUE at 24°C and 25°C was extremely high at west and east areas, respectively, and another moderate peak was observed at around 28-29°C at both core areas. In the south area, both species showed quite different CPUE pattern for SST, that is, high CPUE level from 15-23°C and low CPUE level from 26-31°C for bigeye, while low CPUE at SST from 13 to 26°C and high CPUE at SST from 27-31°C with a prominent peak at 29°C for yellowfin.

LT5LN5 (5 degree square, 6-d): As for bigeye tuna, higher effect of 5 degree (larger than 3) distributes mainly north of 20°S in the east core area and north of 15°S in the west core in which the effect at the region off African coast is relatively low. As for the yellowfin, higher effect of 5 degree concentrated at west core area especially from 10°N to 15°S and west of 75°E with other small concentration at north off Australia, and south off Cape Town.

Vessel ID (call sign, Fig. 7): As for bigeye, annual average of Vessel ID effect showed constant increasing trend through the analyzed period in the core areas, from 4.2 to 6.5 in east core and from 3.5 to 5.9 in west core area in real CPUE scale. As for yellowfin, it increased from 1.2 in 1979 to 2.3 in 1992 in east core, and decreased to around 1.7-1.8 in 2004 and thereafter. In west core area, that of yellowfin increased steadily from 3.5 in 1980 to 6.1 in 1999 and continuously decreased to 4.2 in 2010. In the south area, bigeye showed slight but constant increasing trend from 2.5 in 1980s to 2.0 in recent years, while the vessel effect for yellowfin show opposite trend, that is slight increasing trend from 1.2 in 1979 to 1.8 in 2011.

4) Data resolution analyses

In order to know the effect of data resolution on the CPUE trend, three types of Japanese longline data, non-aggregated operational data, L1 data aggregated by 1 degree latitude and 1 degree longitude, month and NHF (the number of hooks between float), and L5 data aggregated by 5 degree latitude and 5 degree longitude, month and NHF were standardized for each species and region, and their trends were compared.

Fig. 8 shows the standardized bigeye CPUE derived from three types of data 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 5), then the same full model was adopted as final model for all cases. 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). In all core areas (all, west and east) and the south area, bigeye CPUE trend were similar between different data resolutions (Operational, L1 and L5). R square was smallest for operational data in all areas, and highest for L1 data in east core and south areas, and that for L5 was highest in remained area (all core and west core areas).

As for yellowfin tuna also, quite similar trend was observed between standardized CPUEs derived from each of three resolutions of data as shown in Fig. 9. As the case of bigeye, effect of all explanatory variables included in the full model were significant in all area (Table 6), then the same full model was adopted as final model for all cases. In the case of yellowfin, R square was lowest for CPUE derived from operational data as the case of bigeye, and CPUE derived from L5 data showed highest R square in all areas.

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.

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Table 1. ANOVA table of GLM for bigeye CPUE standardization of Japanese and Taiwan-China longline fisheries for all and shared strata of core fishing area in the Indian Ocean for 1967-2012.

Japan: All 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	117	1878.767	16.058	54.950	<.0001	0.337856
						CV =
yr	45	805.085	17.891	61.220	<.0001	29.71816
qt	3	13.451	4.484	15.340	<.0001	
lt5ln5	63	779.929	12.380	42.360	<.0001	
sstcl	6	22.567	3.761	12.870	<.0001	

Japan: Share 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	115	1142.889	9.938	36.970	<.0001	0.377415
						CV =
yr	45	491.332	10.918	40.610	<.0001	29.42924
qt	3	6.511	2.170	8.070	<.0001	
lt5ln5	61	417.179	6.839	25.440	<.0001	
sstcl	6	17.055	2.843	10.570	<.0001	

Taiwan China: All 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	120	1168.956	9.741	25.970	<.0001	0.182023
						CV =
yr	45	363.916	8.087	21.560	<.0001	38.89568
qt	3	47.200	15.733	41.950	<.0001	
lt5ln5	65	649.389	9.991	26.640	<.0001	
sstcl	7	23.829	3.404	9.080	<.0001	

Tiwan China: Share 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	115	375.420	3.265	10.730	<.0001	0.149586
						CV =
yr	45	121.993	2.711	8.910	<.0001	33.82829
qt	3	22.777	7.592	24.950	<.0001	
lt5ln5	61	202.818	3.325	10.930	<.0001	
sstcl	6	4.789	0.798	2.620	0.0153	

Table 2. ANOVA table of GLM for yellowfin CPUE standardization of Japanese and Taiwan-China longline fisheries for all and shared strata of core fishing area in the Indian Ocean for 1967-2012.

Japan: All 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	117	4417.578	37.757	84.680	<.0001	0.440202
						CV =
yr	45	2320.038	51.556	115.630	<.0001	40.45164
qt	3	19.217	6.406	14.370	<.0001	
lt5ln5	63	1806.643	28.677	64.320	<.0001	
sstcl	6	33.904	5.651	12.670	<.0001	

Japan: Share 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	115	2639.258	22.950	54.400	<.0001	0.471473
						CV =
yr	45	1470.488	32.678	77.460	<.0001	39.61147
qt	3	13.011	4.337	10.280	<.0001	
lt5ln5	61	846.599	13.879	32.900	<.0001	
sstcl	6	16.182	2.697	6.390	<.0001	

Taiwan China: All 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	120	5390.199	44.918	91.930	<.0001	0.440578
						CV =
yr	45	4235.854	94.130	192.640	<.0001	63.68826
qt	3	26.430	8.810	18.030	<.0001	
lt5ln5	65	769.159	11.833	24.220	<.0001	
sstcl	7	14.159	2.023	4.140	0.0001	

Tiwan China: Share 1967-2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	115	3393.157	29.506	72.180	<.0001	0.542045
						CV =
yr	45	2500.463	55.566	135.930	<.0001	57.33121
qt	3	10.818	3.606	8.820	<.0001	
lt5ln5	61	439.909	7.212	17.640	<.0001	
sstcl	6	10.269	1.711	4.190	0.0003	

Table 3. ANOVA table of GLM for bigeye CPUE standardization using operational data of Japanese longline fisheries with applying vessel ID as explanatory variable for all and shared strata of core fishing area 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	636	66112.945	103.951	173.910	<.0001	0.309602
						CV =
Year	33	4802.990	145.545	243.500	<.0001	45.65696
Quarter	3	658.722	219.574	367.350	<.0001	
NHF	16	707.407	44.213	73.970	<.0001	
Call sign	501	10699.796	21.357	35.730	<.0001	
LT5LN5	76	9697.112	127.594	213.460	<.0001	
SST	7	498.500	71.214	119.140	<.0001	

Core — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	135	55413.15	410.468	641.550	<.0001	0.259496
						CV =
Year	33	7042.284	213.403	333.540	<.0001	47.23679
Quarter	3	758.017	252.672	394.920	<.0001	
NHF	16	801.333	50.083	78.280	<.0001	
LT5LN5	76	19817.866	260.761	407.560	<.0001	
SST	7	503.612	71.945	112.450	<.0001	

Core East — 1979-2012 with call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	394	9557.457	24.258	46.910	<.0001	0.210394
						CV =
Year	33	1110.683	33.657	65.080	<.0001	36.74532
Quarter	3	242.490	80.830	156.300	<.0001	
NHF	16	350.377	21.899	42.340	<.0001	
Call sign	300	3011.542	10.038	19.410	<.0001	
LT5LN5	36	1302.203	36.172	69.950	<.0001	
SST	6	91.459	15.243	29.480	<.0001	

Core East — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	94	6545.915	69.637	124.760	<.0001	0.144099
						CV =
Year	33	1982.856	60.087	107.650	<.0001	38.17432
Quarter	3	304.027	101.342	181.570	<.0001	
NHF	16	442.144	27.634	49.510	<.0001	
LT5LN5	36	1955.621	54.323	97.330	<.0001	
SST	6	114.840	19.140	34.290	<.0001	

Core West — 1979-2012 with call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	479	53510.745	111.714	180.380	<.0001	0.341066
						CV =
Year	33	3963.422	120.104	193.930	<.0001	50.31711
Quarter	3	988.722	329.574	532.160	<.0001	
NHF	16	369.040	23.065	37.240	<.0001	
Call sign	381	7840.011	20.577	33.230	<.0001	
LT5LN5	39	4507.678	115.581	186.630	<.0001	
SST	7	541.513	77.359	124.910	<.0001	

Core West — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	98	45670.734	466.028	701.040	<.0001	0.291096
						CV =
Year	33	5886.080	178.366	268.310	<.0001	52.1307
Quarter	3	1051.974	350.658	527.490	<.0001	
NHF	16	709.126	44.320	66.670	<.0001	
LT5LN5	39	8657.576	221.989	333.930	<.0001	
SST	7	601.794	85.971	129.320	<.0001	

South — 1979-2012 with call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	647	113969.97	176.151	228.670	<.0001	0.383374
						CV =
Year	33	5455.552	165.320	214.610	<.0001	100.6572
Quarter	3	2803.515	934.505	1213.140	<.0001	
NHF	16	1050.238	65.640	85.210	<.0001	
Call sign	503	22670.680	45.071	58.510	<.0001	
LT5LN5	74	8357.201	112.935	146.610	<.0001	
SST	18	3023.893	167.994	218.080	<.0001	

South — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	144	91299.29	634.023	734.020	<.0001	0.307114
						CV =
Year	33	7641.093	231.548	268.070	<.0001	106.5875
Quarter	3	3684.783	1228.261	1421.990	<.0001	
NHF	16	1474.577	92.161	106.700	<.0001	
LT5LN5	74	12941.976	174.892	202.480	<.0001	
SST	18	3815.722	211.985	245.420	<.0001	

Table 4. ANOVA table of GLM for yellowfin CPUE standardization using operational data of Japanese longline fisheries with applying vessel ID as explanatory variable for all and shared strata of core fishing area in the Indian Ocean for 1979-2012.

Core — 1979-2012 with call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	636	112376.838	176.693	221.650	<.0001	R-Square= 0.363682
Year	33	7740.543	234.562	294.240	<.0001	CV = 66.33603
Quarter	3	90.671	30.224	37.910	<.0001	
NHF	16	278.893	17.431	21.870	<.0001	
Call sign	501	16875.134	33.683	42.250	<.0001	
LT5LN5	76	27766.497	365.349	458.310	<.0001	
SST	7	569.681	81.383	102.090	<.0001	

Core — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	135	95501.70	707.420	818.930	<.0001	R-Square= 0.309069
Year	33	20666.096	626.245	724.960	<.0001	CV = 69.05402
Quarter	3	180.134	60.045	69.510	<.0001	
NHF	16	2931.756	183.235	212.120	<.0001	
LT5LN5	76	53087.098	698.514	808.620	<.0001	
SST	7	587.064	83.866	97.090	<.0001	

Core East — 1979-2012 with call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	394	34440.970	87.414	107.530	<.0001	R-Square= 0.379208
Year	33	2667.439	80.831	99.440	<.0001	CV = 155.38
Quarter	3	368.965	122.988	151.290	<.0001	
NHF	16	228.492	14.281	17.570	<.0001	
Call sign	300	5958.319	19.861	24.430	<.0001	
LT5LN5	36	1931.923	53.665	66.020	<.0001	
SST	6	287.096	47.849	58.860	<.0001	

Core East — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	94	28482.651	303.007	338.580	<.0001	R-Square= 0.313605
Year	33	7427.141	225.065	251.490	<.0001	CV = 163.0317
Quarter	3	577.652	192.551	215.150	<.0001	
NHF	16	463.166	28.948	32.350	<.0001	
LT5LN5	36	2700.786	75.022	83.830	<.0001	
SST	6	414.795	69.133	77.250	<.0001	

Core West — 1979-2012 with call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	479	55072.067	114.973	141.380	<.0001	R-Square= 0.288605
Year	33	5512.981	167.060	205.430	<.0001	CV = 55.39409
Quarter	3	70.942	23.647	29.080	<.0001	
NHF	16	195.347	12.209	15.010	<.0001	
Call sign	381	11150.265	29.266	35.990	<.0001	
LT5LN5	39	14244.937	365.255	449.150	<.0001	
SST	7	342.011	48.859	60.080	<.0001	

Core West — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	98	43921.802	448.182	510.450	<.0001	R-Square= 0.230172
Year	33	12581.898	381.270	434.240	<.0001	CV = 57.55854
Quarter	3	140.538	46.846	53.350	<.0001	
NHF	16	1950.255	121.891	138.830	<.0001	
LT5LN5	39	24022.852	615.971	701.550	<.0001	
SST	7	382.523	54.646	62.240	<.0001	

South — 1979-2012 with call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	647	274394.30	424.103	518.680	<.0001	R-Square= 0.585099
Year	33	3861.833	117.025	143.120	<.0001	CV = 152.2414
Quarter	3	1034.145	344.715	421.590	<.0001	
NHF	16	1153.403	72.088	88.160	<.0001	
Call sign	503	26592.359	52.868	64.660	<.0001	
LT5LN5	74	30808.705	416.334	509.180	<.0001	
SST	18	7720.862	428.937	524.590	<.0001	

South — 1979-2012 without call sign

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	144	247801.94	1720.847	1855.460	<.0001	R-Square= 0.528395
Year	33	5440.506	164.864	177.760	<.0001	CV = 162.1403
Quarter	3	1383.045	461.015	497.080	<.0001	
NHF	16	1807.044	112.940	121.770	<.0001	
LT5LN5	74	55233.837	746.403	804.790	<.0001	
SST	18	9391.930	521.774	562.590	<.0001	

Table. 5. ANOVA table of GLM for bigeye CPUE standardization using operational catch and effort data of Japanese longline fisheries for core fishing areas in the Indian Ocean for 1952-2012.

Core — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	159	80466.820	506.081	778.870	<.0001	0.212866
						CV =
Year	60	10897.937	181.632	279.540	<.0001	44.95568
Quarter	3	991.274	330.425	508.530	<.0001	
NHF	16	1141.571	71.348	109.810	<.0001	
LT5LN5	73	36288.187	497.098	765.050	<.0001	
SST	7	966.083	138.012	212.400	<.0001	

Core East — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	117	17482.58	149.424	243.900	<.0001	0.143995
						CV =
Year	60	4509.430	75.157	122.680	<.0001	40.20979
Quarter	3	222.505	74.168	121.060	<.0001	
NHF	16	1088.108	68.007	111.000	<.0001	
LT5LN5	32	8522.792	266.337	434.730	<.0001	
SST	6	58.626	9.771	15.950	<.0001	

Core West — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	121	5477.79	45.271	85.530	<.0001	0.152719
						CV =
Year	60	1784.113	29.735	56.180	<.0001	38.57168
Quarter	3	49.366	16.455	31.090	<.0001	
NHF	16	279.446	17.465	33.000	<.0001	
LT5LN5	36	2453.526	68.154	128.770	<.0001	
SST	6	21.782	3.630	6.860	<.0001	

South: 15S-35S — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	171	165910.78	970.239	1084.030	<.0001	0.337554
						CV =
Year	60	21815.469	363.591	406.230	<.0001	123.5027
Quarter	3	7909.620	2636.540	2945.750	<.0001	
NHF	16	1760.256	110.016	122.920	<.0001	
LT5LN5	74	15973.940	215.864	241.180	<.0001	
SST	18	7751.588	430.644	481.150	<.0001	

Core — **L1: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	163	26181.566	160.623	284.850	<.0001	0.228758
						CV =
Year	60	4151.533	69.192	122.710	<.0001	43.84062
Quarter	3	257.748	85.916	152.360	<.0001	
NHF	16	319.173	19.948	35.380	<.0001	
LT5LN5	77	11619.646	150.904	267.620	<.0001	
SST	7	414.861	59.266	105.100	<.0001	

Core East — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	124	63349.540	510.883	773.490	<.0001	0.24969
						CV =
Year	58	8454.265	145.763	220.690	<.0001	47.82759
Quarter	3	1172.041	390.680	591.500	<.0001	
NHF	16	572.924	35.808	54.210	<.0001	
LT5LN5	40	16508.525	412.713	624.860	<.0001	
SST	7	1262.853	180.408	273.140	<.0001	

Core West — **L1: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	124	20315.732	163.837	285.320	<.0001	0.26321
						CV =
Year	58	3123.416	53.852	93.780	<.0001	47.11809
Quarter	3	336.490	112.163	195.330	<.0001	
NHF	16	183.006	11.438	19.920	<.0001	
LT5LN5	40	5478.694	136.967	238.520	<.0001	
SST	7	520.048	74.293	129.380	<.0001	

South: 15S-35S — **L1: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	171	34690.547	202.869	260.760	<.0001	0.34605
						CV =
Year	60	3730.124	62.169	79.910	<.0001	120.8135
Quarter	3	1843.017	614.339	789.640	<.0001	
NHF	16	358.838	22.427	28.830	<.0001	
LT5LN5	74	4327.854	58.485	75.170	<.0001	
SST	18	1554.802	86.378	111.030	<.0001	

Core — **L5: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	163	6396.636	39.243	89.580	<.0001	0.272515
						CV =
Year	60	1321.633	22.027	50.280	<.0001	37.75781
Quarter	3	48.530	16.177	36.930	<.0001	
NHF	16	102.521	6.408	14.630	<.0001	
LT5LN5	77	2975.132	38.638	88.200	<.0001	
SST	7	73.861	10.552	24.090	<.0001	

Core East — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	121	1538.725	12.717	30.860	<.0001	0.196814
						CV =
Year	60	537.872	8.965	21.760	<.0001	33.27041
Quarter	3	13.926	4.642	11.270	<.0001	
NHF	16	89.426	5.589	13.560	<.0001	
LT5LN5	36	613.403	17.039	41.350	<.0001	
SST	6	21.580	3.597	8.730	<.0001	

Core West — **L5: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	124	4721.585	38.077	85.960	<.0001	0.310622
						CV =
Year	58	997.686	17.201	38.830	<.0001	40.71993
Quarter	3	80.340	26.780	60.460	<.0001	
NHF	16	45.017	2.814	6.350	<.0001	
LT5LN5	40	1329.500	33.238	75.040	<.0001	
SST	7	106.969	15.281	34.500	<.0001	

South: 15S-35S — **L5: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	171	8203.563	47.974	70.600	<.0001	0.341991
						CV =
Year	60	1174.944	19.582	28.820	<.0001	93.03038
Quarter	3	476.712	158.904	233.830	<.0001	
NHF	16	153.811	9.613	14.150	<.0001	
LT5LN5	74	1373.305	18.558	27.310	<.0001	
SST	18	351.532	19.530	28.740	<.0001	

Table. 6. ANOVA table of GLM for yellowfin CPUE standardization using operational catch and effort data of Japanese longline fisheries for core fishing areas in the Indian Ocean for 1952-2012.

Core — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	159	269036.46	1692.053	2608.810	<.0001	0.475287
						CV =
Year	60	55571.644	926.194	1428.010	<.0001	40.3134
Quarter	3	247.060	82.353	126.970	<.0001	
NHF	16	2370.420	148.151	228.420	<.0001	
LT5LN5	73	63506.004	869.945	1341.280	<.0001	
SST	7	1295.846	185.121	285.420	<.0001	

Core East — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	117	122251.25	1044.883	1774.660	<.0001	0.550357
						CV =
Year	60	21118.927	351.982	597.820	<.0001	45.29316
Quarter	3	279.912	93.304	158.470	<.0001	
NHF	16	466.084	29.130	49.480	<.0001	
LT5LN5	32	8265.225	258.288	438.680	<.0001	
SST	6	1332.770	222.128	377.270	<.0001	

Core West — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	124	150471.59	1213.481	1849.790	<.0001	0.443158
						CV =
Year	58	40079.745	691.030	1053.390	<.0001	37.50481
Quarter	3	239.563	79.854	121.730	<.0001	
NHF	16	1541.477	96.342	146.860	<.0001	
LT5LN5	40	22353.610	558.840	851.880	<.0001	
SST	7	617.083	88.155	134.380	<.0001	

South: 15S-35S — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	171	365558.40	2137.768	2357.320	<.0001	0.525635
						CV =
Year	60	16954.781	282.580	311.600	<.0001	157.7832
Quarter	3	1561.069	520.357	573.800	<.0001	
NHF	16	1747.297	109.206	120.420	<.0001	
LT5LN5	74	94349.260	1274.990	1405.930	<.0001	
SST	18	13234.359	735.242	810.750	<.0001	

Core — **L1: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	163	90293.242	553.946	967.710	<.0001	0.501906
						CV =
Year	60	20231.044	337.184	589.040	<.0001	39.83305
Quarter	3	88.128	29.376	51.320	<.0001	
NHF	16	714.537	44.659	78.020	<.0001	
LT5LN5	77	17477.165	226.976	396.510	<.0001	
SST	7	467.400	66.771	116.650	<.0001	

Core East — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	121	39611.688	327.369	638.140	<.0001	0.573512
						CV =
Year	60	36342.782	605.713	1180.710	<.0001	44.7727
Quarter	3	554.856	184.952	360.520	<.0001	
NHF	16	231.620	14.476	28.220	<.0001	
LT5LN5	36	2033.884	56.497	110.130	<.0001	
SST	6	448.545	74.758	145.720	<.0001	

Core West — **L1: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	124	50863.693	410.191	699.770	<.0001	0.466999
						CV =
Year	58	14016.267	241.660	412.260	<.0001	37.20246
Quarter	3	130.697	43.566	74.320	<.0001	
NHF	16	451.084	28.193	48.100	<.0001	
LT5LN5	40	6798.691	169.967	289.960	<.0001	
SST	7	160.635	22.948	39.150	<.0001	

South: 15S-35S — **L1: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	171	84765.317	495.704	647.170	<.0001	0.567725
						CV =
Year	60	4320.198	72.003	94.000	<.0001	124.348
Quarter	3	344.206	114.735	149.790	<.0001	
NHF	16	345.342	21.584	28.180	<.0001	
LT5LN5	74	24200.496	327.034	426.960	<.0001	
SST	18	2791.858	155.103	202.500	<.0001	

Core — **L5: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	163	22124.250	135.732	271.330	<.0001	0.531527
						CV =
Year	60	5091.472	84.858	169.630	<.0001	39.38812
Quarter	3	38.092	12.697	25.380	<.0001	
NHF	16	237.237	14.827	29.640	<.0001	
LT5LN5	77	4661.865	60.544	121.030	<.0001	
SST	7	123.070	17.581	35.150	<.0001	

Core East — **Operational: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	121	10696.377	88.400	205.620	<.0001	0.620135
						CV =
Year	60	1979.296	32.988	76.730	<.0001	44.00066
Quarter	3	57.789	19.263	44.810	<.0001	
NHF	16	50.370	3.148	7.320	<.0001	
LT5LN5	36	343.537	9.543	22.200	<.0001	
SST	6	95.427	15.905	36.990	<.0001	

Core West — **L5: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	124	11273.305	90.914	174.610	<.0001	0.477863
						CV =
Year	58	3416.814	58.911	113.140	<.0001	36.5092
Quarter	3	47.551	15.850	30.440	<.0001	
NHF	16	154.760	9.672	18.580	<.0001	
LT5LN5	40	1862.550	46.564	89.430	<.0001	
SST	7	36.250	5.179	9.950	<.0001	

South: 15S-35S — **L5: 1952-2012**

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	171	23250.111	135.966	189.300	<.0001	0.582224
						CV =
Year	60	1119.185	18.653	25.970	<.0001	101.5938
Quarter	3	81.375	27.125	37.760	<.0001	
NHF	16	131.226	8.202	11.420	<.0001	
LT5LN5	74	8701.580	117.589	163.710	<.0001	
SST	18	730.374	40.576	56.490	<.0001	

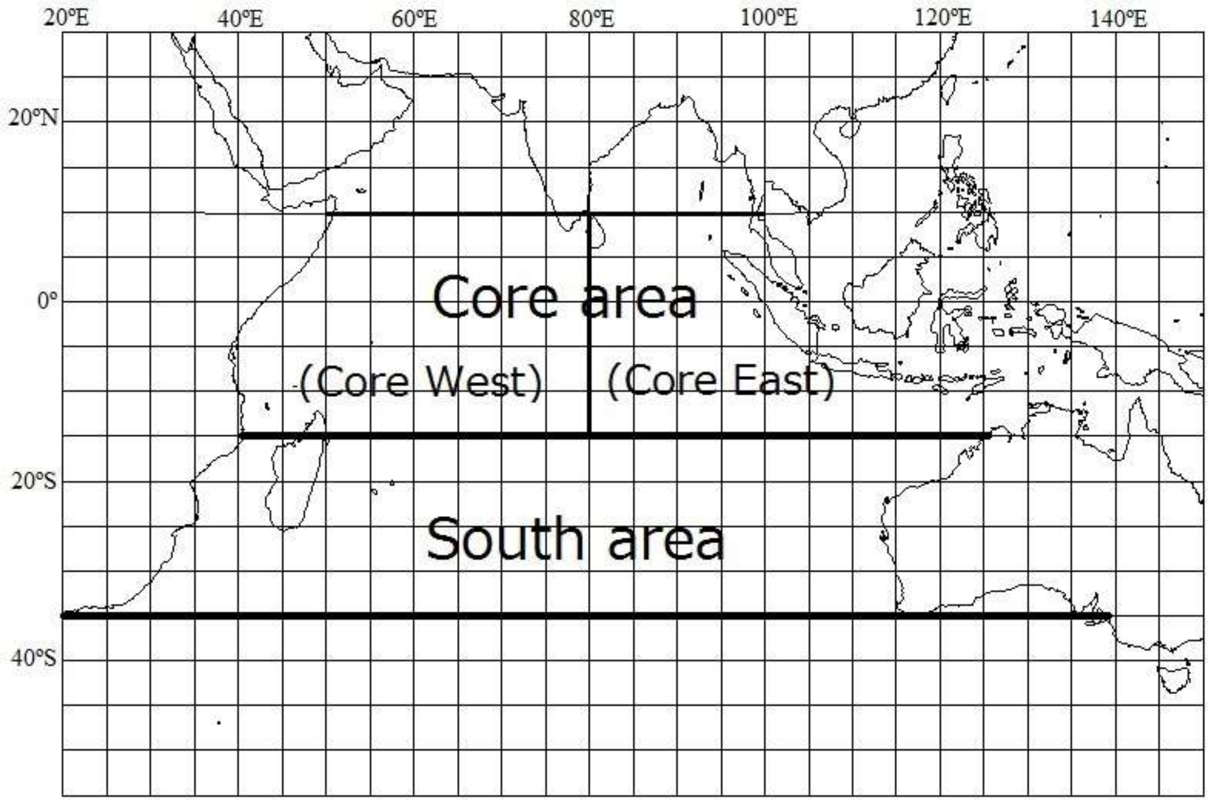


Fig. 1 Area definition used in this analysis.

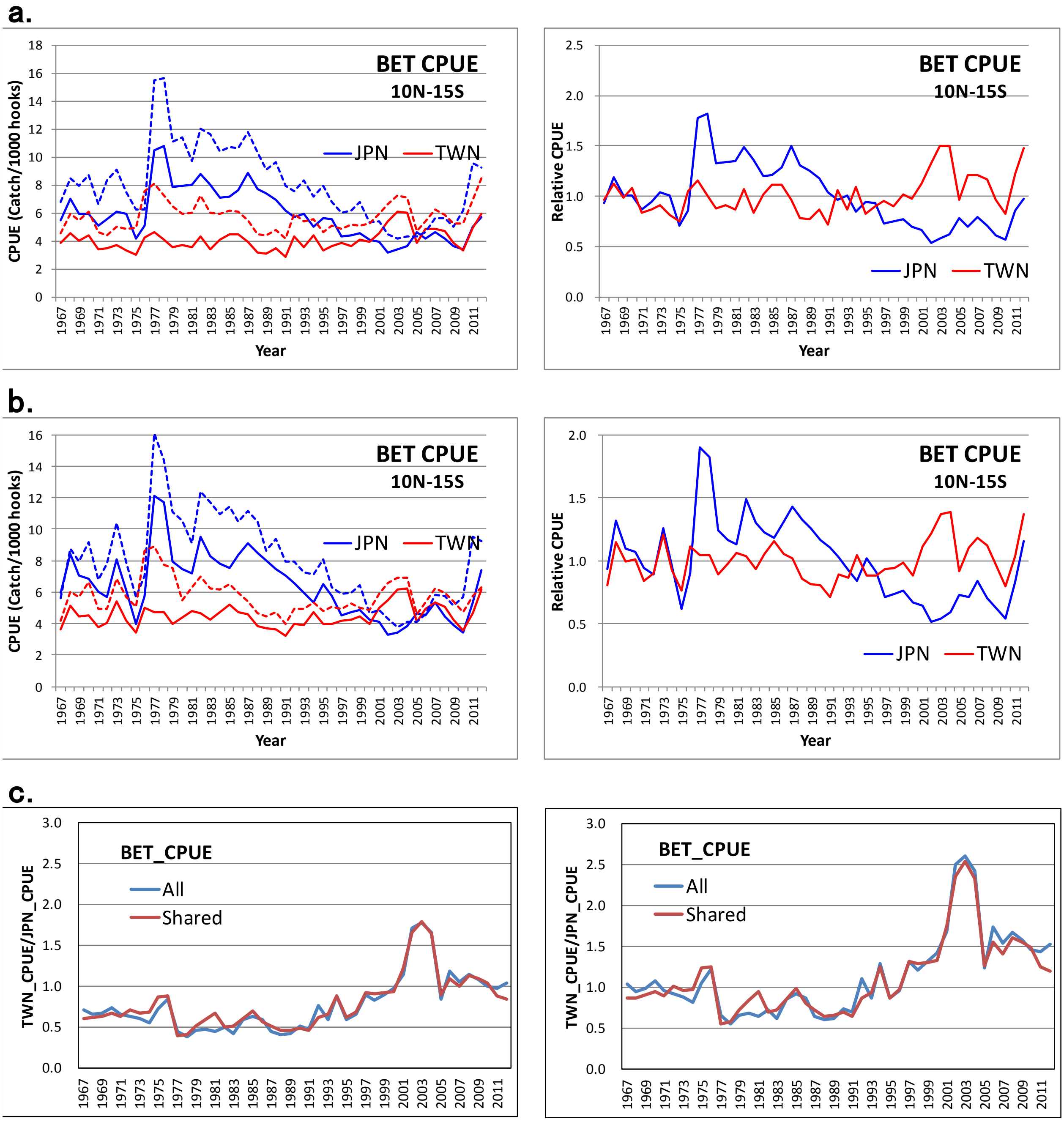


Fig. 2 Standardized bigeye CPUE derived from all strata (a) and that from shared strata (b) in core areas for Japanese and Taiwan-China longline fishery in real scale (left) with nominal CPUE and relative scale (right), and ratio of CPUE of both fleets (c).

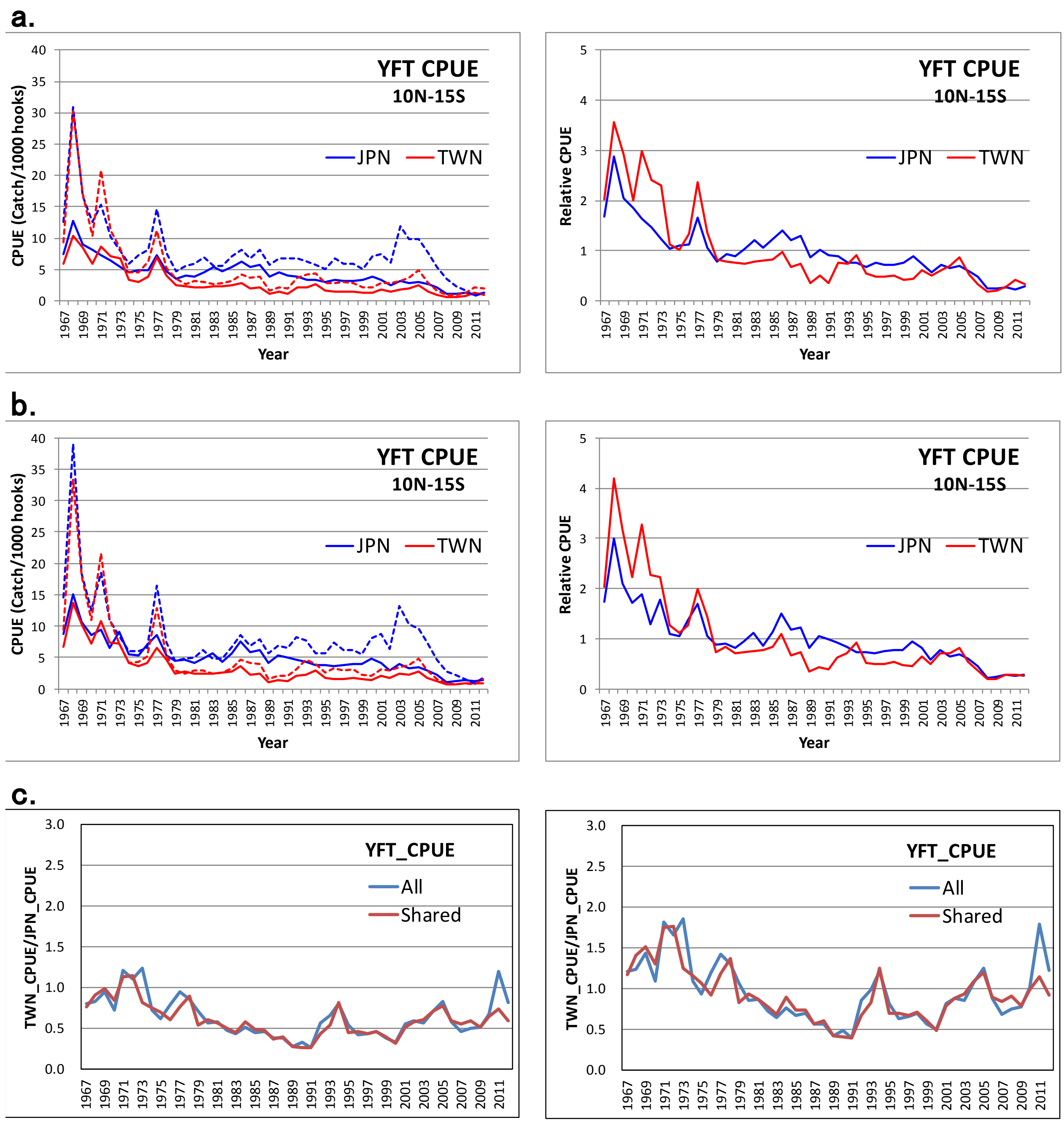


Fig. 3 Standardized yellowfin CPUE derived from all strata (a) and that from shared strata (b) in core areas for Japanese and Taiwan-China longline fishery in real scale (left) with nominal CPUE and relative scale (right), and ratio of CPUE of both fleets (c).

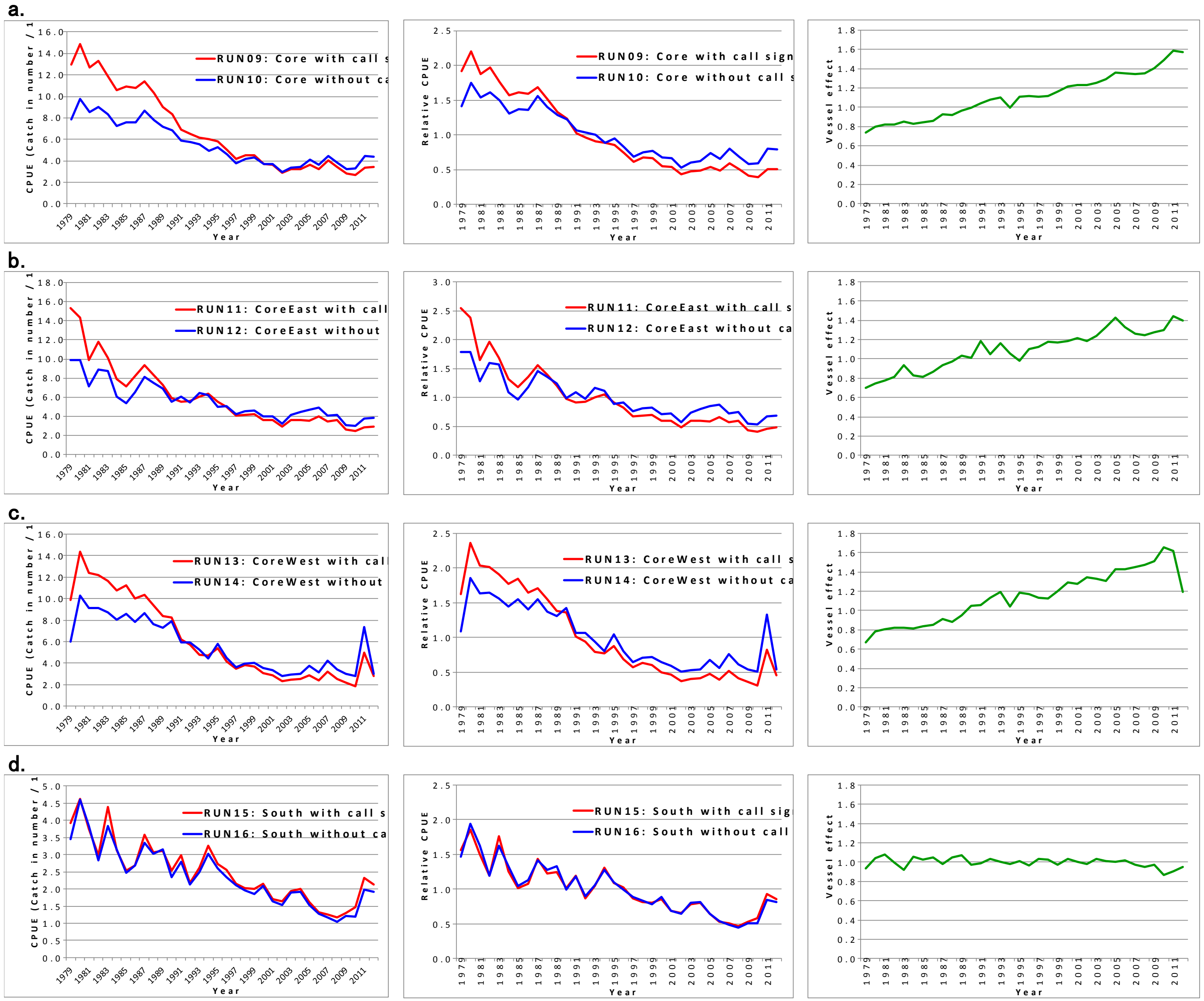


Fig. 4 Standardized bigeye CPUE of Japanese longline fishery from 1979 to 2012 using operational data with (red) and without (blue) applying vessel ID as explanatory variable in the model in all (a), east (b) and west (c) core areas and south area. CPUE in real scale (left), CPUE in relative scale (middle) and ratio of relative CPUEs standardized with and without Vessel ID.

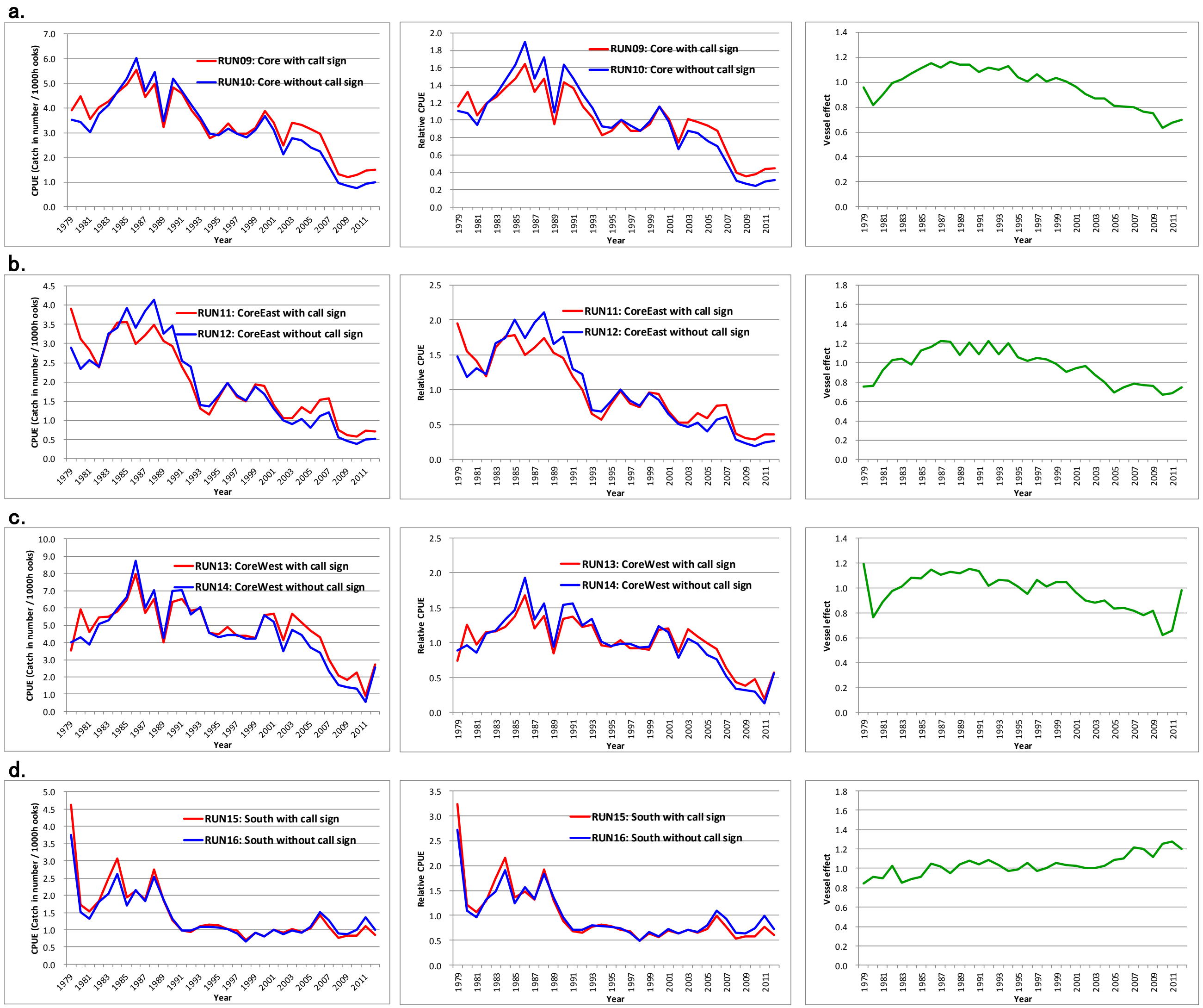


Fig. 5 Standardized yellowfin CPUE of Japanese longline fishery from 1979 to 2012 using operational data with (red) and without (blue) applying vessel ID as explanatory variable in the model in all (a), east (b) and west (c) core areas and south area. CPUE in real scale (left), CPUE in relative scale (middle) and ratio of relative CPUEs standardized with and without Vessel ID.

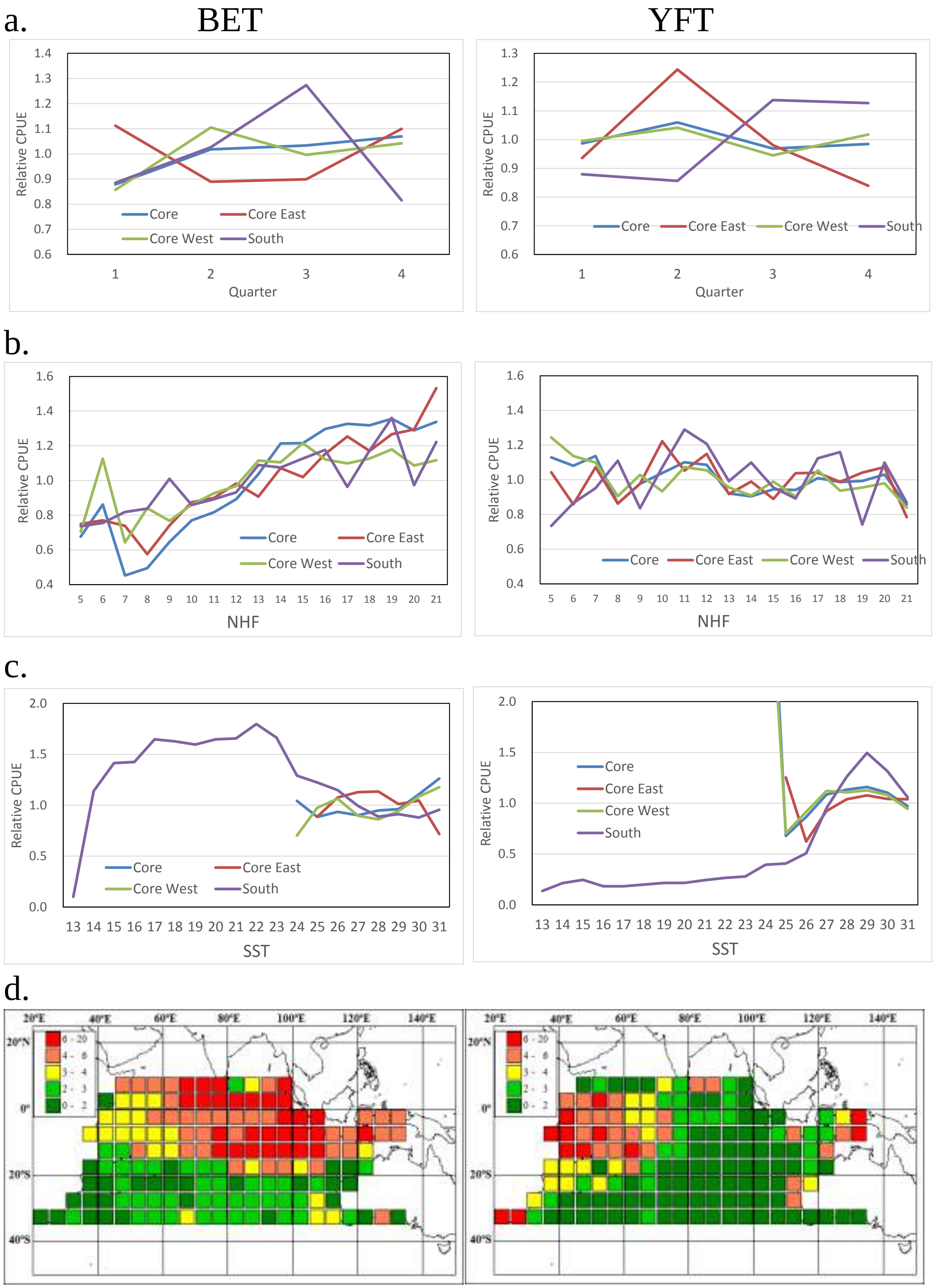


Fig. 6 Effect of Quarter (a), the number of hooks between float (b), sea surface temperature (c) and 5 degree square (d) in the standardization of Japanese longline CPUE for bigeye (left) and yellowfin (right)

tuna.

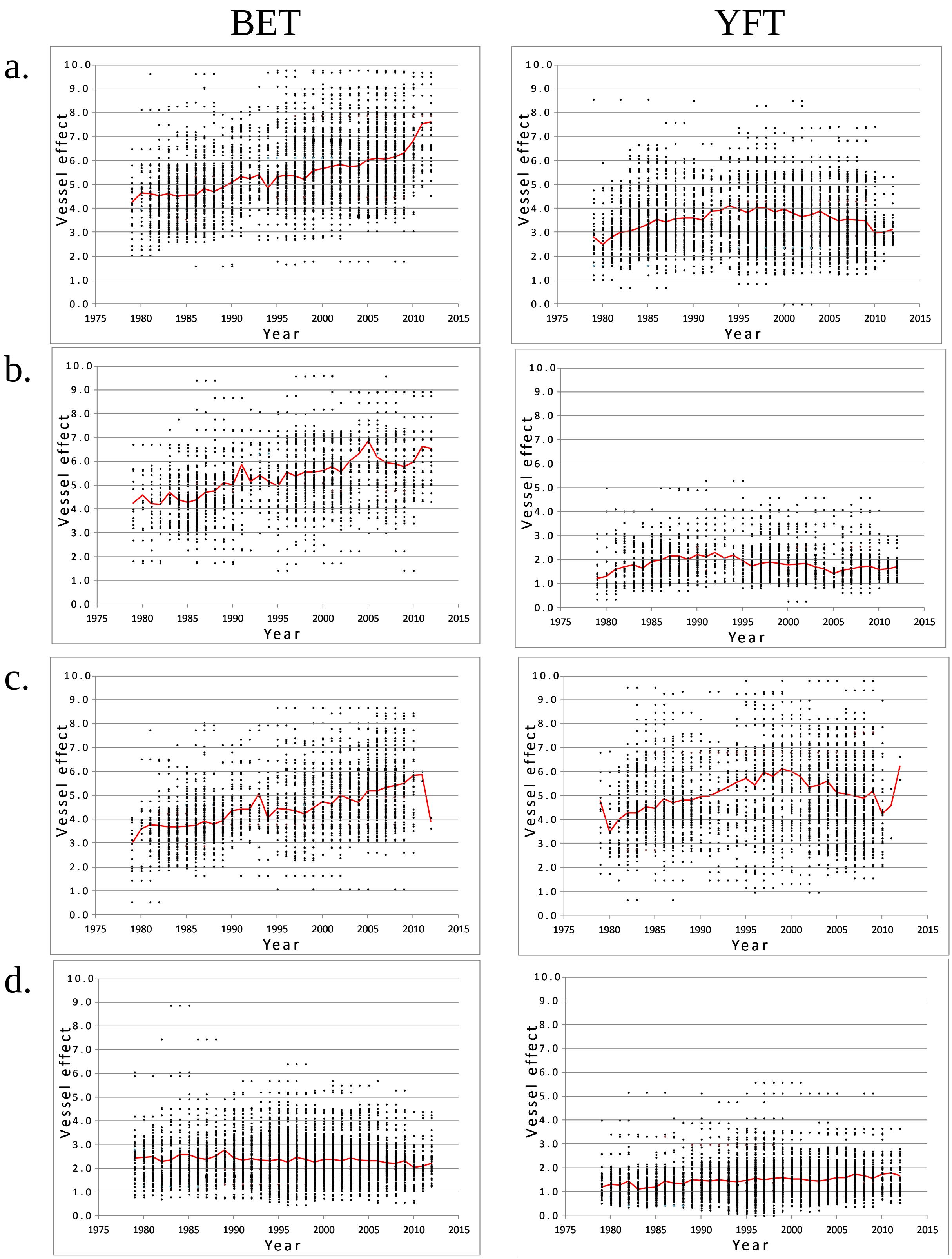


Fig. 7 Effect of vessel ID (call sign) in the standardization of Japanese longline CPUE for bigeye (left) and yellowfin (right) tuna in whole core (a), east core (b), west core (c) and south (d) areas. Red line means annual average of vessel effect weighted by the number of set made by each cessel.

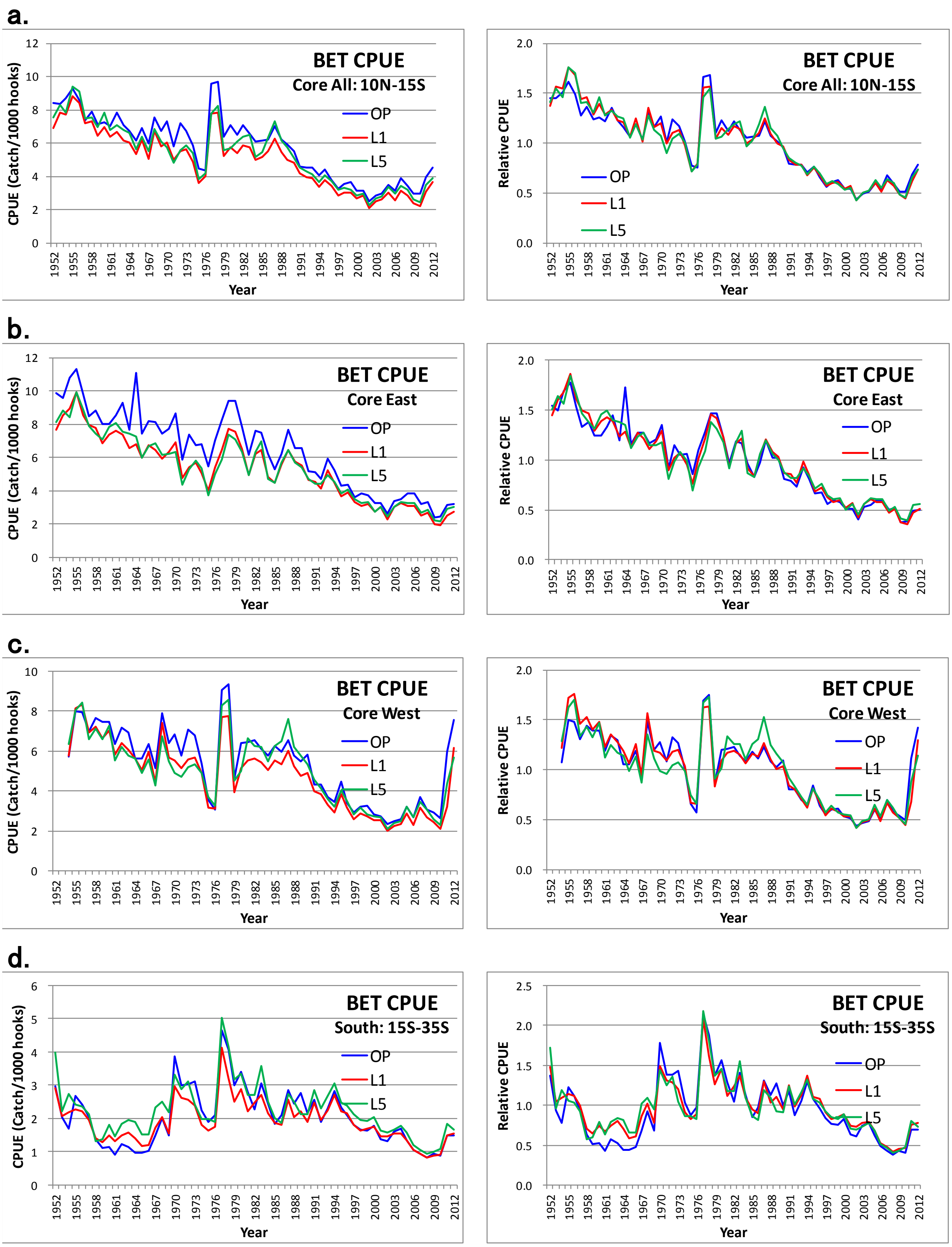


Fig. 8 Standardized bigeye CPUE of Japanese longline fishery from 1952 to 2012 using operational data without applying vessel ID as explanatory variable in the model in all (a), east (b) and west (c) core areas and south area. CPUE in real (left), and relative (right) scale.

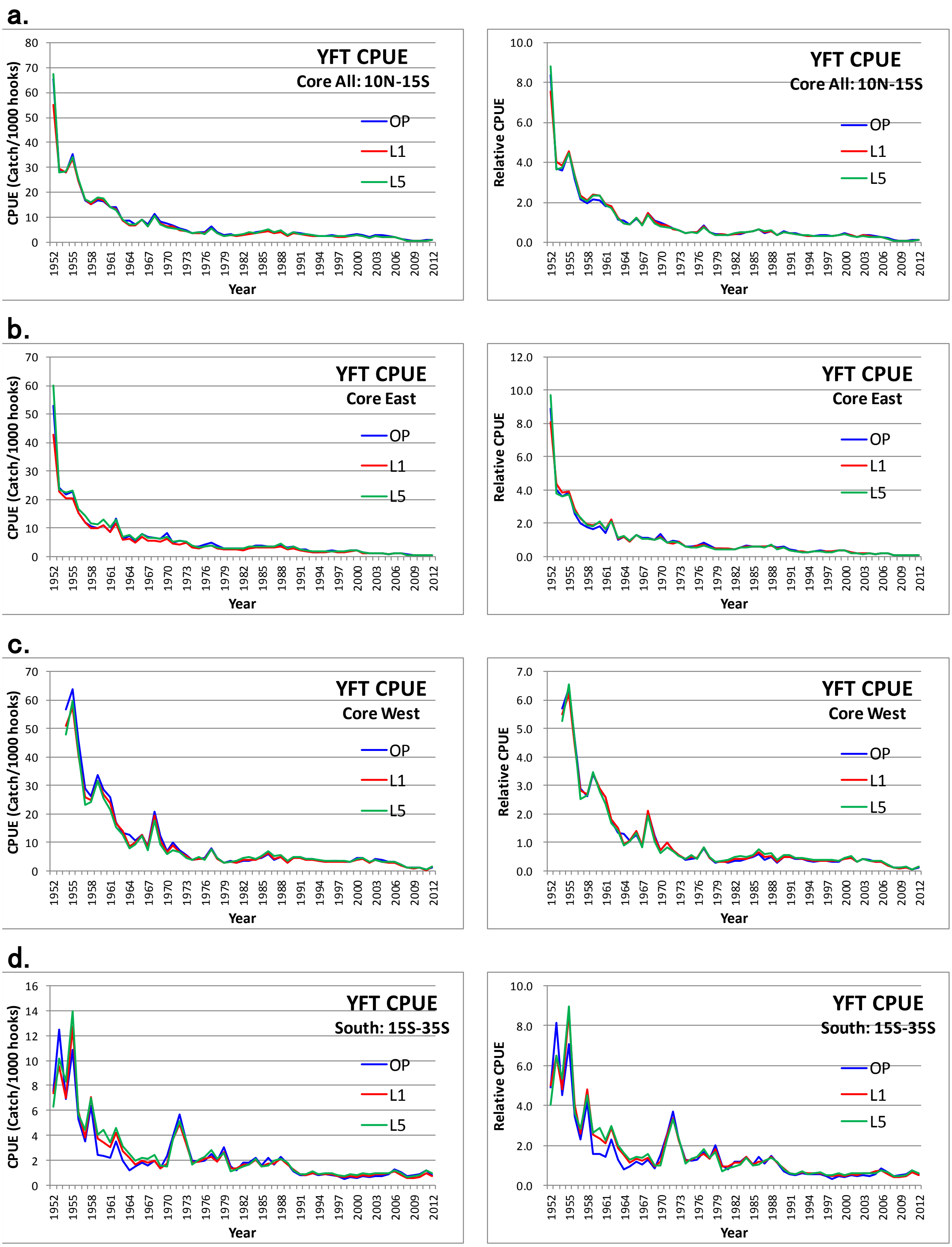
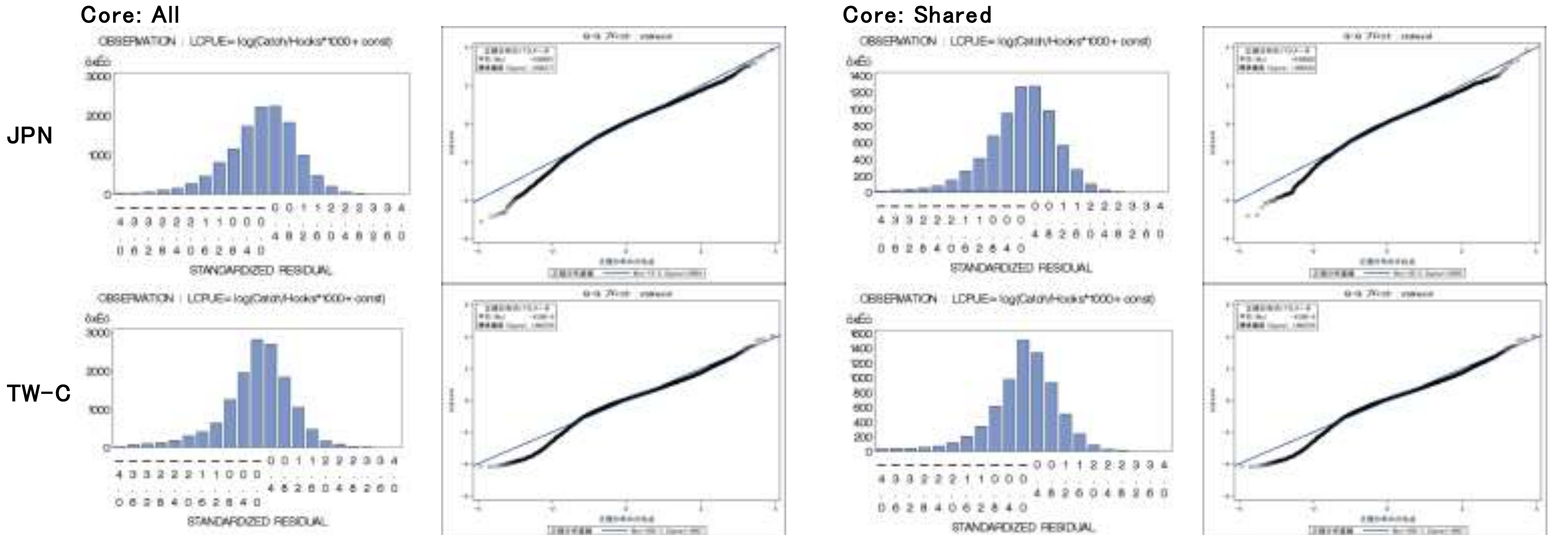
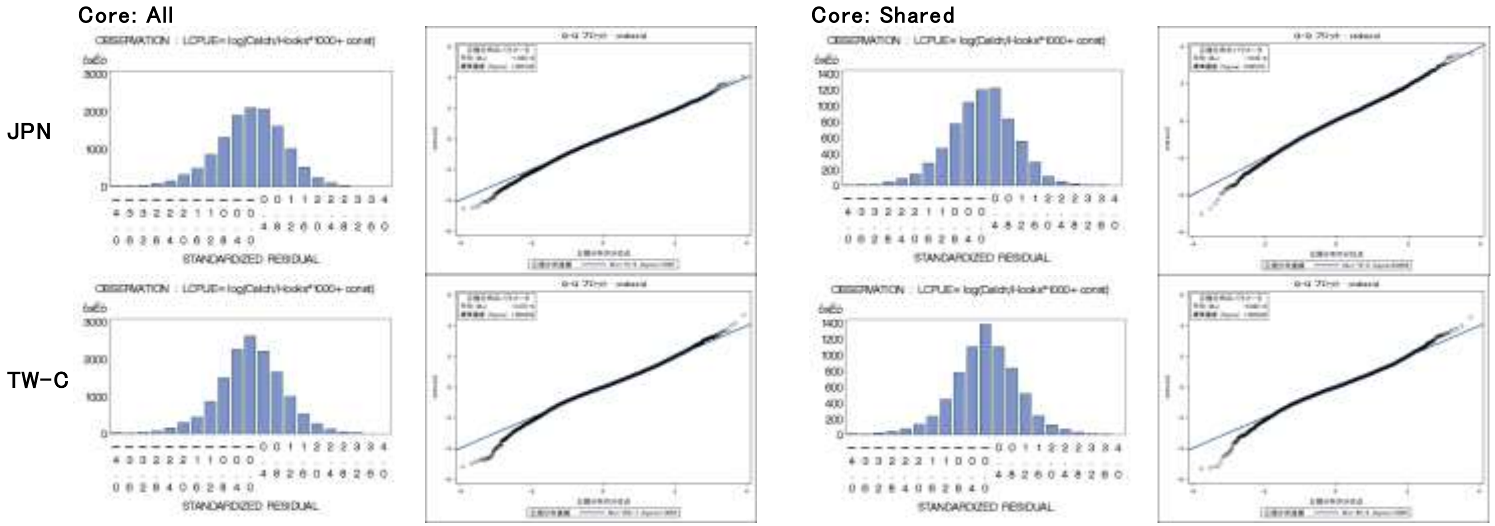


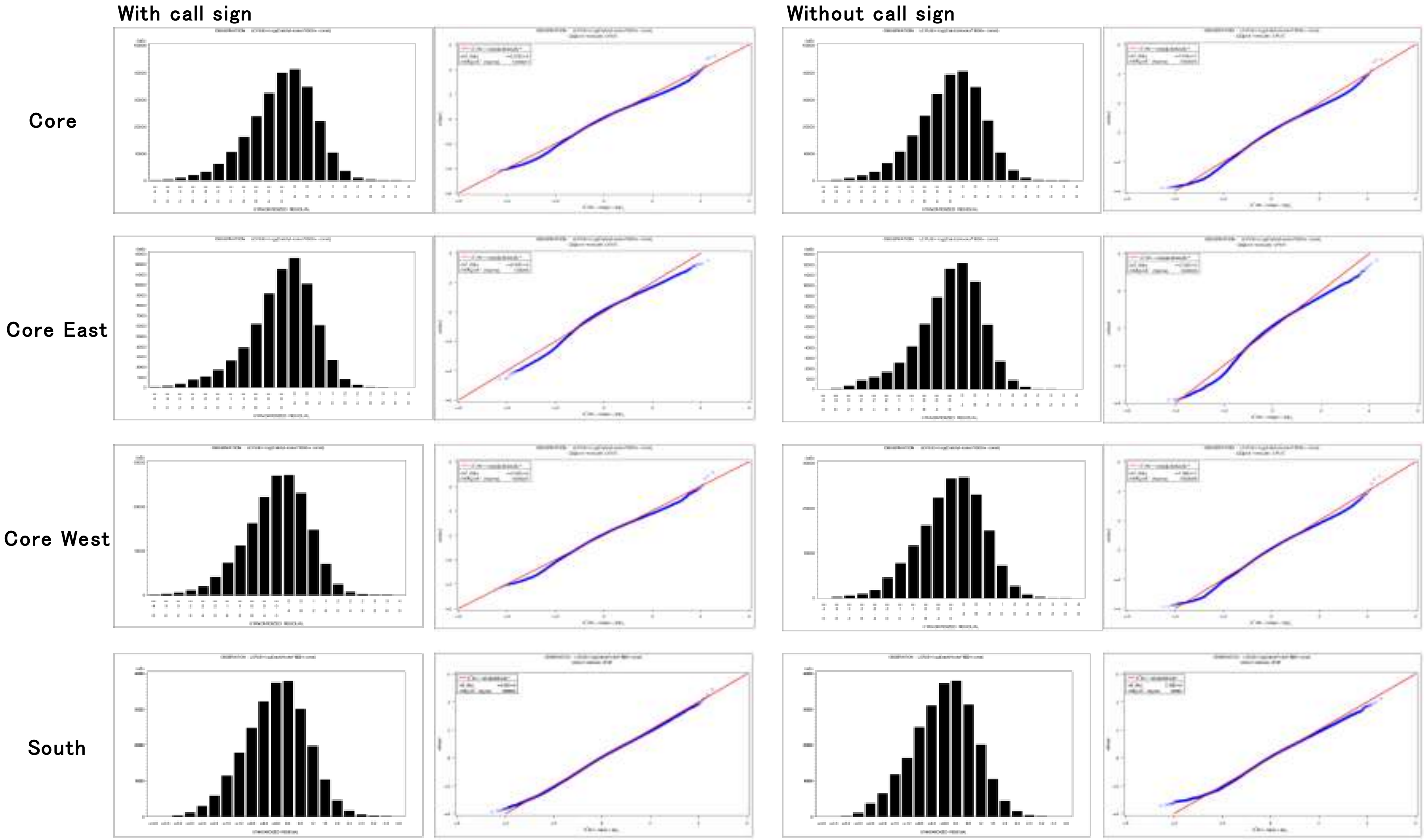
Fig. 9 Standardized yellowfin CPUE of Japanese longline fishery from 1952 to 2012 using operational data without applying vessel ID as explanatory variable in the model in all (a), east (b) and west (c) core areas and south area. CPUE in real (left), and relative (right) scale.



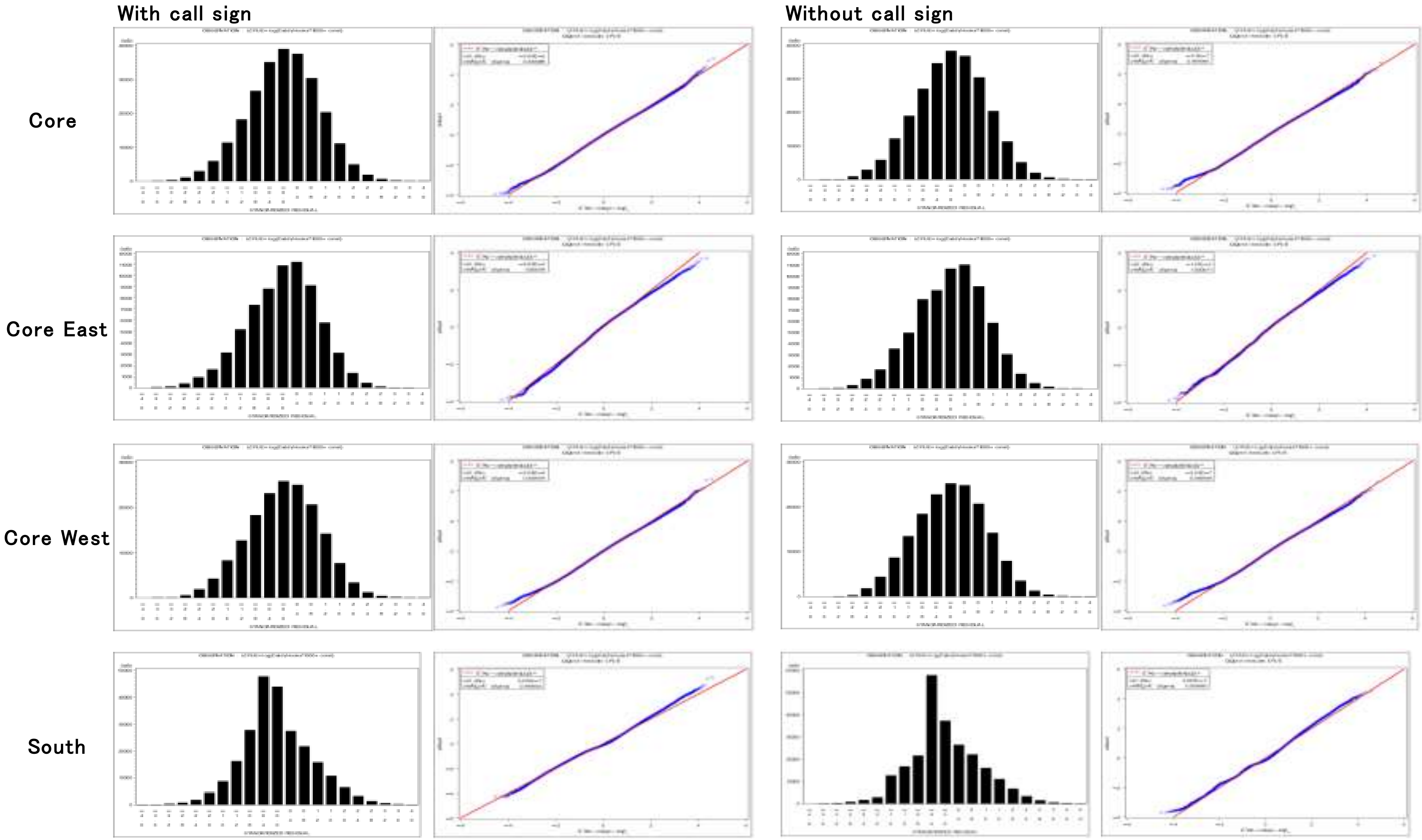
Appendix Fig. 1 Standardized residuals of standardization of bigeye CPUE for Japanese and Taiwan-China longline fishery for all and shared strata in core fishing area expressed as histogram and QQ plot.



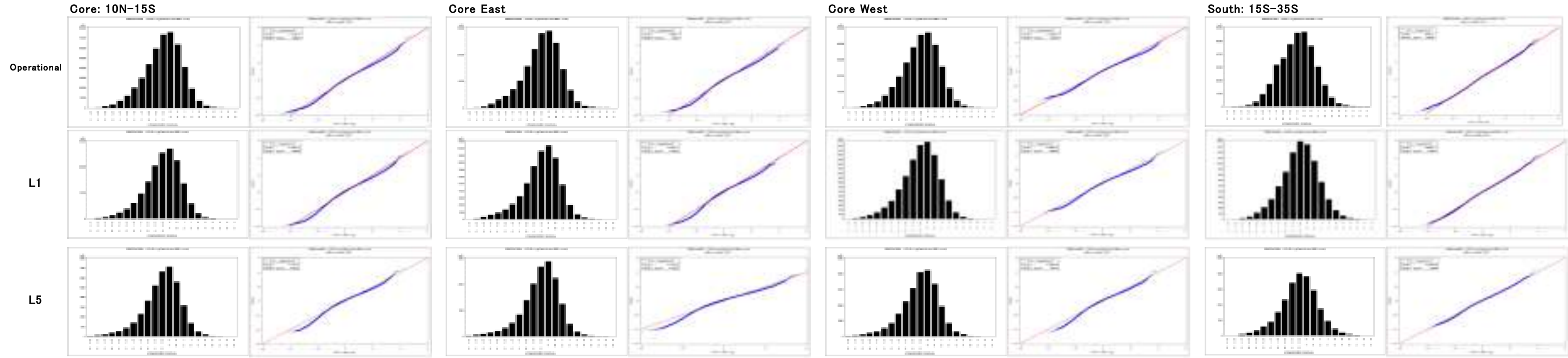
Appendix Fig. 2 Standardized residuals of standardization of yellowfin CPUE for Japanese and Taiwan-China longline fishery for all and shared strata in core fishing area expressed as histogram and QQ plot.



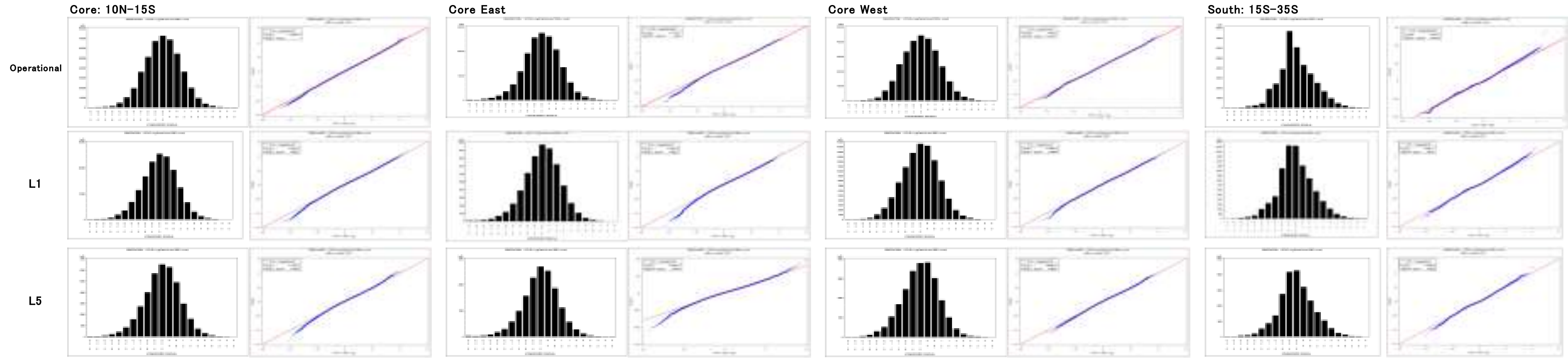
Appendix Fig. 3 Standardized residuals of standardization of bigeye CPUE of Japanese longline fishery using operational data with and without applying vessel ID (call sign) as explanatory variable in the model for all, east and west core areas and south area expressed as histogram and QQ plot.



Appendix Fig. 4 Standardized residuals of standardization of yellowfin CPUE of Japanese 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.



Appendix Fig. 5 Standardized residuals of standardization of bigeye CPUE of Japanese longline fishery using operational, L1 and L5 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. 6 Standardized residuals of standardization of yellowfin CPUE of Japanese longline fishery using operational, L1 and L5 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.