Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM

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Abstract

Standardization of Japanese longline CPUE for bigeye tuna was conducted up to 2019 by using GLM (generalized linear model, log normal error structured). The effects of season (month or quarter), subarea or LT5LN5 (five degree latitude-longitude block), SST (sea surface temperature), NHF (number of hooks between floats) and material of main line, and several interactions between them were used for standardization. The trend of CPUE slightly differed by area, but high jump in 1977 and 1978, slight decrease after that, and increasing trend in the recent few years were observed.

1. Introduction

Bigeye tuna is one of main target species for Japanese longline fishery in the Indian Ocean. Its abundance indices are very important for stock assessment of this species because they have high spatial and temporal coverage, and detailed information on catch and effort is available through logbooks.

Satoh and Okamoto (2012), Matsumoto et al. (2013; 2015; 2016), Ochi et al. (2014a) and Matsumoto (2017; 2018; 2019) reported area aggregated annual standardized Japanese longline CPUE for bigeye tuna based on GLM (generalized linear model, log normal error structured) for an indicator of the stock. Also, area specific CPUE for integrated models was reported at the IOTC WPTT meetings (Ochi et al. 2014a, Matsumoto et al. 2015; 2016, Matsumoto, 2017; 2018; 2019). Methods of standardization in this study are similar to above mentioned studies.

Although stock assessment of Indian Ocean bigeye tuna is not planned this year, it was aimed to conduct continuity analysis and to see the trend of CPUE including recent trend.

2. Materials and methods

Area and sub-area definition:

Sub-area definition for area aggregated CPUE used in this study (Fig. 1), which consists of seven areas, is the same as those used in the IOTC bigeye assessment in 2006 (Okamoto and Shono 2006) and in 2010 (Okamoto and Shono 2010), and updated CPUE submitted at 2012 - 2019 IOTC WPTT meetings (Satoh and Okamoto 2012, Matsumoto et al. 2013, Ochi et al. 2014a, Matsumoto et al. 2015; 2016, Matsumoto 2017; 2018; 2019). Main fishing ground of Japanese longline fishery for bigeye was divided into seven areas and CPUE standardization was done for three cases of area combinations, tropical (areas 1-5), south (areas 6 & 7) and whole (areas 1-7) Indian Ocean. Area 67 (central south area) was not used in this study because there are few fishing effort by Japanese longline. Area aggregated CPUE was standardized for each of three area categories, tropical, south and whole Indian Ocean.

Area definition for area specific CPUE used in this study (Fig. 2) is the same as that for Matsumoto

(2019), which changed from previous studies to harmonize with that for Indian Ocean joint longline CPUE analysis (e.g. Hoyle et al., 2017). Fishing ground was divided into four areas: R1 (northwest area), R2 (northeast area), R3 (southwest area) and R4 (southeast area).

Environmental factors:

As environmental factors, which are available for the period of 1952-2019, SST (sea surface temperature) was used. The original SST data, whose resolution is 1-degree latitude and 1-degree longitude by month, were downloaded from NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA) http://near-goos1.jodc.go.jp/index_j.html. The SST data for several month during 2014-2017 were replaced by SST data for the same month for nearest past year because these data were unreleased in the data base. The SST in integer value was used as a continuous variable in the GLM models with subareas.

Catch and effort data used:

The Japanese longline catch (in number) and effort statistics from 1952 up to 2019 (all available period) were used. Data for 2019 were preliminary. Start year was usually 1960 in the previous studies for using in the stock assessment models. In this study it is 1952 (longest series) for comparing the trend of CPUEs with those by Indian Ocean longline CPUE collaborative analyses, which uses longest series. Operational level (set by set) logbook data were used, which include the number of hooks between floats (NHF), were used for the analysis. CPUE was defined as the number of fish caught per 1,000 hooks. As the NHF information is only partly available for the period before 1975, NHF was regarded to be 5 in this period if there is no information. Main line material was categorized into two: 1 = Nylon and 2 = other, which is not available before 1993. The main line material was assumed as 'other' from 1975 to 1993 except as NHF was over 18 from 1990 to 1993, in which it was assumed as 'Nylon'. Fig. 3-Fig. 5 show geographical distribution of catch in each decade, geographical distribution of fishing effort and nominal CPUE for bigeye and yellowfin tuna, and geographical distribution of annual catch in recent years, respectively.

CPUE standardizations by GLM

CPUEs based on the number of catch were used; (the number of fish caught) / (the number of hooks) * 1000. Initial models used for GLM analyses (CPUE log normal error structured model) are as follows;

<u>Area aggregated CPUE (annual):</u>

Log [CPUE +const] = μ + year + month + area + NHFC + SST + ML + year*area + month*area + area*NHFC + area*SST + NHFC*ML + error

<u>Area aggregated CPUE (quarterly):</u>

Log [CPUE +const] = μ + year + quarter + area + NHFC + SST + ML + year*quarter *area + area*NHFC + area*SST + NHFC*ML + error

<u>Area specific CPUE (quarterly):</u>

Log [CPUE +const] = μ + year + quarter + NHFC + ML + SST + LT5LN5 + year*quarter + NHFC*ML +

error

where

Log: natural logarithm,

CPUE: catch in number of bigeye per 1000 hooks,

const: 10% of overall mean of CPUE,

μ: intercept,

year: effect of year,

month: effect of fishing season (month),

area: effect of sub-area,

NHFC: effect of gear type (class of the number of hooks between floats). The number of hooks between floats (NHF) was divided into 6 classes (NHFC 1: 5-7, NHFC 2: 8-10, NHFC 3: 11-13, NHFC 4: 14-16, NHFC 5: 17-19, NHFC 6: 20-21),

SST: effect of SST (sea surface temperature),

ML: effect of material of main line,

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

quarter: effect of fishing season (quarter),

error ~ normal $(0, \sigma^2)$.

Input variables for the model was selected 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.

Effect of year was obtained by the method used in Shono and Ogura (1999) that uses lsmean of Year-Area interaction as the following equation except for area specific CPUE.

$CPUE_i = \Sigma W_j * (\exp(\text{lsmean}(\text{year } i*\text{area }_j)) - \text{constant})$

where $CPUE_i$ = CPUE in year i, W_j = area rate of Area j, ($\Sigma W_j = 1$), lsmean (year*area_{ij}) = least square mean of year-area interaction in year i and area j, constant = 10% of overall mean of CPUE. As for area aggregated CPUE in the tropical and whole Indian Ocean which includes Areas 1 and 3, CPUE in 2010, 2011 2015-2016 and 2017 was calculated using area rate without Area 1, Area 1 & 3 Area 1 and Area 1 & 2, respectively because no effort was observed in these year and area due to piracy activities (Fig. 4, **Fig. 5**). Time period of standardization was 1952-2019 for all CPUEs.

As for alternative method, area aggregated CPUE (annual base) was standardized using the effect of LT5LN5 instead of subarea. The models are as follows.

Area aggregated CPUE (annual, with LT5LN5):

Log [CPUE +const] = μ + year + month + LT5LN5 + NHFC + SST + ML + NHFC*ML + error

In this model, SST (integer value) was incorporated as categorical value. The results were compared with those with the effect of subarea. In these models, effect of year was obtained using the following equation.

$CPUE_i$ = exp(lsmean(year i)) - constant

3. Results and discussion

Area aggregated CPUE

Trends of area aggregated CPUE in each region (tropical, south and whole of the Indian Ocean) are shown in Fig. 6 (annual) and Fig. 7 (quarterly). In the tropical Indian Ocean, CPUE increased from around 5.1 (real scale) in 1952 to 8.8 in 1956, and slightly decreased to 4.8 in 1976. It suddenly jumped up to around 10 in 1977 and 1978 and then it declined and became stable until around 1990 with some fluctuation, after which it had continuously decreased to 3.0 in 2002. CPUE after 2009 shows increasing trend with fluctuation. The standardized CPUE in the south region was stable during 1959-1967, sharply increased during 1968-1970 and then showed fluctuation or decreasing trend. As a result, CPUE in the whole Indian Ocean, which had been in the same level around 4 to 7 until 1976 and increased to around 7 in 1977 and 1978 and after that showed slightly decreasing trend with fluctuation. It increased during 2009-2012, and decreased again after that. Comparatively large difference between standardized and nominal CPUE (scaled) is seen in the tropical area, though not apparent in the south area. This is considered to be due to the development of fishing gear (deep longline and nylon material) which was pronounced in the tropical area (Satoh and Okamoto, 2012). Large difference between two CPUEs in the tropical area in recent years may be also due to the shift of fishing ground to the east area, where bigeye CPUE is usually higher, by the influence of piracy activities. Results of ANOVA are shown in Table 1, and distributions of the standardized residual and QQ-plot for annual and quarterly CPUE are shown in Fig. 8 and Fig. 9, respectively. Distributions of the standardized residual did not show remarkable difference from the normal distribution.

Results of ANOVA for annual CPUE with the effect of LT5LN5 in each area are shown in Table 2. ANOVA table indicates that, in the model with LT5LN5, the effect of LT5LN5 was the largest in the tropical and whole areas, indicating that the effect of fishing ground is important. Comparison of CPUE trend among the model with different effect of fishing ground (subarea or LT5LN5) (Fig. 10) indicates that there is not large difference of the trend of CPUE except for a part of the period. This is different trend from the case of yellowfin tuna CPUE by Japanese longline (e.g. Ochi et al., 2014b). Possible cause of the difference is that subareas for bigeye tuna CPUE are smaller than those for yellowfin tuna hence the effect of fishing ground was well incorporated by using subareas.

Area specific CPUE

Trends of area specific CPUE in each region are shown in Fig. 11. Basically the trends for northeast and northwest area are similar to that of area aggregated CPUE in the tropical area. CPUE for south area is similar to that of area aggregated CPUE in the south Indian Ocean. Results of ANOVA are shown in Table 3, and the distributions of the standardized residual and QQ-plot are shown in Fig. 12. Distributions of the standardized residual did not show remarkable difference from the normal distribution.

4. References

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Table 1. ANOVA tables of GLM for bigeye tuna standardized CPUE (area aggregated) for Japanese longline. CV, the coefficient of variation, which describes the amount of variation in the population, is 100 times the standard deviation estimate of the dependent variable (CPUE). Left: annual, right: quarterly.

Annual

tropical

RSquare	CV
0.21	44.61

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	409	88775.38	217.05	336.71	<.0001
year	67	6279.41	93.72	145.39	<.0001
month	11	2197.49	199.77	309.9	<.0001
area	4	1698.36	424.59	658.65	<.0001
nhfc	5	429.17	85.83	133.15	<.0001
sst	1	107.82	107.82	167.26	<.0001
ML	1	122.81	122.81	190.51	<.0001
year*area	247	10076.42	40.80	63.28	<.0001
month*area	44	3120.58	70.92	110.02	<.0001
area*nhfc	20	990.41	49.52	76.82	<.0001
sst*area	4	1486.44	371.61	576.46	<.0001
nhfc*ML	5	562.88	112.58	174.64	<.0001

south

RSquare	CV
0.31	136.25

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	169	155270.70	918.76	992.72	<.0001
year	67	26940.13	402.09	434.46	<.0001
month	11	13503.33	1227.58	1326.39	<.0001
area	1	96.92	96.92	104.72	<.0001
nhfc	5	1995.12	399.02	431.14	<.0001
sst	1	4502.65	4502.65	4865.1	<.0001
ML	1	59.53	59.53	64.33	<.0001
year*area	61	6881.95	112.82	121.9	<.0001
month*area	11	2374.33	215.85	233.22	<.0001
area*nhfc	5	1014.54	202.91	219.24	<.0001
sst*area	1	381.18	381.18	411.86	<.0001
nhfc*ML	5	309.61	61.92	66.91	<.0001

whole

RSquare	CV
0.37	60.02

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	573	366257.67	639.19	914.08	<.0001
year	67	11196.89	167.12	238.99	<.0001
month	11	3181.18	289.20	413.57	<.0001
area	6	2104.52	350.75	501.6	<.0001
nhfc	5	1249.06	249.81	357.24	<.0001
sst	1	12.73	12.73	18.2	<.0001
ML	1	0.24	0.24	0.34	0.5583
year*area	375	34021.53	90.72	129.74	<.0001
month*area	66	14037.19	212.68	304.15	<.0001
area*nhfc	30	2761.10	92.04	131.62	<.0001
sst*area	6	2529.82	421.64	602.96	<.0001
nhfc*ML	5	412.12	82.42	117.87	<.0001

Quarterly

tropical

RSquare	CV
0.24	43.83

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	1262	100835.14	79.90	128.44	<.0001
year	67	3004.96	44.85	72.1	<.0001
quarter	3	79.86	26.62	42.79	<.0001
area	4	725.30	181.32	291.48	<.0001
nhfc	5	334.34	66.87	107.49	<.0001
sst	1	0.34	0.34	0.54	0.4613
ML	1	102.36	102.36	164.54	<.0001
year*quarter*area	1152	27112.36	23.54	37.83	<.0001
area*nhfc	20	814.83	40.74	65.49	<.0001
sst*area	4	604.60	151.15	242.97	<.0001
nhfc*ML	5	497.43	99.49	159.92	<.0001

south

RSquare	CV
0.35	132.25

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	522	175340.35	335.90	385.18	<.0001
year	67	13242.57	197.65	226.65	<.0001
quarter	3	1113.98	371.33	425.8	<.0001
area	1	395.78	395.78	453.84	<.0001
nhfc	5	1393.34	278.67	319.55	<.0001
sst	1	8214.44	8214.44	9419.5	<.0001
ML	1	15.60	15.60	17.89	<.0001
year*quarter*area	433	33780.80	78.02	89.46	<.0001
area*nhfc	5	341.10	68.22	78.23	<.0001
sst*area	1	926.08	926.08	1061.9	<.0001
nhfc*ML	5	154.59	30.92	35.45	<.0001

whole

RSquare	CV
0.40	58.65

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	1779	394750.46	221.89	332.25	<.0001
year	67	4590.63	68.52	102.59	<.0001
quarter	3	201.64	67.21	100.64	<.0001
area	6	1206.26	201.04	301.03	<.0001
nhfc	5	891.82	178.36	267.07	<.0001
sst	1	97.89	97.89	146.58	<.0001
ML	1	0.00	0.00	0.01	0.943
year*quarter*area	1655	81091.85	49.00	73.37	<.0001
area*nhfc	30	1719.43	57.31	85.82	<.0001
sst*area	6	1913.50	318.92	477.53	<.0001
nhfc*ML	5	317.25	63.45	95.01	<.0001

Table 2. ANOVA tables of GLM for bigeye tuna standardized CPUE (area aggregated, with LT5LN5 instead of subareas) for Japanese longline. CV, the coefficient of variation, which describes the amount of variation in the population, is 100 times the standard deviation estimate of the dependent variable (CPUE).

Annual with LT5LN5

tropical

RSquare	CV
0.22	44.36

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	171	92307.65	539.81	846.85	<.0001
year	67	9820.68	146.58	229.95	<.0001
month	11	2203.89	200.35	314.31	<.0001
LT5LN5	74	40534.37	547.76	859.33	<.0001
nhfc	5	145.12	29.02	45.53	<.0001
sst	8	1464.45	183.06	287.18	<.0001
ML	1	93.88	93.88	147.29	<.0001
nhfc*ML	5	401.87	80.37	126.09	<.0001

south

RSquare	CV
0.33	134.11

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	153	165915.45	1084.41	1209.37	<.0001
year	67	27291.81	407.34	454.28	<.0001
month	11	12487.98	1135.27	1266.08	<.0001
LT5LN5	46	14731.18	320.24	357.14	<.0001
nhfc	5	774.91	154.98	172.84	<.0001
sst	18	7697.99	427.67	476.94	<.0001
ML	1	14.76	14.76	16.46	<.0001
nhfc*ML	5	129.35	25.87	28.85	<.0001

whole

RSquare	CV
0.36	60.75

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	229	350926.10	1532.43	2139.09	<.0001
year	67	19644.43	293.20	409.27	<.0001
month	11	4411.42	401.04	559.8	<.0001
LT5LN5	121	140622.39	1162.17	1622.25	<.0001
nhfc	5	393.07	78.61	109.74	<.0001
sst	19	10143.06	533.85	745.18	<.0001
ML	1	84.76	84.76	118.31	<.0001
nhfc*ML	5	388.55	77.71	108.47	<.0001

Table 3. ANOVA tables of GLM for bigeye tuna standardized CPUE (area specific, quarterly) for Japanese longline. CV, the coefficient of variation, which describes the amount of variation in the population, is 100 times the standard deviation estimate of the dependent variable (CPUE).

Northwest(R1)

RSquare	CV
0.32	49.63

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	312	104128.48	333.75	521.43	<.0001
year	65	6028.93	92.75	144.91	<.0001
quarter	3	433.52	144.51	225.77	<.0001
nhfc	5	74.16	14.83	23.17	<.0001
ML	1	9.56	9.56	14.93	0.0001
LT5LN5	1	7.82	7.82	12.21	0.0005
year*quarter	42	21119.13	502.84	785.61	<.0001
nhfc*ML	190	7411.14	39.01	60.94	<.0001

Southwest(R3)

RSquare	CV
0.32	187.05

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	298	83366.55	279.75	281.09	<.0001
year	65	6795.59	104.55	105.05	<.0001
quarter	3	642.04	214.01	215.03	<.0001
nhfc	5	905.50	181.10	181.96	<.0001
ML	1	7.25	7.25	7.29	0.0069
sst	1	1452.40	1452.40	1459.3	<.0001
LT5LN5	33	5962.12	180.67	181.53	<.0001
year*quarter	185	6762.99	36.56	36.73	<.0001
nhfc*ML	5	370.88	74.18	74.53	<.0001

Northeast(R2)

RSquare	CV
0.17	38.29

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	310	21947.75	70.80	122.15	<.0001
year	67	2747.90	41.01	70.76	<.0001
quarter	3	134.62	44.87	77.42	<.0001
nhfc	5	126.82	25.36	43.76	<.0001
ML	1	45.45	45.45	78.42	<.0001
sst	1	4.14	4.14	7.14	0.0075
LT5LN5	33	9258.91	280.57	484.09	<.0001
year*quarter	195	3300.06	16.92	29.2	<.0001
nhfc*ML	5	132.51	26.50	45.72	<.0001

Southeast(R4)

RSquare	CV
0.41	91.57

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	311	102827.69	330.64	461.43	<.0001
year	67	10684.66	159.47	222.56	<.0001
quarter	3	725.18	241.73	337.35	<.0001
nhfc	5	577.48	115.50	161.19	<.0001
ML	1	10.01	10.01	13.98	0.0002
sst	1	35.52	35.52	49.57	<.0001
LT5LN5	34	6468.89	190.26	265.53	<.0001
year*quarter	195	15711.69	80.57	112.45	<.0001
nhfc*ML	5	193.33	38.67	53.96	<.0001

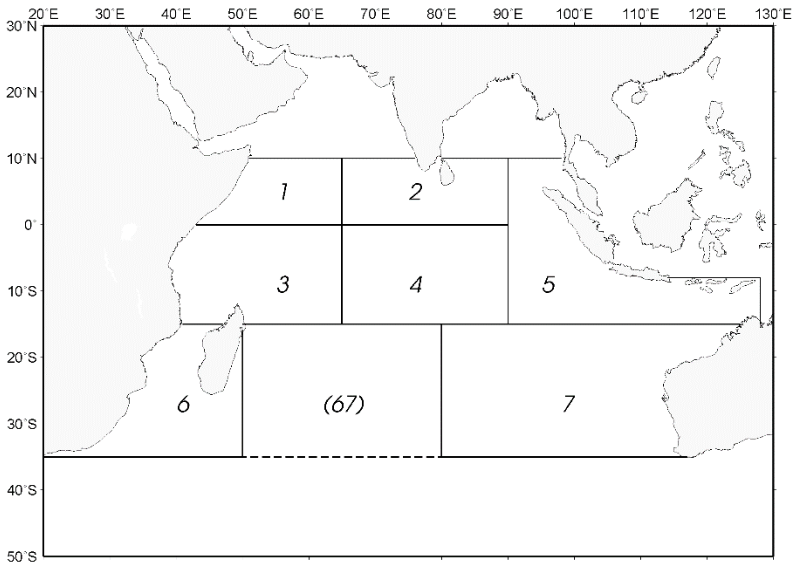


Fig. 1. Definition of sub-areas for area aggregated CPUE used in this study. The tropical, south and whole Indian Ocean regions in this paper consist of areas 1-5, areas 6-7 and areas1-7, respectively. Area 67 was not used in this study.

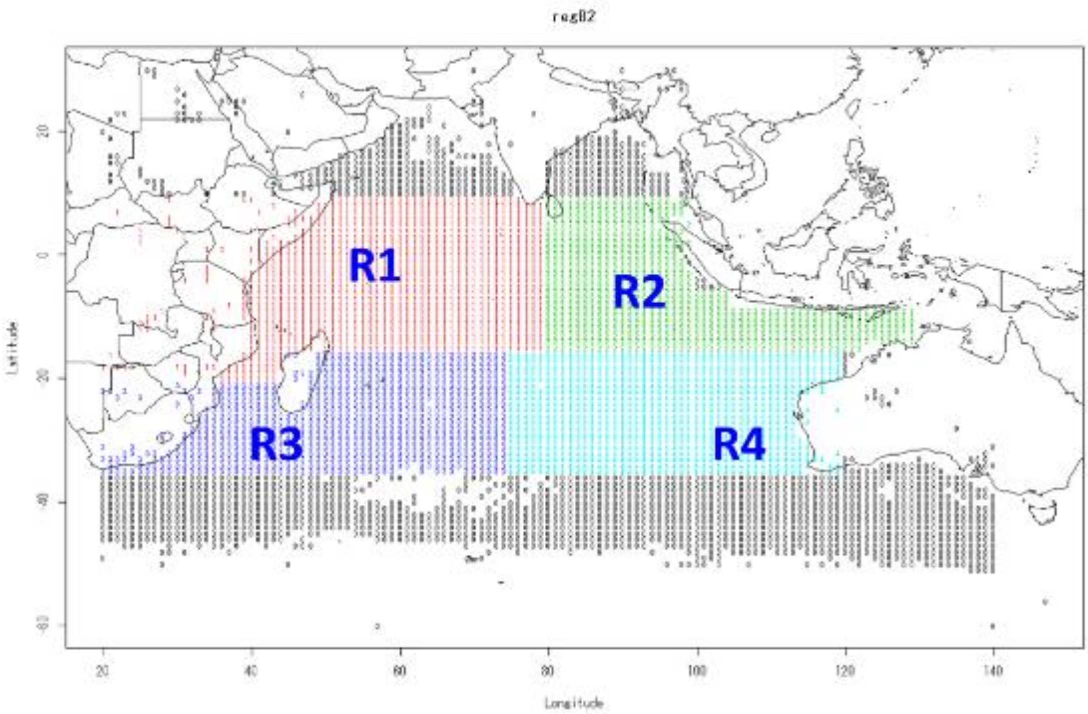


Fig. 2. Another definition of areas for area specific CPUE formatted for integrated model.

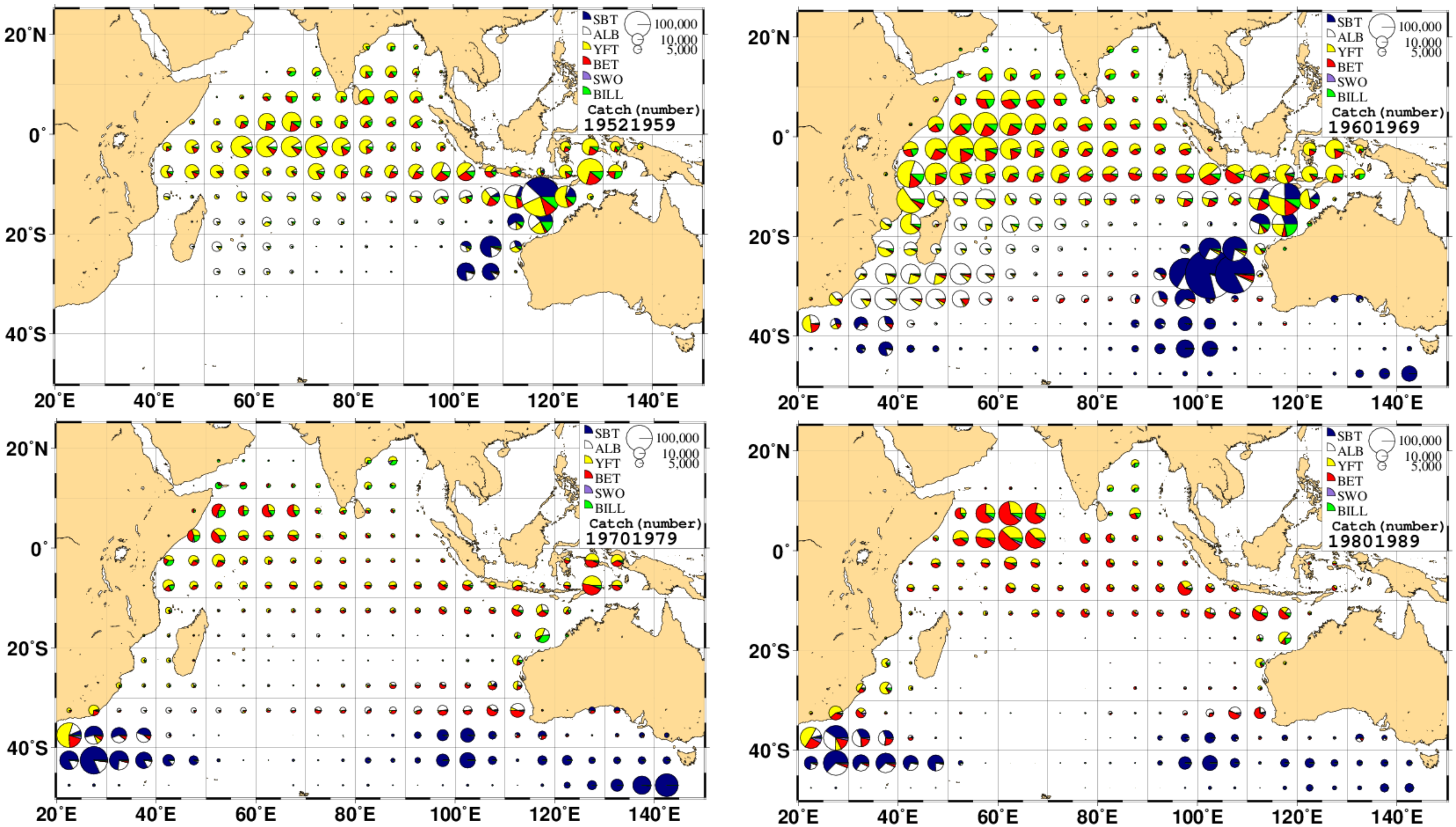
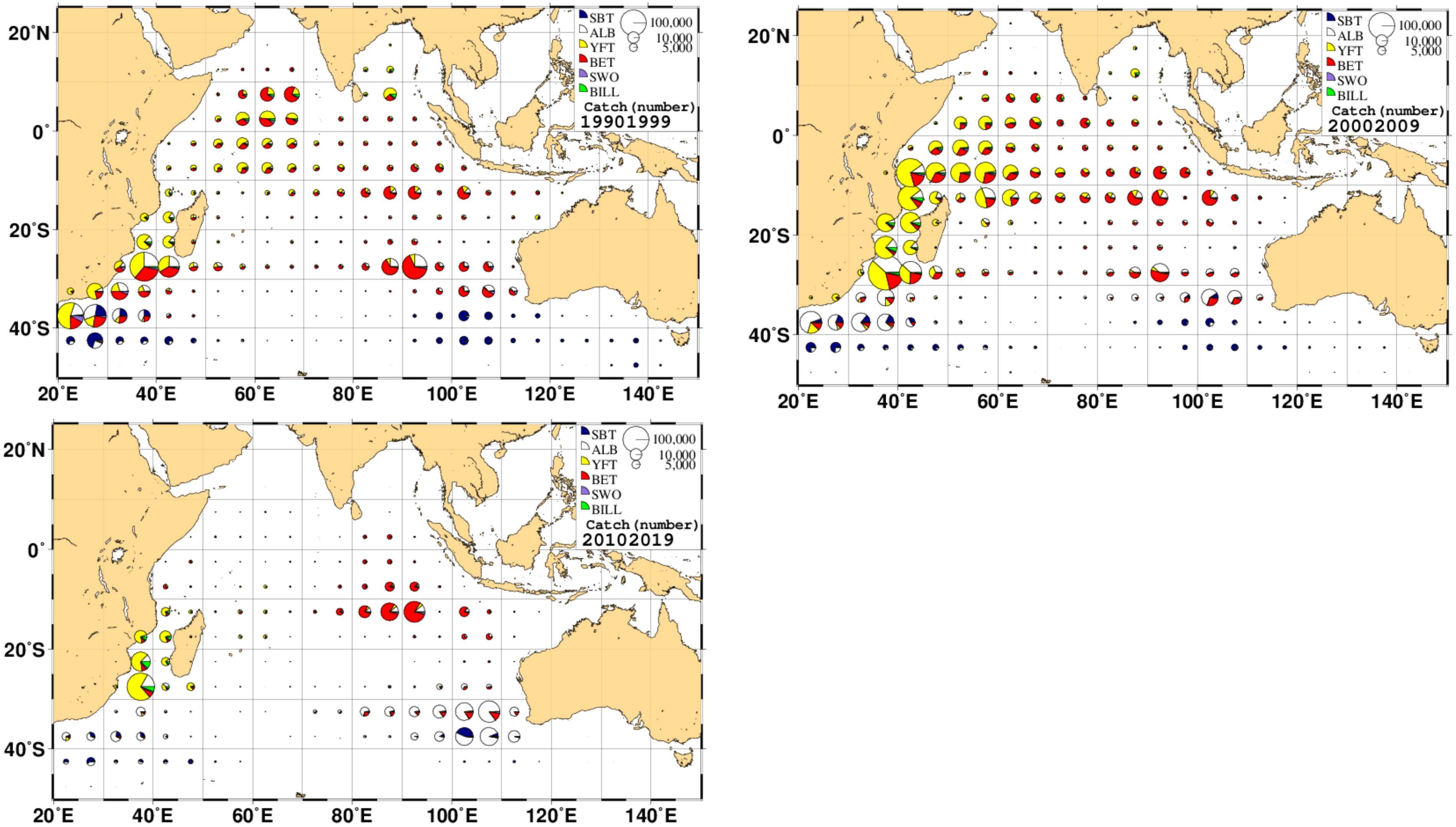


Fig. 3. The averaged distribution of amount of catch in number by species for each decade. Size of circle shows amount of total of catches i.e. southern bluefin tuna (SBT), albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO) and billfishes (Bill).



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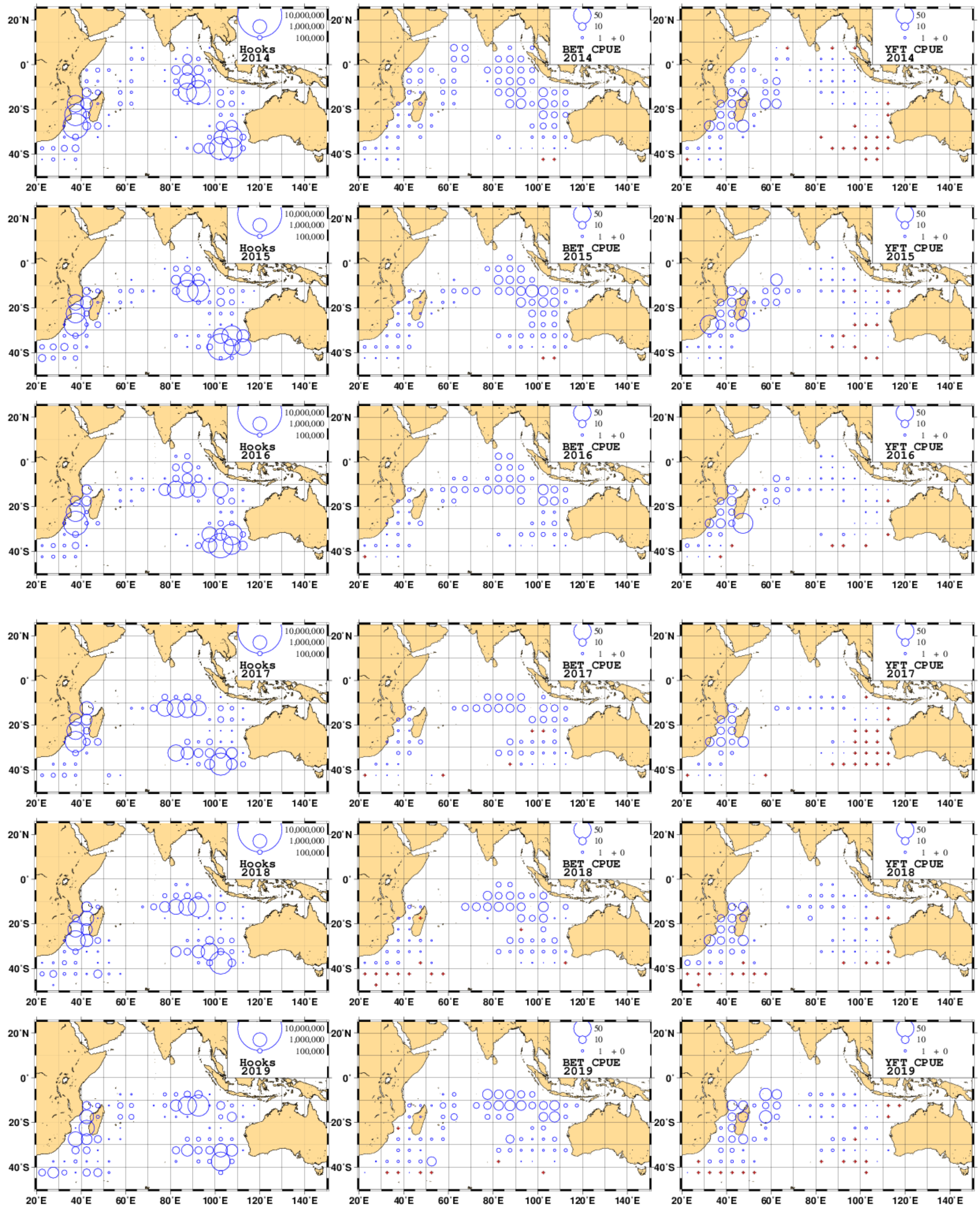

Fig. 4. Geographical distribution of fishing effort and nominal CPUE for bigeye and yellowfin tuna by Japanese longline in recent years.

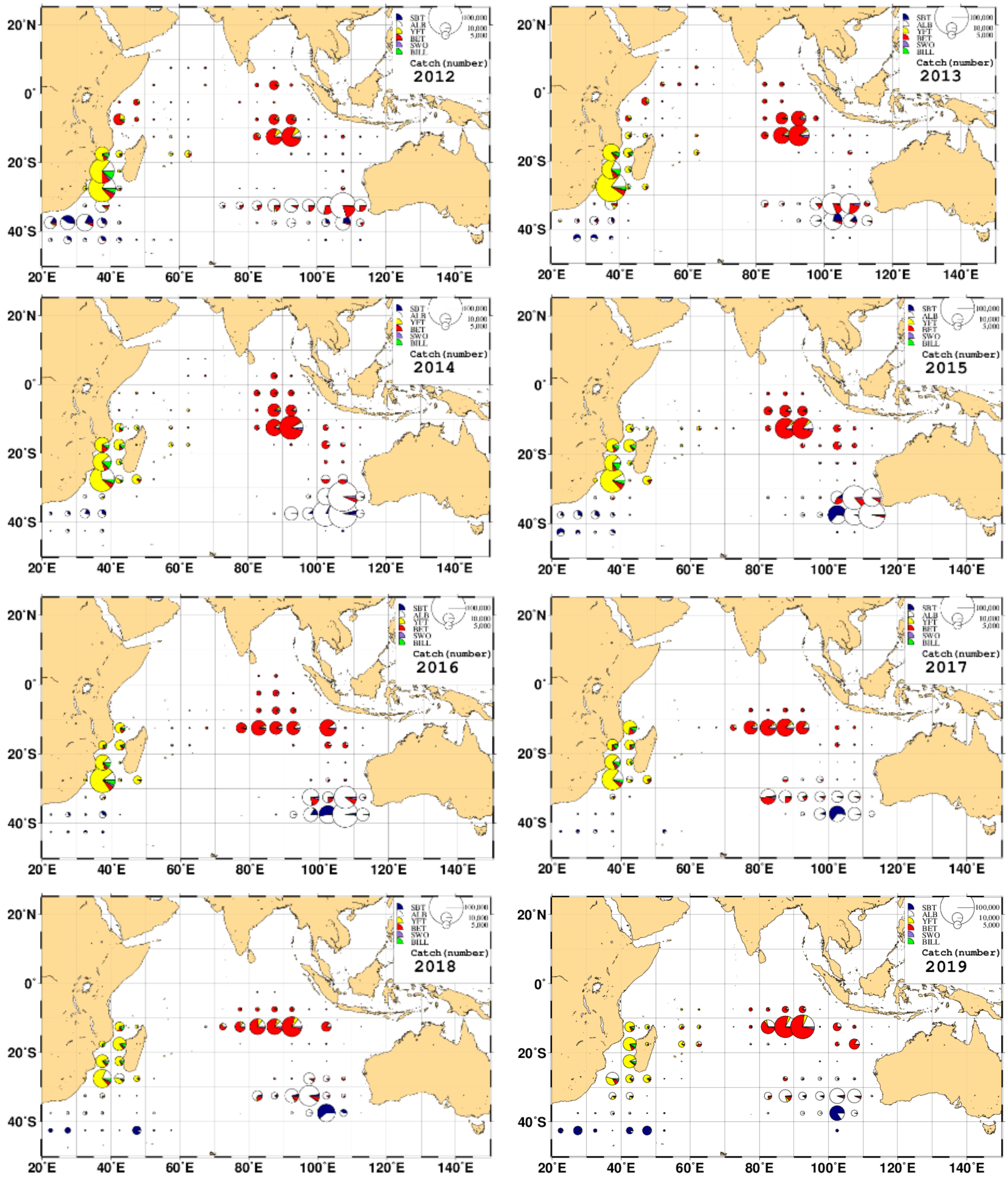

Fig. 5. Geographical distribution of species composition of catch for tuna and billfish species by Japanese longline in recent years. Size of circle shows amount of total of catches i.e. southern bluefin tuna (SBT), albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO) and billfishes (Bill).

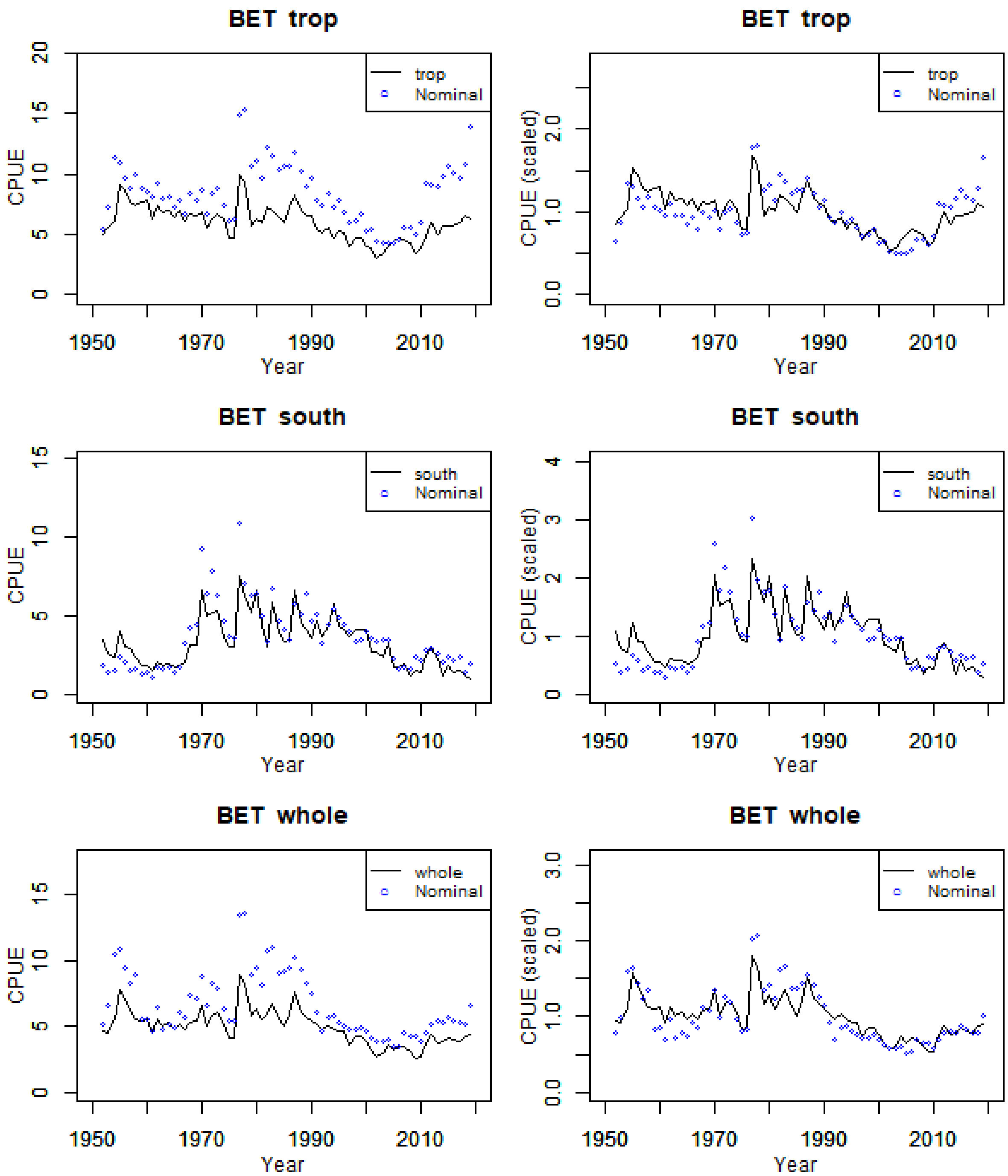

Fig. 6. Trend of area aggregated annual CPUE (left: real scale, right: relative scale) of bigeye. Standardized CPUE created in 2019 (solid line) and nominal CPUE (open circle) of Japanese longline for the tropical (top), south (middle) and whole (bottom) Indian Ocean.

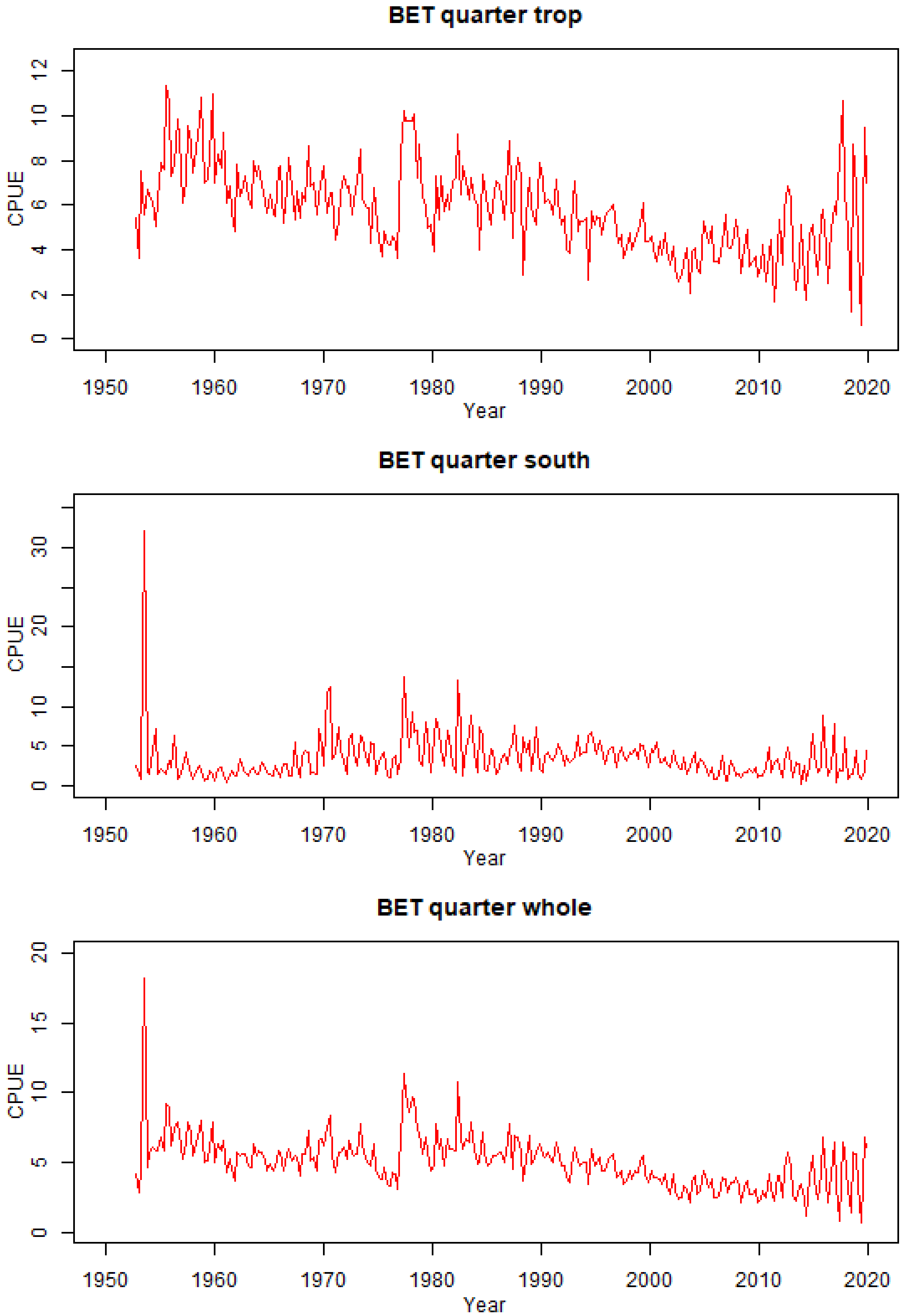

Fig. 7. Trend of area aggregated quarterly CPUE series of bigeye for tropical (top), south (middle) and whole (bottom) Indian Ocean

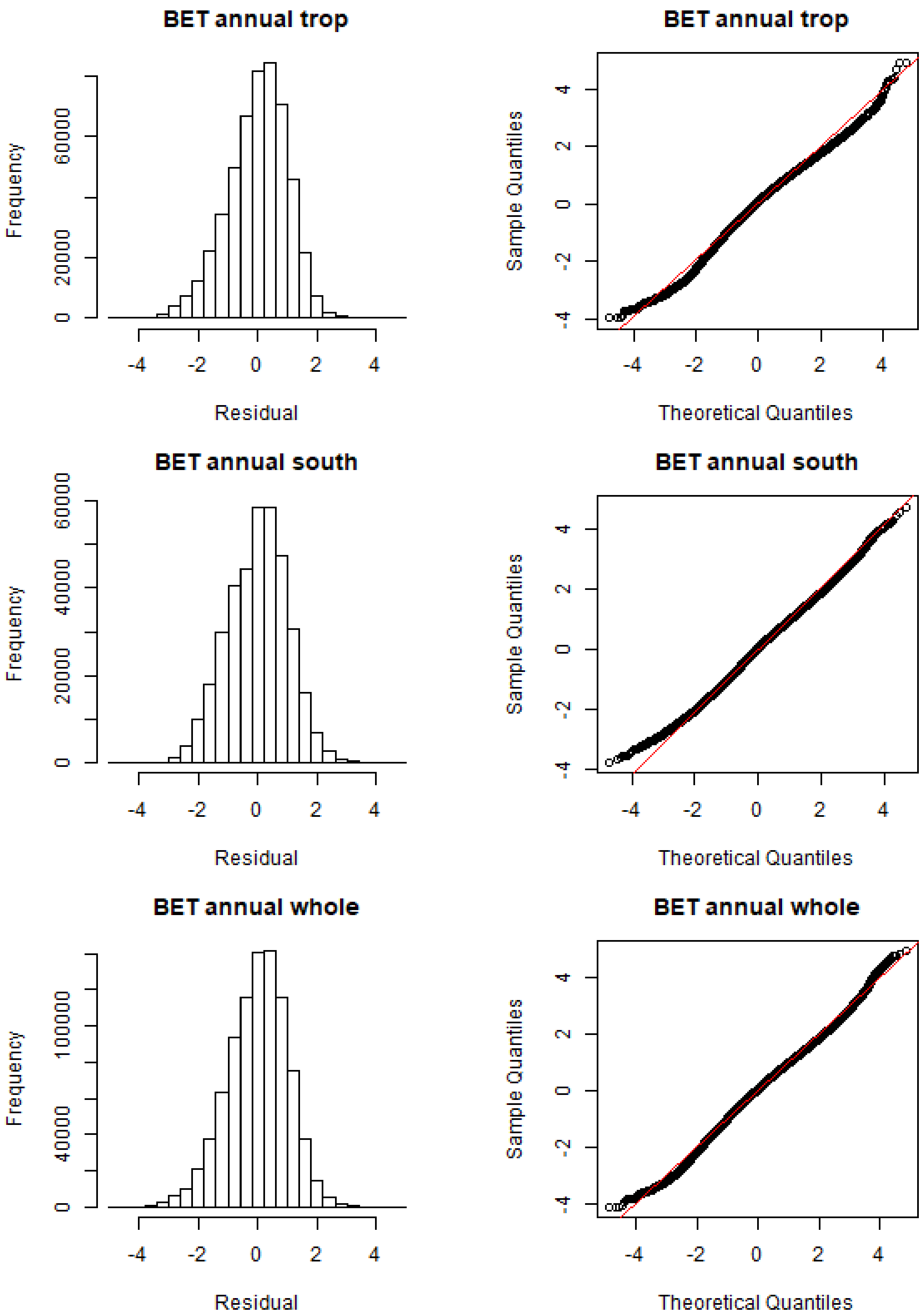

Fig. 8. Standardized residuals of area aggregated annual CPUE standardization.

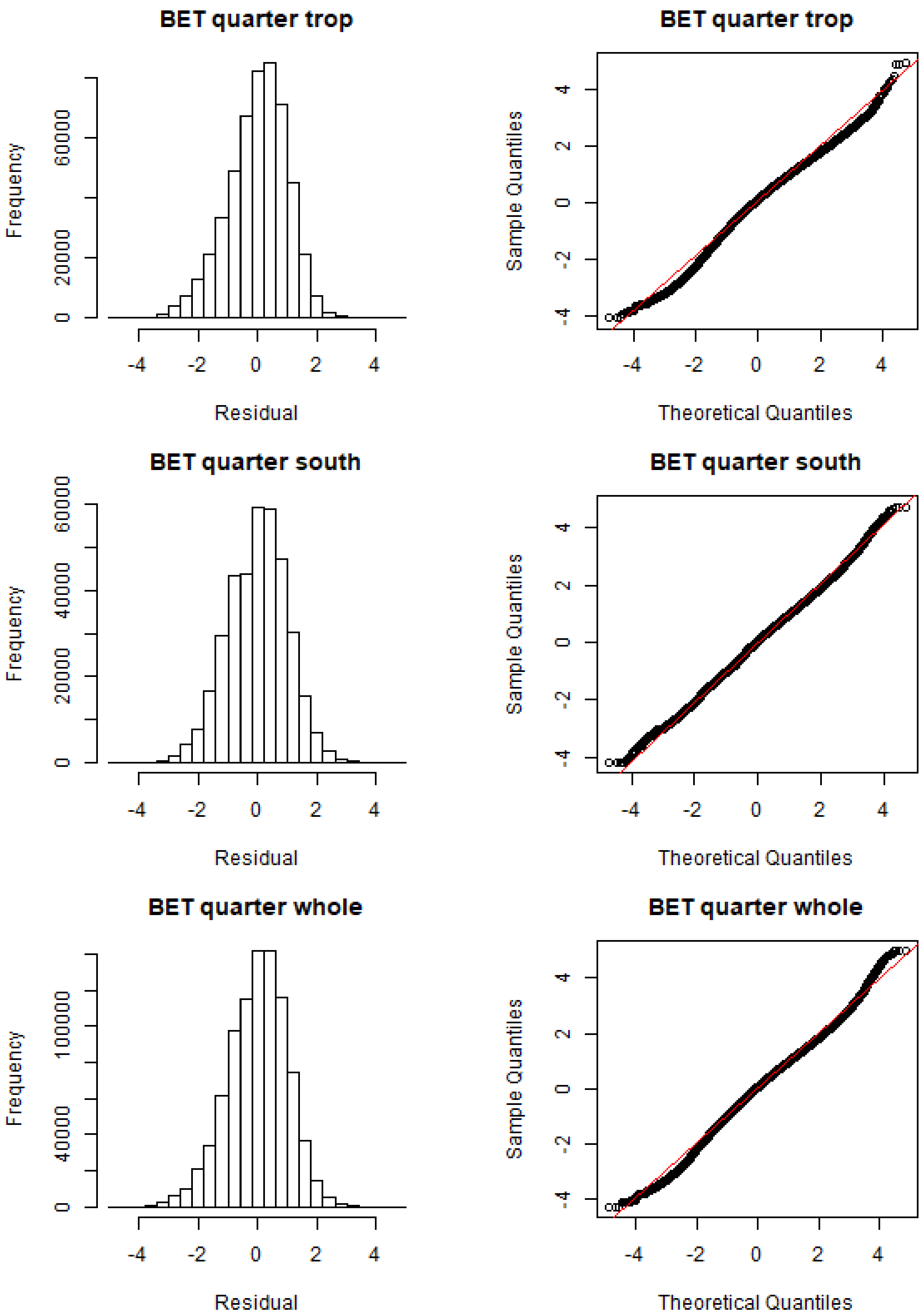

Fig. 9. Standardized residuals of area aggregated quarterly CPUE standardization.

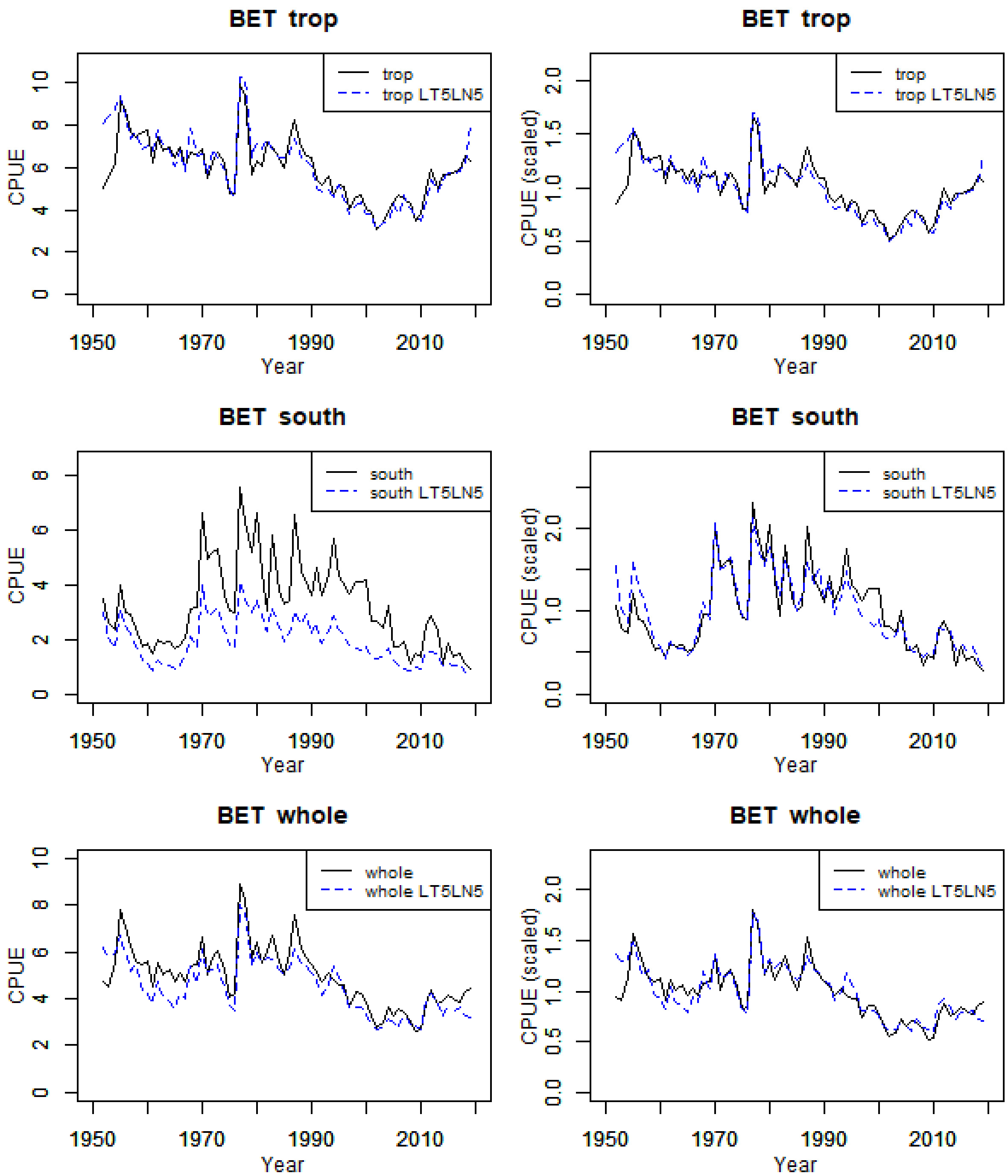

Fig. 10. Comparison of area aggregated CPUE series of bigeye between the model including subarea effect and that including LT5LN5 effect. Left: real scale, right: relative scale.

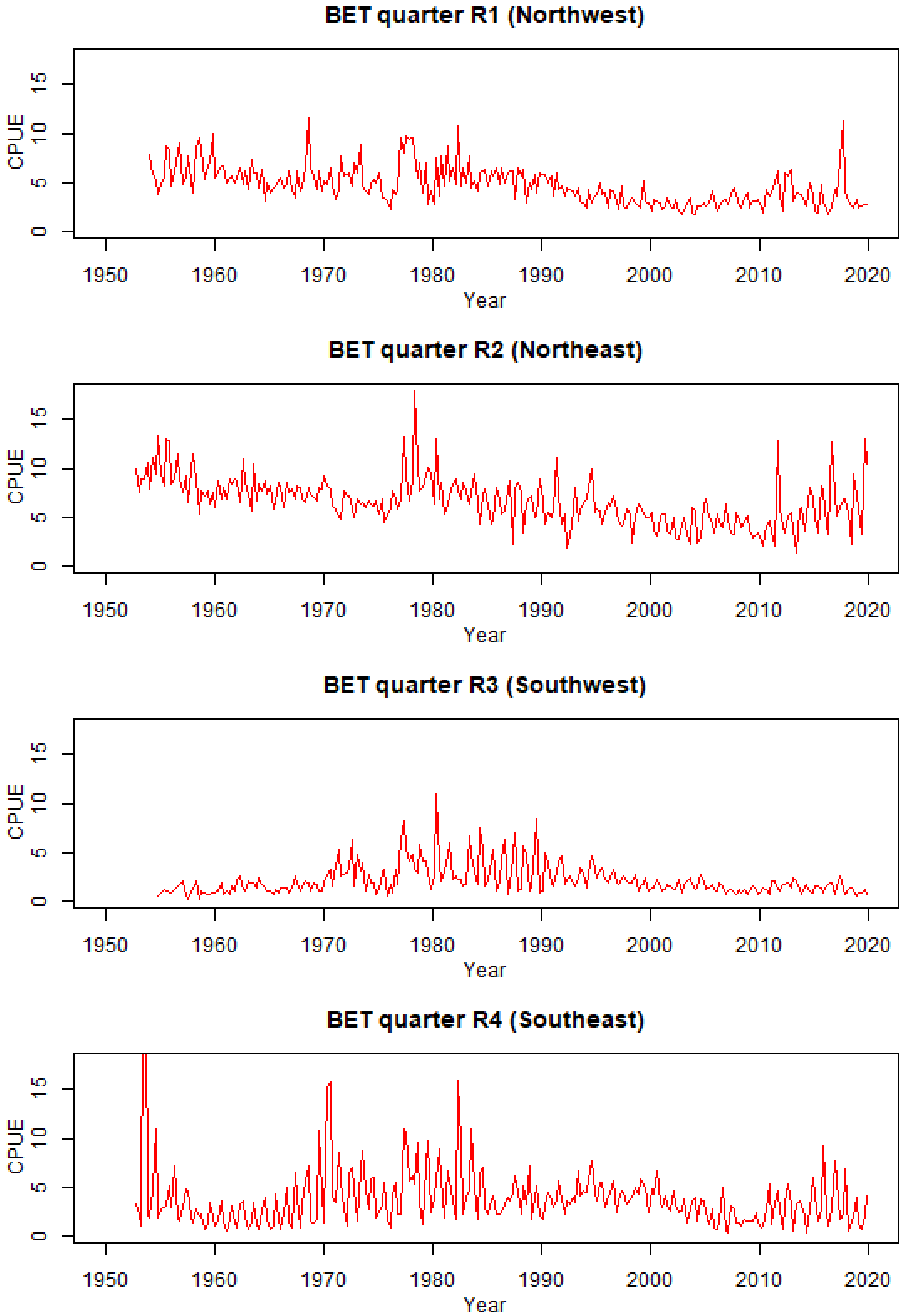

Fig. 11. Comparison of area specific quarterly CPUE series of bigeye tuna by Japanese longline.

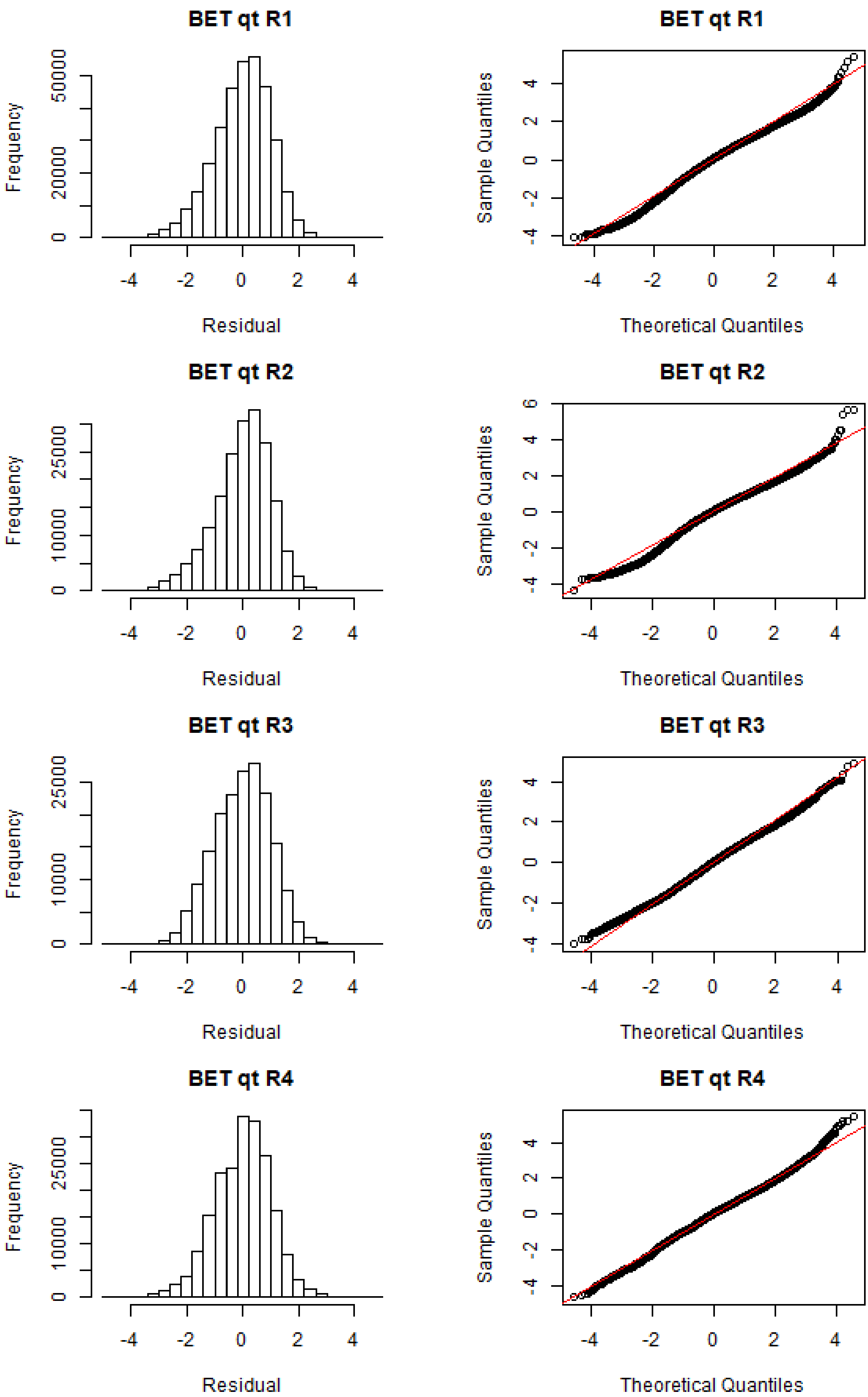

Fig. 12. Standardized residuals of area specific quarterly CPUE standardization.