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Updated 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 for 1960-2016 by using GLM (generalized linear model, log normal error structured). Methods of standardization are the same as or similar to those provided at IOTC WPTT in 2016 or before. 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, but decrease in the latest year are seen as for each area.

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) and Ochi et al. (2014) 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. 2014, Matsumoto et al. 2015; 2016). Methods of standardization in this study are similar to above mentioned studies.

This year IOTC joint CPUE analysis was conducted and joint CPUE for bigeye and yellowfin tuna, which is based on operational level data for Japanese, Korean, Seychelles and Taiwanese longline fishery, were created along with CPUE for each fleet, which incorporated fishing power based on vessel ID and cluster analysis to incorporate targeting. One of the objectives of this study is to compare CPUE indices with those by the joint CPUE and CPUE for each fleet. It was also aimed to conduct continuity analysis and to see recent trend of CPUE.

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 - 2016 IOTC WPTT meetings (Satoh and Okamoto 2012, Matsumoto et al. 2013, Ochi et al. 2014, Matsumoto et al. 2015; 2016). 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 also the same as that for previous studies. Fishing ground was divided into three areas: West (tropical area), East (tropical area) and South (subtropical and temperate area).

Environmental factors:

As environmental factors, which are available for the period of 1960-2014 (up to October for 2014), 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 after October 2014 were replaced by SST data for the same month in 2013 or 2014 (nearest near) because these data were unreleased in 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 1960 up to 2016 were used. Data for 2016 are preliminary. 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'.

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:</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 and 2015 was calculated using area rate without Area 1, Area 1 & 3 and Area 1, respectively because no effort was observed in these year and area due to piracy activities (Fig. 3). Time period of standardization was 1960-2016 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.

<u>Area aggregated CPUE (annual, with LT5LN5):</u>

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.

$$CPUE_i = \exp(\text{lsmean}(\text{year } i)) - \text{constant}$$

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. 4 (annual) and Fig. 5 (quarterly). In the tropical Indian Ocean, CPUE slightly decreased from around 7.7 (real scale) in 1960 to 4.7 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 also sharply increased (7.3) in 1977 and then showed slightly decreasing trend. It was increasing trend during 2009-2012 but decreased with fluctuation after that. As a result, CPUE in the whole Indian Ocean, which had been in the same level around 4 to 6 until 1976 and suddenly increased around 8 in 1977 and 1978 and after that showed slightly decreasing trend. It increased after 2009 with fluctuation. Comparatively large difference between standardized and nominal CPUE 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. 6 and Fig. 7, 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. 8) 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 (Ochi et al., 2014). 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 (east, west and south area) are shown in Fig. 9. Basically the trends for east and west area are similar to that of area aggregated CPUE in the tropical area. CPUE for south area is very close 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. 10. Distributions of the standardized residual did not show remarkable difference from the normal distribution.

4. References

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Satoh, K. and Okamoto, H. (2012): Updated Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM. IOTC-2012/WPTT14/26, p. 18.

Shono, H. and M. Ogura, M. (1999): The standardized skipjack CPUE including the effect of searching devices, of the Japanese distant water pole and line fishery in the Western Central Pacific Ocean. ICCAT-SCRS/99/59, p.18

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	45.13

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	370	81854.81	221.23	344.31	<.0001
year	56	5097.28	91.02	141.66	<.0001
month	11	2046.08	186.01	289.49	<.0001
area	4	1596.72	399.18	621.27	<.0001
nhfc	5	428.88	85.78	133.5	<.0001
sst	1	121.82	121.82	189.6	<.0001
ML	1	94.42	94.42	146.96	<.0001
year*area	219	8504.88	38.84	60.44	<.0001
month*area	44	2975.16	67.62	105.24	<.0001
area*nhfc	20	996.65	49.83	77.56	<.0001
sst*area	4	1402.94	350.73	545.87	<.0001
nhfc*ML	5	565.93	113.19	176.16	<.0001

south

RSquare	CV
0.31	131.84

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	153	148250.98	968.96	1046.51	<.0001
year	56	24969.21	445.88	481.56	<.0001
month	11	12973.90	1179.45	1273.84	<.0001
area	1	78.70	78.70	85	<.0001
nhfc	5	1622.33	324.47	350.44	<.0001
sst	1	4525.03	4525.03	4887.19	<.0001
ML	1	27.75	27.75	29.97	<.0001
year*area	56	6519.09	116.41	125.73	<.0001
month*area	11	2433.68	221.24	238.95	<.0001
area*nhfc	5	839.12	167.82	181.26	<.0001
sst*area	1	309.74	309.74	334.53	<.0001
nhfc*ML	5	262.23	52.45	56.64	<.0001

whole

RSquare	CV
0.37	60.64

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	518	331214.37	639.41	914.63	<.0001
year	56	10391.67	185.57	265.44	<.0001
month	11	2756.38	250.58	358.44	<.0001
area	6	2062.69	343.78	491.75	<.0001
nhfc	5	1120.12	224.02	320.45	<.0001
sst	1	18.70	18.70	26.76	<.0001
ML	1	0.10	0.10	0.14	0.7105
year*area	331	29517.55	89.18	127.56	<.0001
month*area	66	13565.76	205.54	294.01	<.0001
area*nhfc	30	2516.39	83.88	119.98	<.0001
sst*area	6	2485.04	414.17	592.44	<.0001
nhfc*ML	5	454.53	90.91	130.03	<.0001

Quarterly

tropical

RSquare	CV
0.24	44.46

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	1104	91761.75	83.12	133.64	<.0001
year	55	2539.63	46.18	74.24	<.0001
quarter	3	41.05	13.68	22	<.0001
area	4	768.85	192.21	309.04	<.0001
nhfc	5	314.77	62.95	101.22	<.0001
sst	1	2.13	2.13	3.42	0.0642
ML	1	69.90	69.90	112.39	<.0001
year*quarter*area	1006	23789.67	23.65	38.02	<.0001
area*nhfc	20	824.64	41.23	66.29	<.0001
sst*area	4	653.02	163.26	262.48	<.0001
nhfc*ML	5	498.77	99.75	160.39	<.0001

south

RSquare	CV
0.35	127.18

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	461	165938.98	359.95	412.93	<.0001
year	55	12525.26	227.73	261.25	<.0001
quarter	3	2078.32	692.77	794.73	<.0001
area	1	425.52	425.52	488.15	<.0001
nhfc	5	1083.20	216.64	248.52	<.0001
sst	1	8257.26	8257.26	9472.5	<.0001
ML	1	0.81	0.81	0.93	0.3344
year*quarter*area	384	32161.58	83.75	96.08	<.0001
area*nhfc	5	243.56	48.71	55.88	<.0001
sst*area	1	878.37	878.37	1007.6	<.0001
nhfc*ML	5	131.20	26.24	30.1	<.0001

whole

RSquare	CV
0.39	59.27

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	1560	352969.18	226.26	338.34	<.0001
year	55	4277.20	77.77	116.29	<.0001
quarter	3	157.79	52.60	78.65	<.0001
area	6	1300.57	216.76	324.13	<.0001
nhfc	5	760.81	152.16	227.53	<.0001
sst	1	78.63	78.63	117.58	<.0001
ML	1	2.07	2.07	3.1	0.0784
year*quarter*area	1448	72726.23	50.23	75.1	<.0001
area*nhfc	30	1588.79	52.96	79.19	<.0001
sst*area	6	1999.07	333.18	498.21	<.0001
nhfc*ML	5	353.34	70.67	105.67	<.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	45.02

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	160	83220.35	520.13	813.55	<.0001
year	56	7535.08	134.55	210.46	<.0001
month	11	1866.25	169.66	265.37	<.0001
LT5LN5	74	35531.73	480.16	751.04	<.0001
nhfc	5	130.87	26.17	40.94	<.0001
sst	8	1345.63	168.20	263.1	<.0001
ML	1	63.12	63.12	98.73	<.0001
nhfc*ML	5	339.67	67.93	106.26	<.0001

south

RSquare	CV
0.33	129.67

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	142	158926.00	1119.20	1249.43	<.0001
year	56	25365.10	452.95	505.65	<.0001
month	11	12081.72	1098.34	1226.14	<.0001
LT5LN5	46	14087.74	306.26	341.89	<.0001
nhfc	5	657.11	131.42	146.72	<.0001
sst	18	7798.29	433.24	483.65	<.0001
ML	1	5.77	5.77	6.44	0.0111
nhfc*ML	5	118.52	23.70	26.46	<.0001

whole

RSquare	CV
0.35	61.41

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	218	316293.17	1450.89	2023.7	<.0001
year	56	17501.49	312.53	435.91	<.0001
month	11	4273.99	388.54	541.94	<.0001
LT5LN5	121	127430.74	1053.15	1468.93	<.0001
nhfc	5	327.29	65.46	91.3	<.0001
sst	19	10378.94	546.26	761.93	<.0001
ML	1	44.65	44.65	62.28	<.0001
nhfc*ML	5	273.75	54.75	76.37	<.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).

East

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	287	24982.26	87.05	148.33	<.0001
year	56	2435.17	43.49	74.1	<.0001
quarter	3	121.63	40.54	69.09	<.0001
nhfc	5	100.15	20.03	34.13	<.0001
ML	1	52.95	52.95	90.22	<.0001
LT5LN5	1	1.57	1.57	2.68	0.1015
year*quarter	48	10526.10	219.29	373.68	<.0001
nhfc*ML	168	3275.66	19.50	33.23	<.0001

West

RSquare	CV
0.29	52.43

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	257	59663.78	232.15	349.36	<.0001
year	55	4251.84	77.31	116.34	<.0001
quarter	3	268.15	89.38	134.51	<.0001
nhfc	5	78.94	15.79	23.76	<.0001
ML	1	4.43	4.43	6.66	0.0098
sst	1	19.99	19.99	30.09	<.0001
LT5LN5	25	7357.97	294.32	442.91	<.0001
year*quarter	162	6581.81	40.63	61.14	<.0001
nhfc*ML	5	99.70	19.94	30.01	<.0001

South

RSquare	CV
0.34	129.00

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	285	162371.14	569.72	642.73	<.0001
year	56	19455.90	347.43	391.95	<.0001
quarter	3	7513.94	2504.65	2825.6	<.0001
nhfc	5	838.89	167.78	189.28	<.0001
ML	1	12.60	12.60	14.22	0.0002
sst	1	300.85	300.85	339.4	<.0001
LT5LN5	46	17218.99	374.33	422.29	<.0001
year*quarter	168	14997.98	89.27	100.71	<.0001
nhfc*ML	5	160.23	32.05	36.15	<.0001

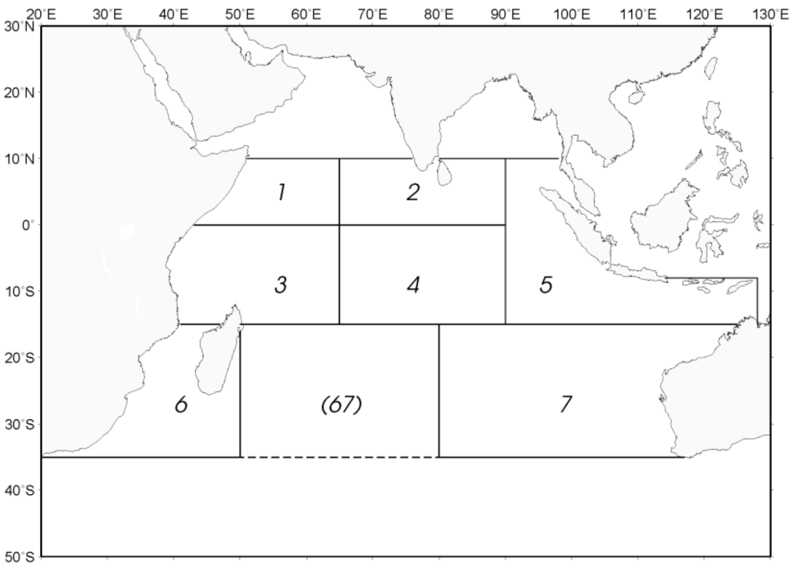


Fig. 1. Definition of sub-areas for area aggregated CPUE used in this study. The tropical, south and whole Indian Ocean regions in this paper consist of areas 1-5, areas 6-7 and areas1-7, respectively. Area 67 was not used in this study.

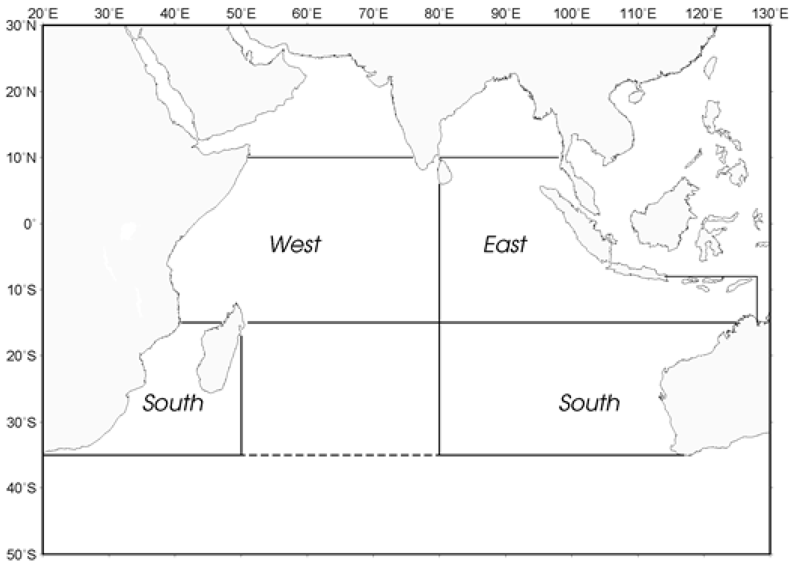


Fig. 2. Another definition of areas for area specific CPUE formatted for integrated model.

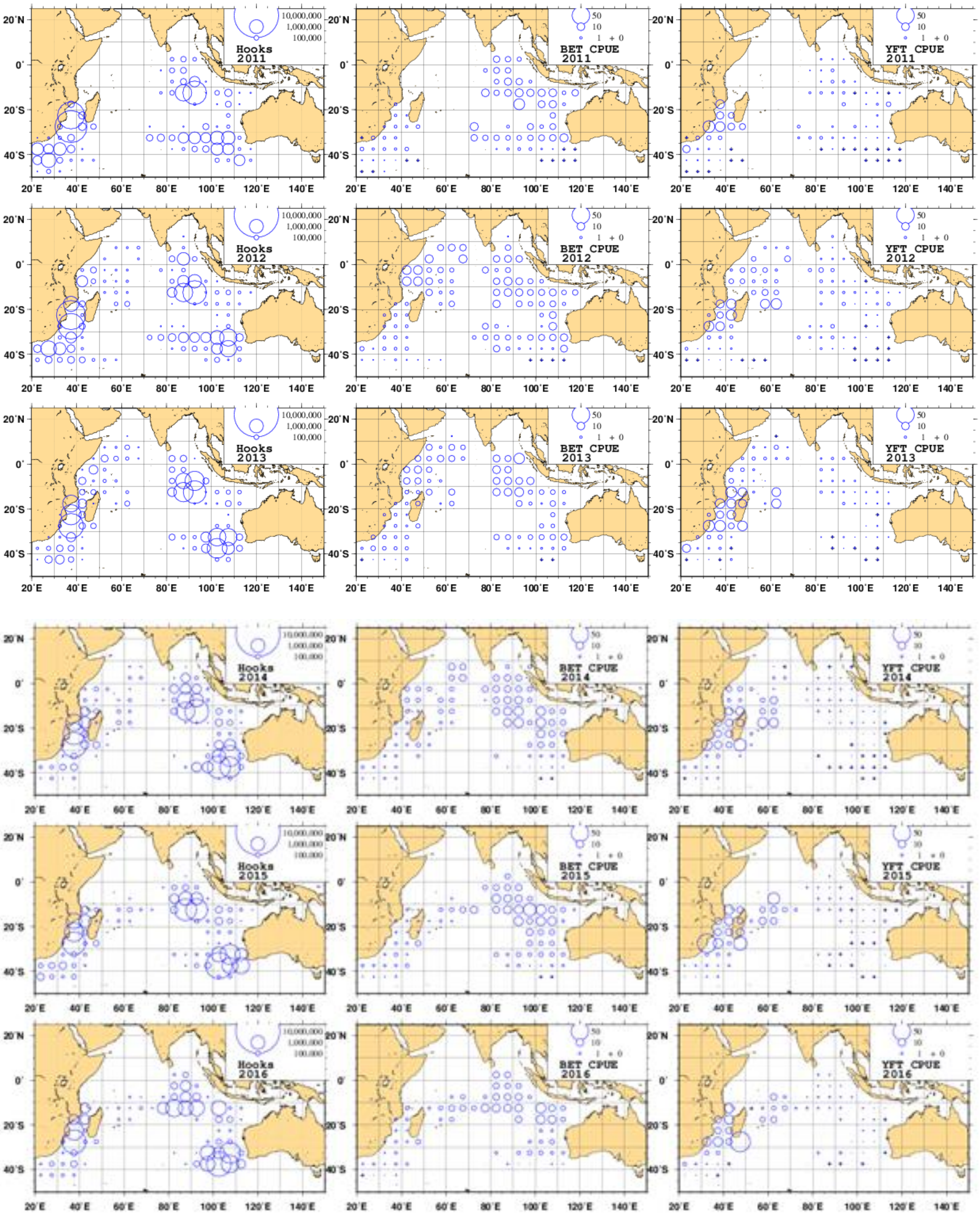


Fig. 3. Geographical distribution of fishing effort and nominal CPUE for bigeye and yellowfin tuna by Japanese longline in recent years.

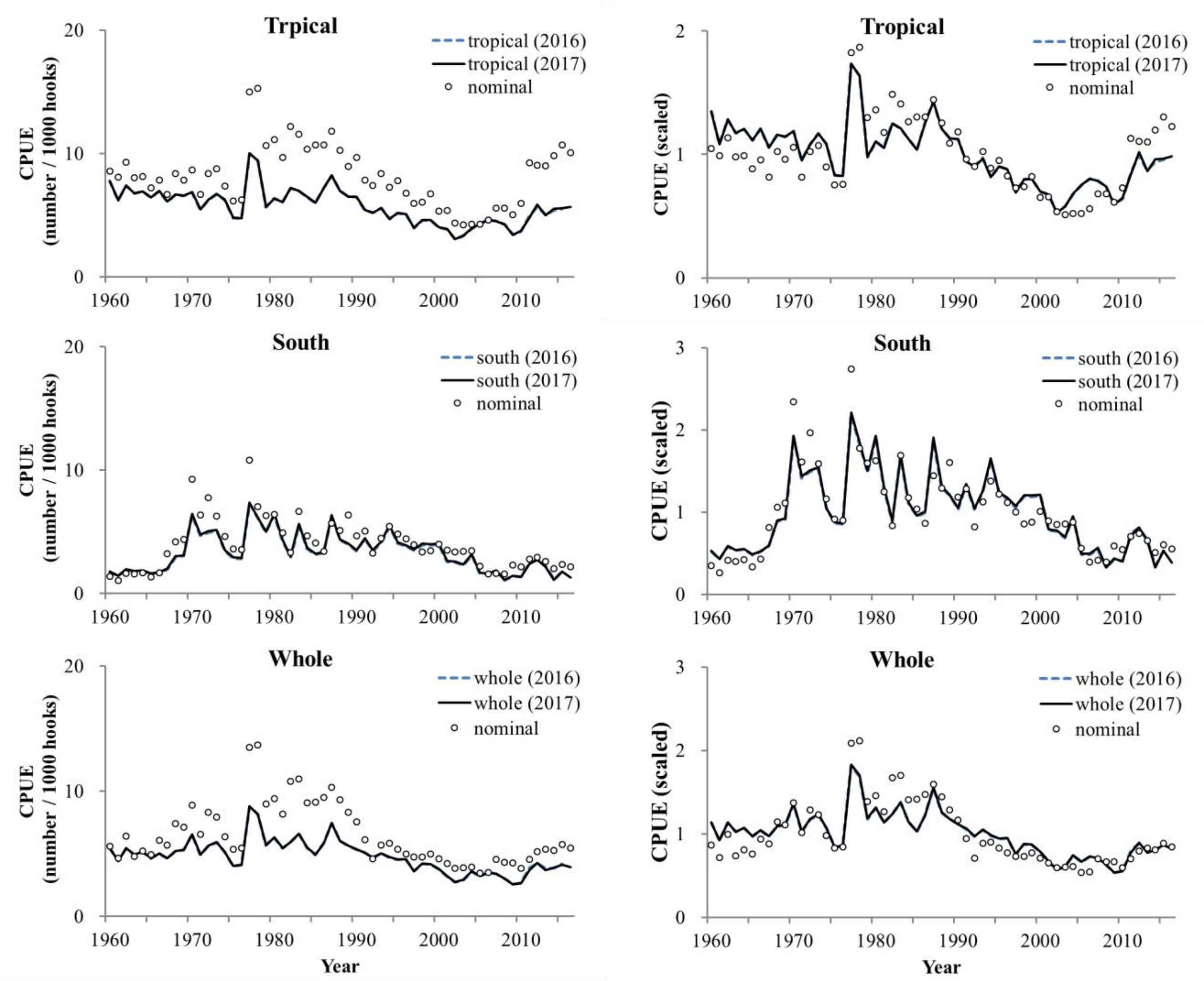


Fig. 4. Trend of area aggregated annual CPUE (left: real scale, right: relative scale) of bigeye. Standardized CPUE created in 2017 (solid line), nominal CPUE (open circle), and standardized CPUE created in 2016 (dashed line: Matsumoto el al., 2016) of Japanese longline for the tropical (top), south (middle) and whole (bottom) Indian Ocean.

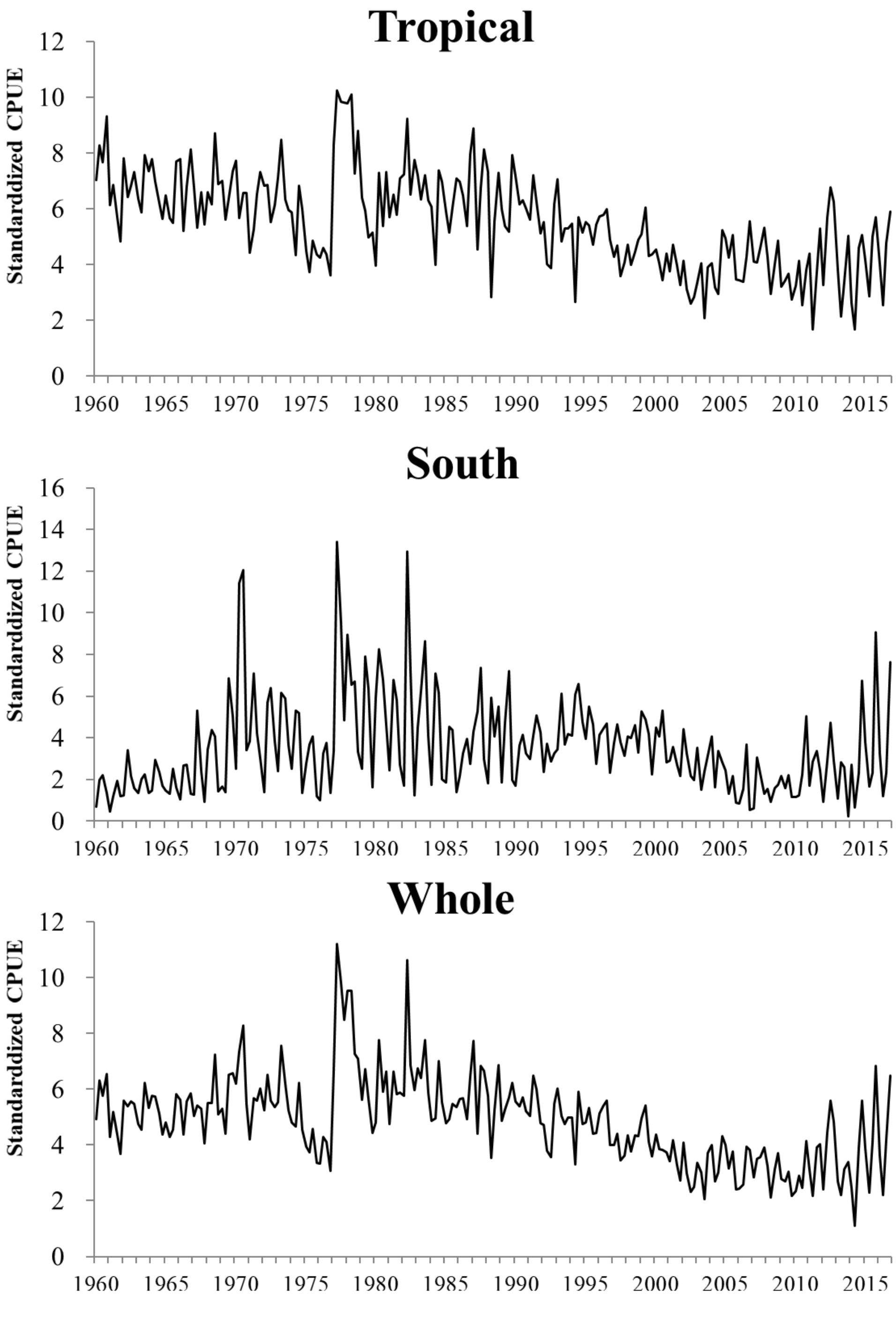
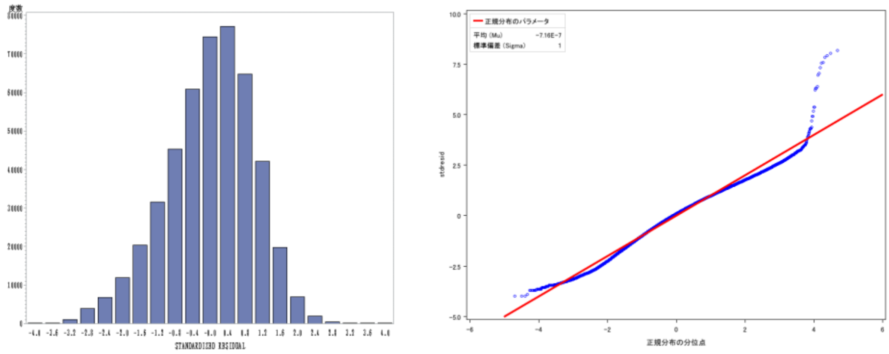


Fig. 5. Trend of area aggregated quarterly CPUE series of bigeye for tropical (top), south (middle) and whole (bottom) Indian Ocean

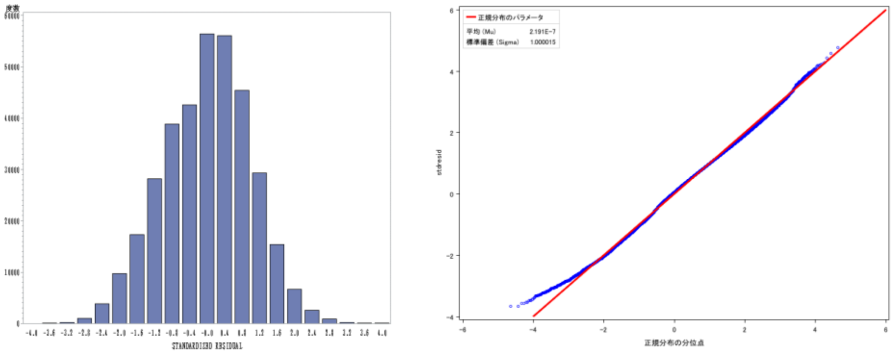
1960-2016 Year based

Tropical area



1960-2016 Year based

South area



1960-2016 Year based

Whole area

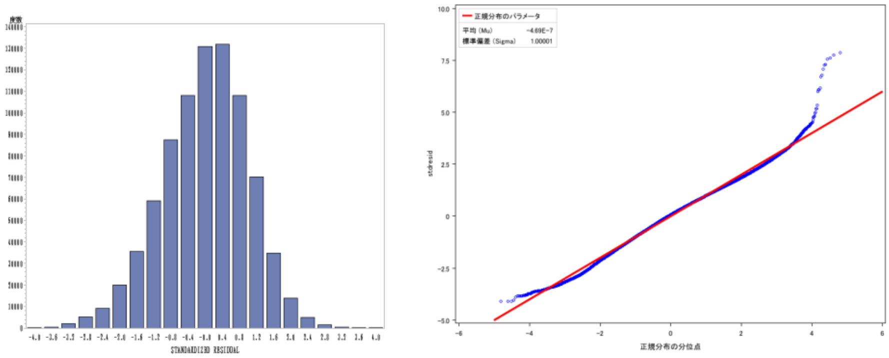
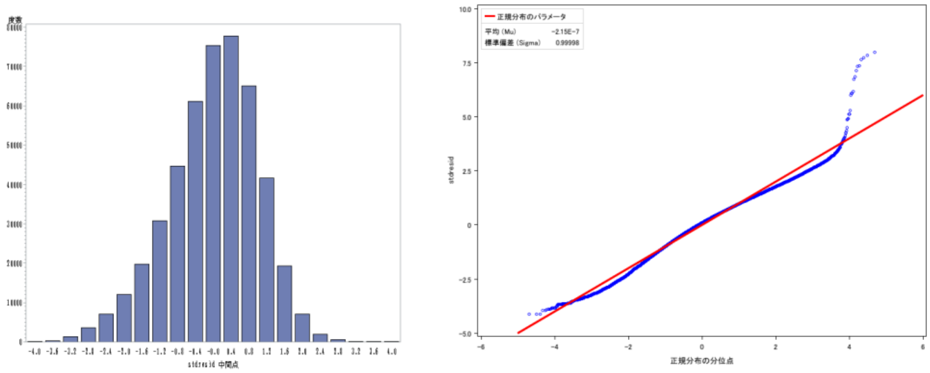


Fig. 6. Standardized residuals of area aggregated annual CPUE standardization.

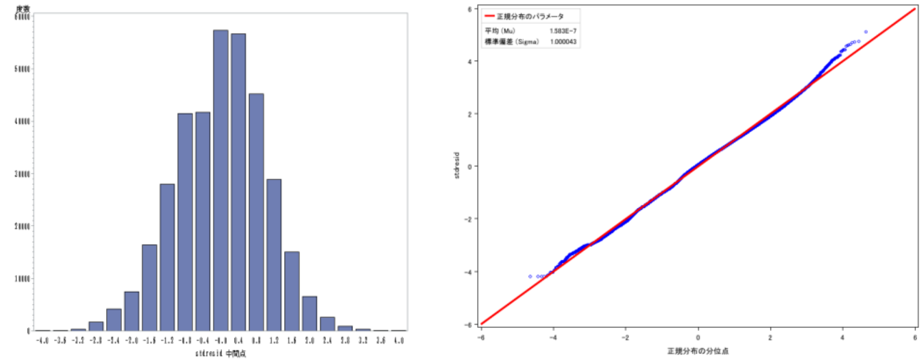
1960-2016 quarter based

Tropical area



1960-2016 quarter based

South area



1960-2016 quarter based

Whole area

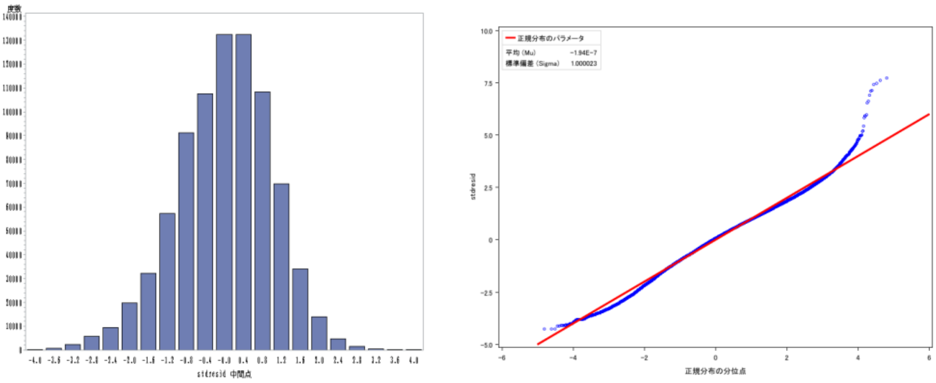


Fig. 7. Standardized residuals of area aggregated quarterly CPUE standardization.

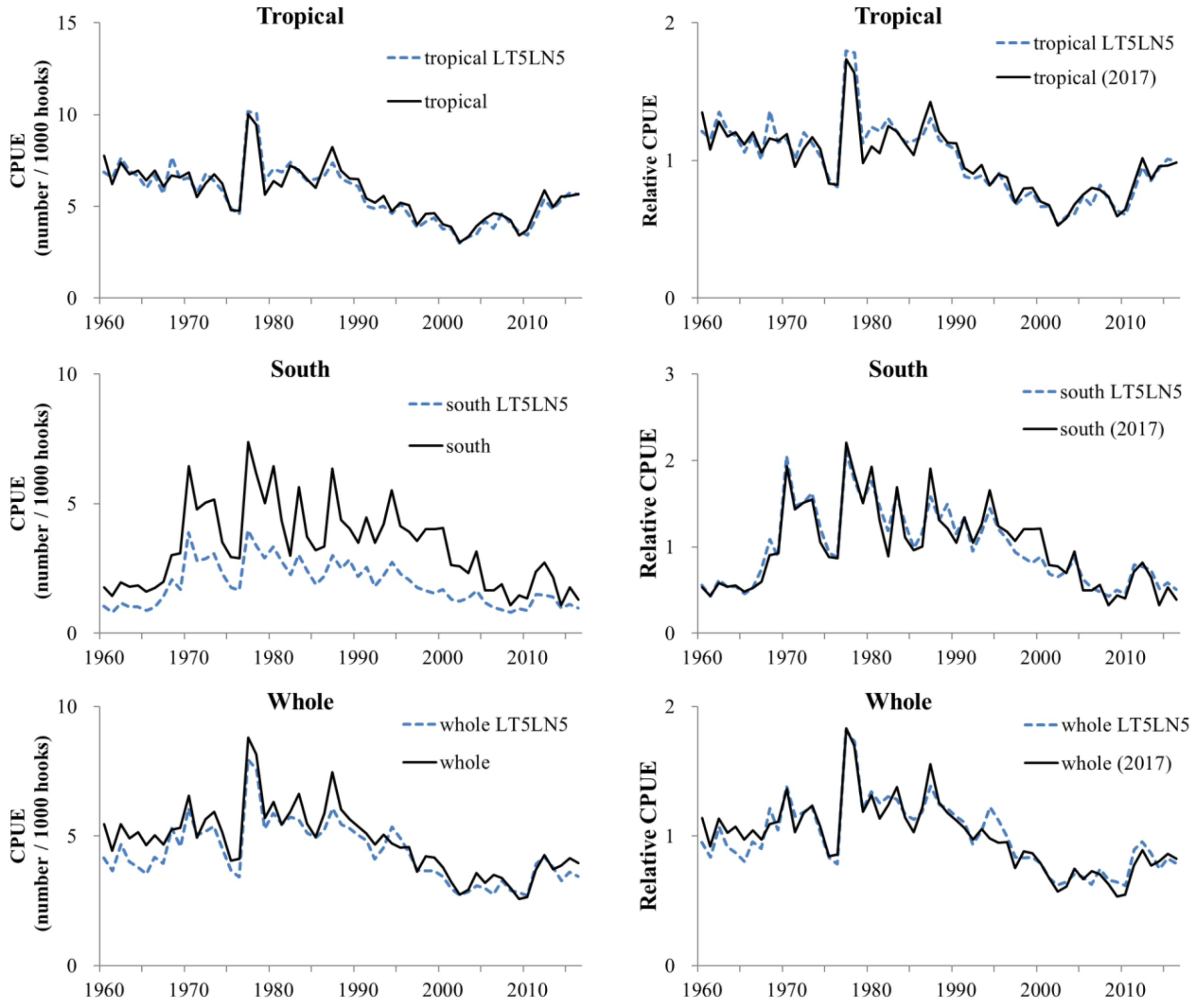


Fig. 8. Comparison of area aggregated CPUE series of bigeye between the model including subarea effect and that including LT5LN5 effect. Left: real scale, right: relative scale.

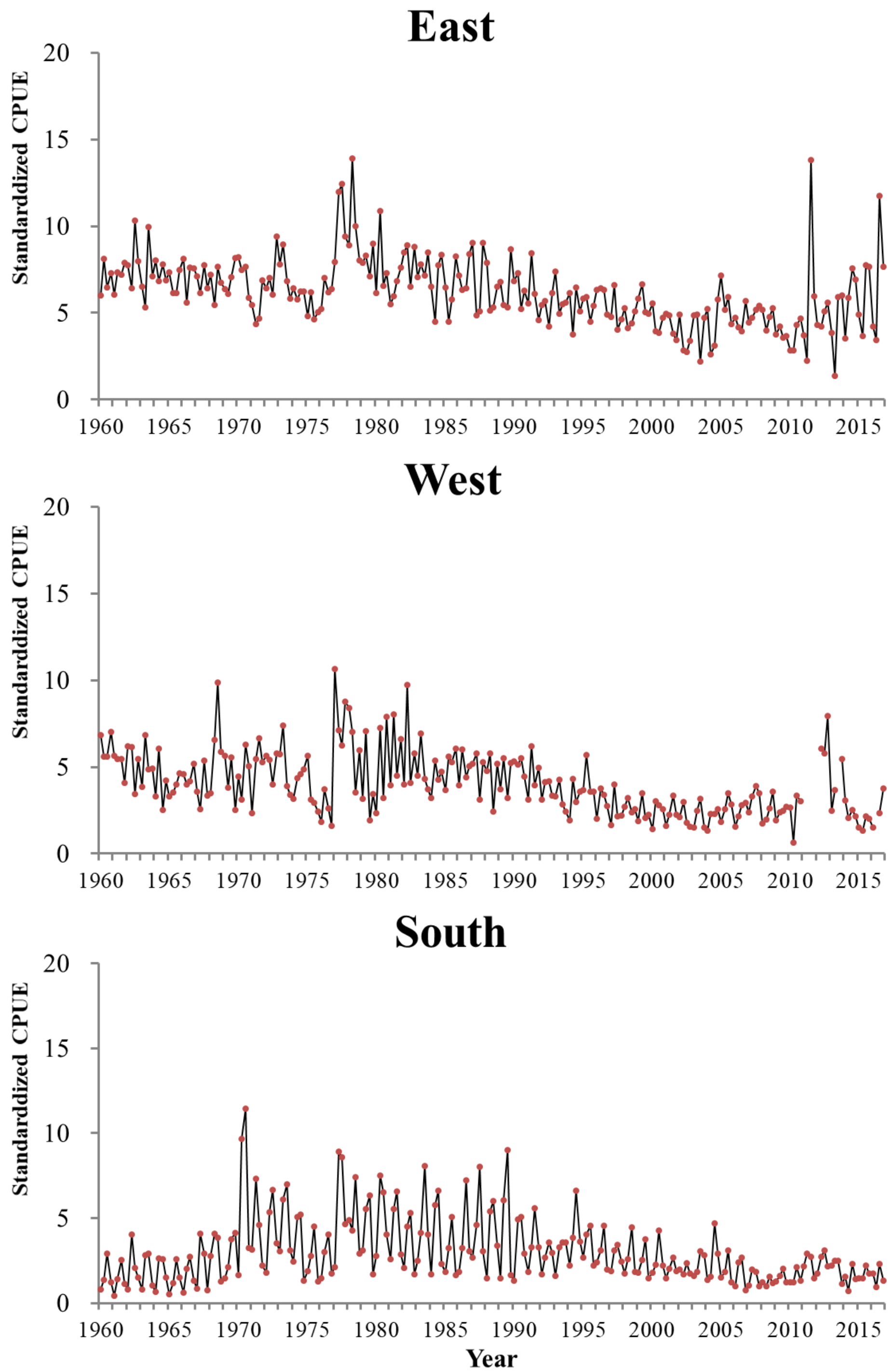
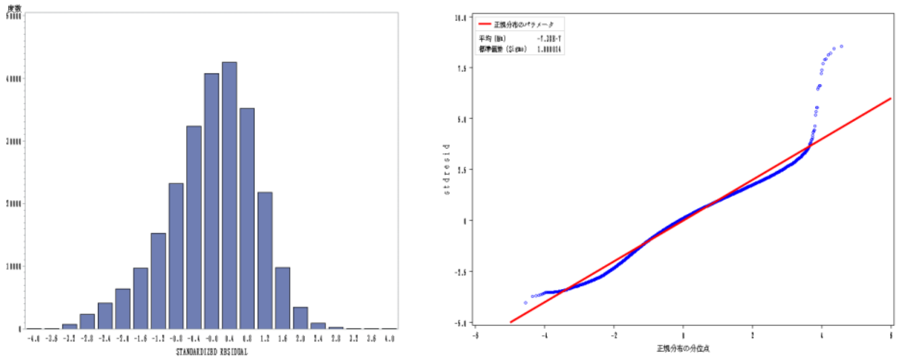


Fig. 9. Comparison of area specific quarterly CPUE series of bigeye tuna by Japanese longline for the east (top), west (middle) and south (bottom) area.

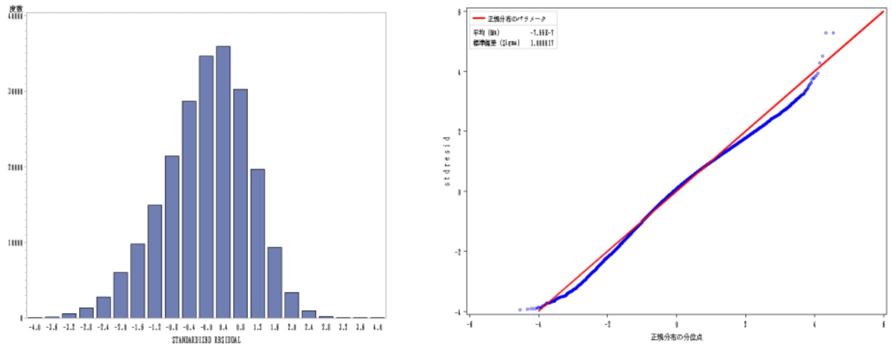
1960-2016 quarter based

East area



1960-2016 quarter based

West area



1960-2016 quarter based

South area

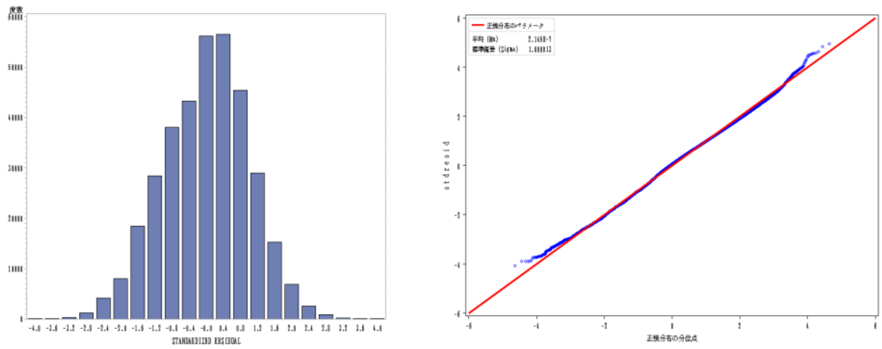


Fig. 10. Standardized residuals of area specific quarterly CPUE standardization.