IOTC–2016–WPTT18–13
Received: 21 October 2016

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 1960-2015 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 2015 or before. The effects of season (month or quarter), subarea, LT1LN1 (one degree latitude-longitude block), 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. No clear difference of the trend of CPUE was observed based on the model with subarea, LT1LN1 or LT5LN5.

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) 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). Methods of standardization in this study are the similar to above mentioned studies. In this study, area specific and area aggregated CPUEs have been created for the stock assessment of bigeye tuna scheduled this year as well as to provide an indicator of the stock. In addition, an alternative method was also examined for area aggregated CPUE to consider if the trend of CPUE differs depending on standardization methods, by using the effect of each latitude 1 degree and longitude 1 degree square as for fishing ground instead of each latitude 5 degree and longitude 5 degree square or subareas.

This year IOTC joint CPUE analysis was conducted and standardized CPUE for bigeye tuna as well as yellowfin tuna and albacore were created using operational level data for Japanese, Korean and Taiwanese longline fishery combined. One of the objectives of this study is to compare CPUE indices with those by the joint CPUE analysis.

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 - 2015 IOTC WPTT meetings (Satoh and Okamoto 2012, Matsumoto et al. 2013, Ochi et al. 2014, Matsumoto et al. 2015). 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 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 2015 were used. 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;

Area aggregated CPUE (annual):

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

Area aggregated CPUE (quarterly):

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

Area specific CPUE:

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 1960-2015 for all CPUEs.

As for alternative method, area aggregated CPUE (annual base) was standardized using the effect of LT5LN5 or LT1LN1 (effect of each latitude 1 degree and longitude 1 degree square) 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

Area aggregated CPUE (annual, with LT1LN1):

Log [CPUE +const] = μ + year + month + LT1LN1 + NHFC + SST + ML + NHFC*ML + error

LT1LN1: effect of each latitude 1 degree and longitude 1 degree square,

In these models, 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. 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 in 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 until 2014, and increased again in 2015. 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 or LT1LN1 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 and the second largest in the south area, indicating that the effect of fishing ground is important. Comparison of CPUE trend among the model with different effect of fishing ground (subarea, LT5LN5 or LT1LN1) (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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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	45.22

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	366	81307.90	222.15	345.28	<.0001
year	55	5066.38	92.12	143.17	<.0001
month	11	1997.18	181.56	282.19	<.0001
area	4	1593.11	398.28	619.03	<.0001
nhfc	5	406.29	81.26	126.3	<.0001
sst	1	116.27	116.27	180.72	<.0001
ML	1	77.47	77.47	120.42	<.0001
year*area	216	8446.18	39.10	60.78	<.0001
month*area	44	3068.92	69.75	108.41	<.0001
area*nhfc	20	992.56	49.63	77.13	<.0001
sst*area	4	1404.33	351.08	545.68	<.0001
nhfc*ML	5	581.22	116.24	180.67	<.0001

south

RSquare	CV
0.31	131.01

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	151	146949.18	973.17	1052.02	<.0001
year	55	24230.80	440.56	476.26	<.0001
month	11	12892.58	1172.05	1267.02	<.0001
area	1	57.07	57.07	61.69	<.0001
nhfc	5	1446.73	289.35	312.79	<.0001
sst	1	4392.10	4392.10	4747.96	<.0001
ML	1	14.91	14.91	16.12	<.0001
year*area	55	6331.21	115.11	124.44	<.0001
month*area	11	2506.60	227.87	246.34	<.0001
area*nhfc	5	748.81	149.76	161.9	<.0001
sst*area	1	255.40	255.40	276.1	<.0001
nhfc*ML	5	226.06	45.21	48.88	<.0001

whole

RSquare	CV
0.36	60.62

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	512	327016.31	638.70	912.9	<.0001
year	55	10390.93	188.93	270.03	<.0001
month	11	2712.22	246.57	352.41	<.0001
area	6	2042.56	340.43	486.57	<.0001
nhfc	5	1025.28	205.06	293.09	<.0001
sst	1	16.79	16.79	23.99	<.0001
ML	1	3.06	3.06	4.37	0.0366
year*area	326	28791.52	88.32	126.23	<.0001
month*area	66	13668.11	207.09	296	<.0001
area*nhfc	30	2368.42	78.95	112.84	<.0001
sst*area	6	2442.24	407.04	581.78	<.0001
nhfc*ML	5	449.32	89.86	128.44	<.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
quarter	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 or LT1LN1 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	45.13

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	159	82391.26	518.18	808.67	<.0001
year	55	7310.10	132.91	207.42	<.0001
month	11	1787.45	162.50	253.59	<.0001
LT5LN5	74	35159.17	475.12	741.47	<.0001
nhfc	5	127.90	25.58	39.92	<.0001
sst	8	1119.47	139.93	218.38	<.0001
ML	1	50.75	50.75	79.2	<.0001
nhfc*ML	5	342.15	68.43	106.79	<.0001

south

RSquare	CV
0.33	128.93

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	141	157201.23	1114.90	1244.57	<.0001
year	55	25252.24	459.13	512.53	<.0001
month	11	12107.16	1100.65	1228.66	<.0001
LT5LN5	46	14033.53	305.08	340.56	<.0001
nhfc	5	606.07	121.21	135.31	<.0001
sst	18	7152.93	397.38	443.6	<.0001
ML	1	2.97	2.97	3.31	0.0687
nhfc*ML	5	114.88	22.98	25.65	<.0001

whole

RSquare	CV
0.35	61.40

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	217	312036.31	1437.96	2003.52	<.0001
year	55	17374.99	315.91	440.16	<.0001
month	11	4417.80	401.62	559.58	<.0001
LT5LN5	121	126013.29	1041.43	1451.04	<.0001
nhfc	5	325.46	65.09	90.69	<.0001
sst	19	9849.00	518.37	722.25	<.0001
ML	1	20.73	20.73	28.89	<.0001
nhfc*ML	5	235.97	47.19	65.75	<.0001

Annual with LT1LN1

tropical

RSquare	CV
0.25	44.24

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	1693	94977.56	56.10	91.1	<.0001
year	55	6895.18	125.37	203.57	<.0001
month	11	1618.22	147.11	238.88	<.0001
LT1LN1	1608	47745.47	29.69	48.21	<.0001
nhfc	5	90.46	18.09	29.38	<.0001
sst	8	1326.62	165.83	269.27	<.0001
ML	1	32.65	32.65	53.02	<.0001
nhfc*ML	5	264.67	52.93	85.95	<.0001

south

RSquare	CV
0.36	126.05

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	1118	171903.66	153.76	179.56	<.0001
year	55	19149.00	348.16	406.59	<.0001
month	11	9315.54	846.87	988.98	<.0001
LT1LN1	1023	28735.97	28.09	32.8	<.0001
nhfc	5	505.71	101.14	118.11	<.0001
sst	18	3387.05	188.17	219.75	<.0001
ML	1	2.08	2.08	2.43	0.1191
nhfc*ML	5	86.99	17.40	20.32	<.0001

whole

RSquare	CV
0.38	59.87

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	2728	342555.68	125.57	183.99	<.0001
year	55	14885.47	270.64	396.56	<.0001
month	11	3639.16	330.83	484.75	<.0001
LT1LN1	2632	156532.65	59.47	87.14	<.0001
nhfc	5	219.17	43.83	64.23	<.0001
sst	19	4965.08	261.32	382.89	<.0001
ML	1	12.42	12.42	18.2	<.0001
nhfc*ML	5	182.23	36.45	53.4	<.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

RSquare	CV
0.15	39.25

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	282	24593.80	87.21	148.24	<.0001
year	55	2428.38	44.15	75.05	<.0001
quarter	3	111.33	37.11	63.08	<.0001
nhfc	5	89.33	17.87	30.37	<.0001
ML	1	41.31	41.31	70.22	<.0001
LT5LN5	48	10574.34	220.30	374.46	<.0001
year*quarter	165	3120.06	18.91	32.14	<.0001
nhfc*ML	5	125.19	25.04	42.56	<.0001

West

RSquare	CV
0.29	52.41

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	254	59598.93	234.64	353.06	<.0001
year	54	4242.70	78.57	118.22	<.0001
quarter	3	472.82	157.61	237.15	<.0001
nhfc	5	78.93	15.79	23.75	<.0001
ML	1	4.44	4.44	6.68	0.0097
sst	1	20.71	20.71	31.16	<.0001
LT5LN5	25	7352.37	294.09	442.52	<.0001
year*quarter	160	6575.94	41.10	61.84	<.0001
nhfc*ML	5	99.82	19.96	30.04	<.0001

South

RSquare	CV
0.34	128.19

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Model	281	160897.29	572.59	646.53	<.0001
year	55	19118.61	347.61	392.5	<.0001
quarter	3	7611.32	2537.11	2864.7	<.0001
nhfc	5	785.52	157.10	177.39	<.0001
ML	1	7.85	7.85	8.86	0.0029
sst	1	299.87	299.87	338.6	<.0001
LT5LN5	46	17056.87	370.80	418.68	<.0001
year*quarter	165	14550.28	88.18	99.57	<.0001
nhfc*ML	5	156.73	31.35	35.39	<.0001

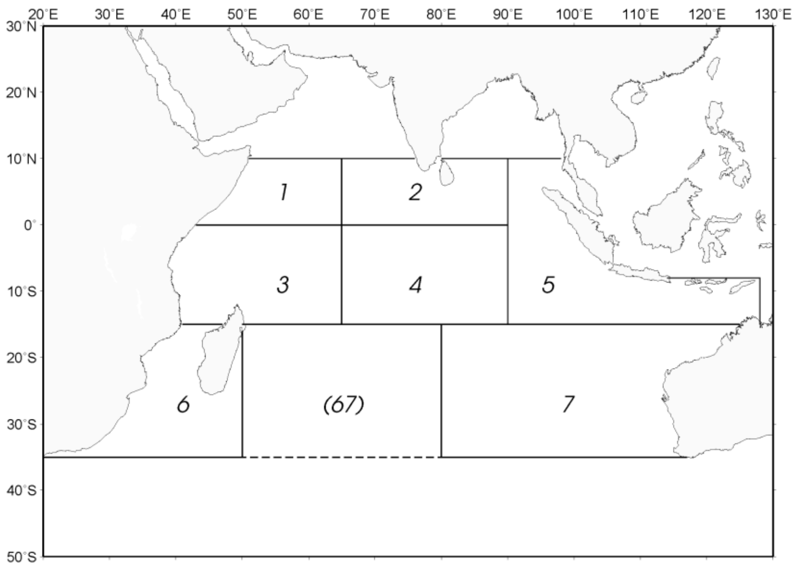


Fig. 1. Definition of sub-areas for area aggregated CPUE used in this study. The tropical, south and whole Indian Ocean regions in this paper consist of areas 1-5, areas 6-7 and areas1-7, respectively. Area 67 was not used in this study.

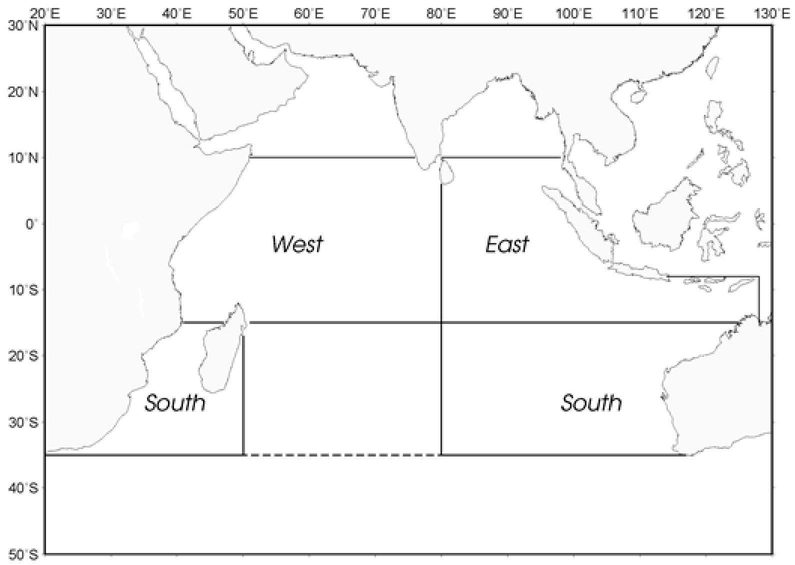


Fig. 2. Another definition of areas for area specific CPUE formatted for integrated model.

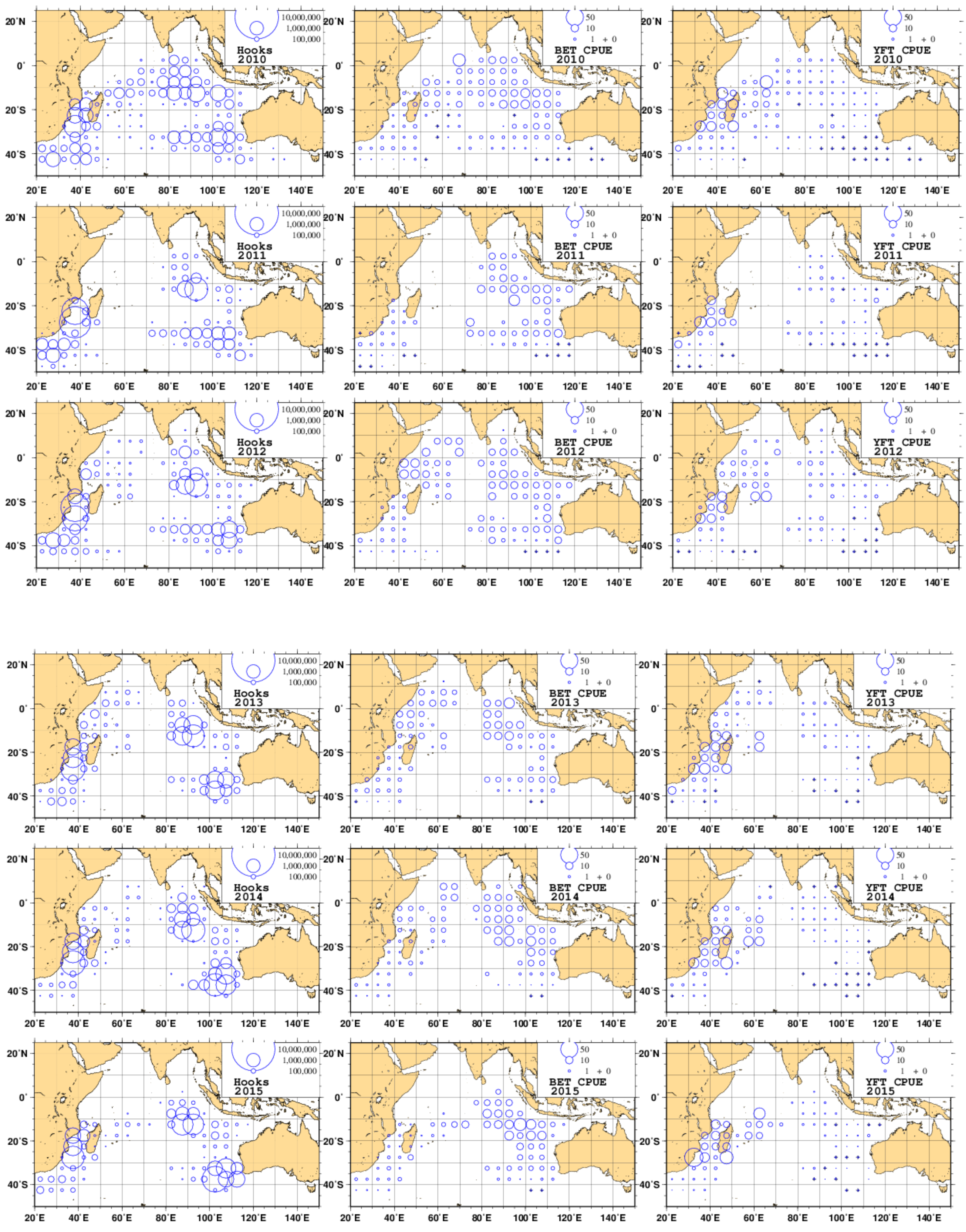


Fig. 3. Geographical distribution of fishing effort and nominal CPUE for bigeye and yellowfin tuna by Japanese longline in recent years.

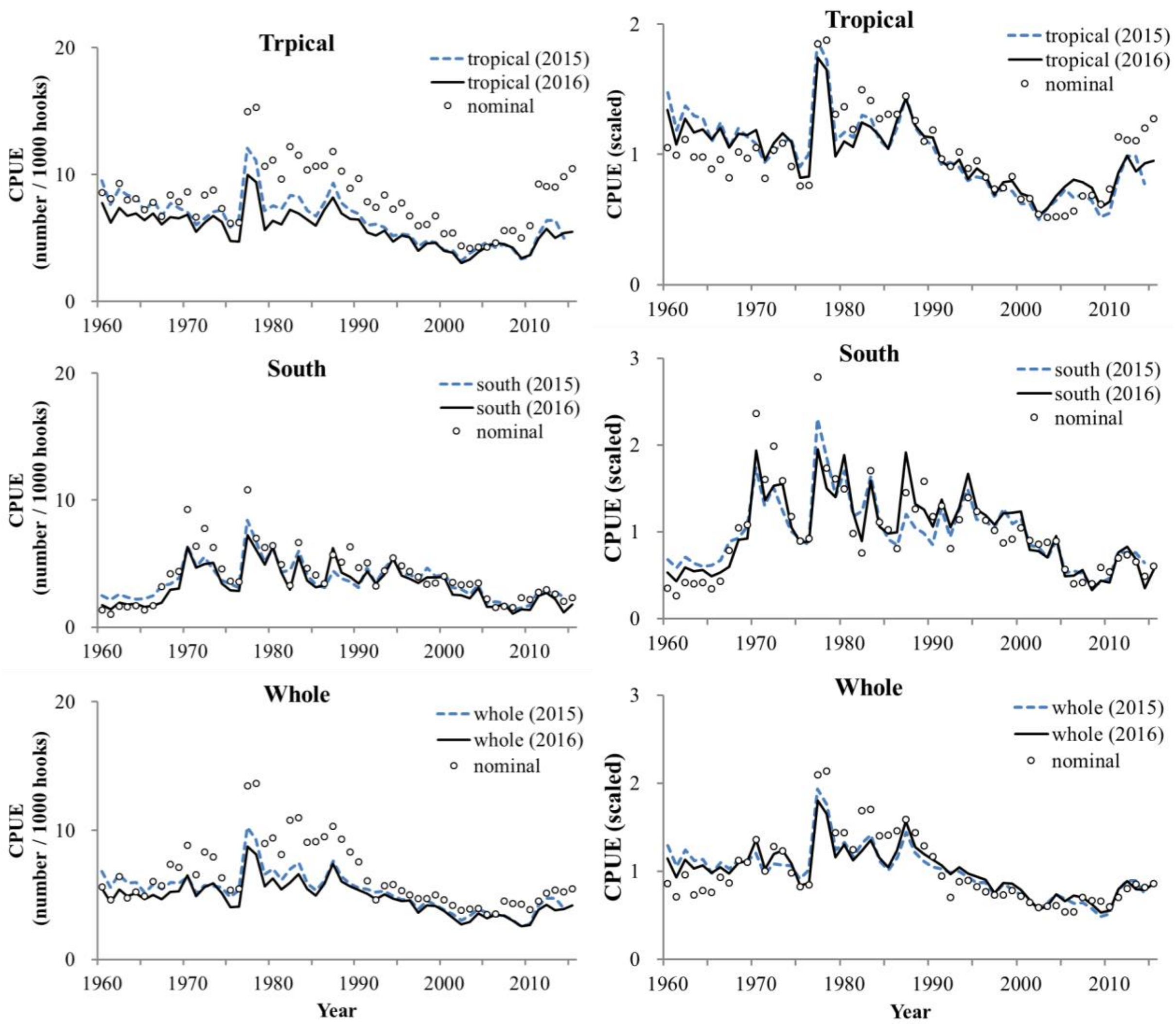


Fig. 4. Trend of area aggregated annual CPUE (left: real scale, right: relative scale) of bigeye. Standardized CPUE created in 2016 (solid line), nominal CPUE (open circle), and standardized CPUE created in 2015 (dashed line: Matsumoto el al., 2015) of Japanese longline for the tropical (top), south (middle) and whole (bottom) Indian Ocean.

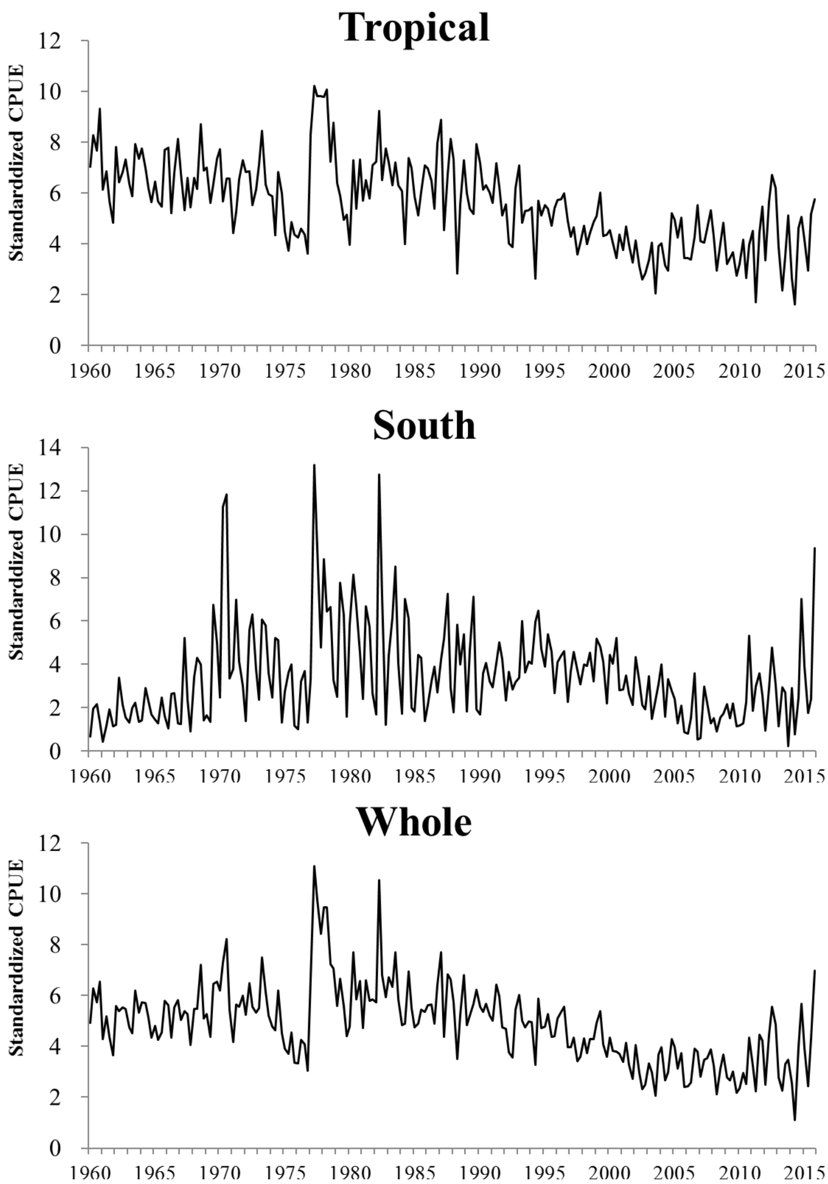
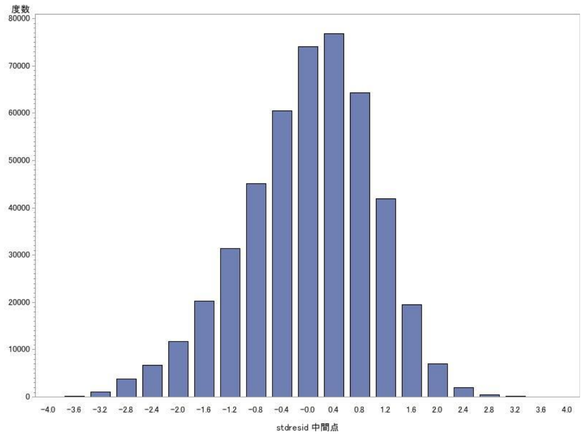
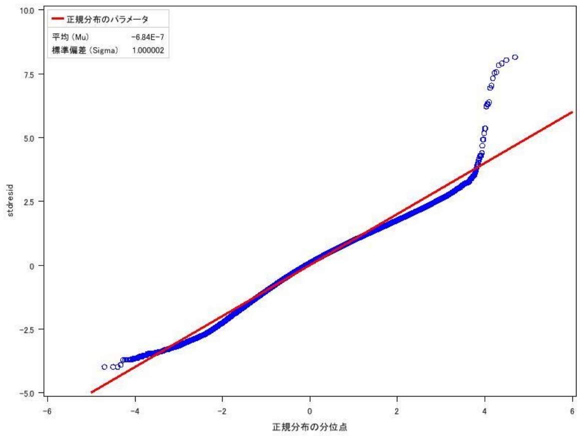


Fig. 5. Trend of area aggregated quarterly CPUE series of bigeye for tropical (top), south (middle) and whole (bottom) Indian Ocean

1960-2015 Year based

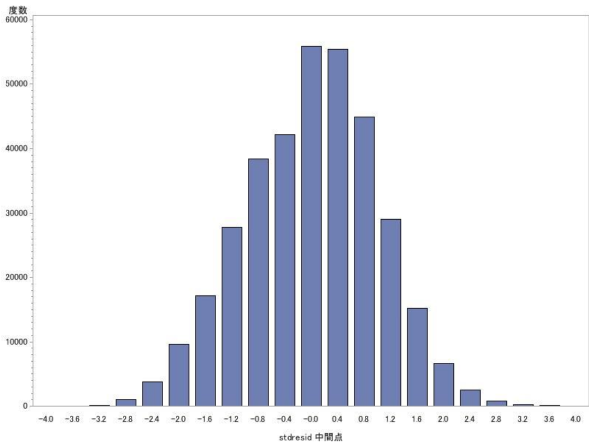
Tropical area

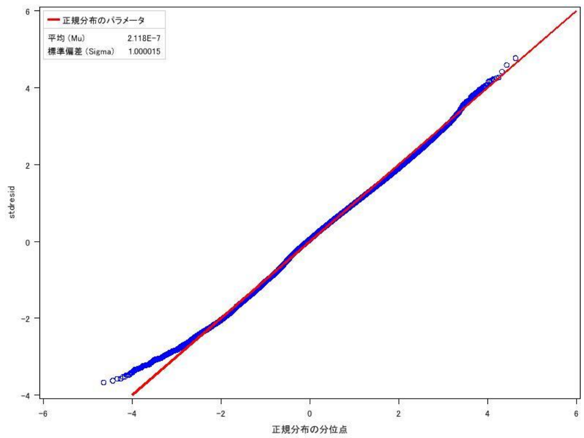




1960-2015 Year based

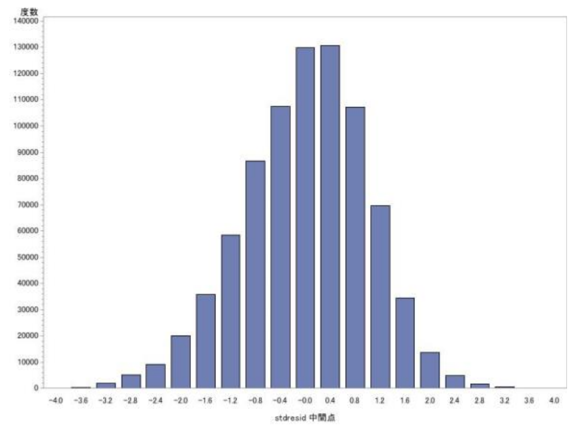
South area





1960-2015 Year based

Whole area



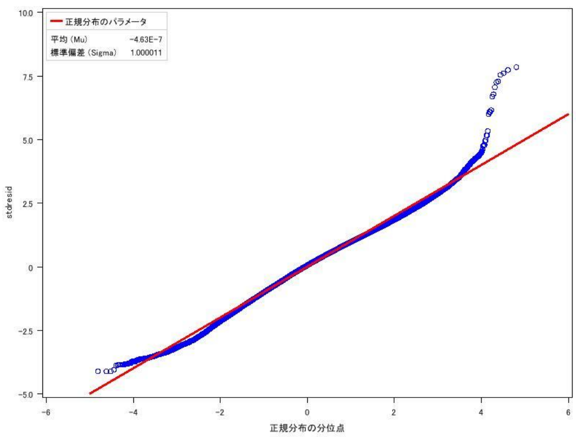
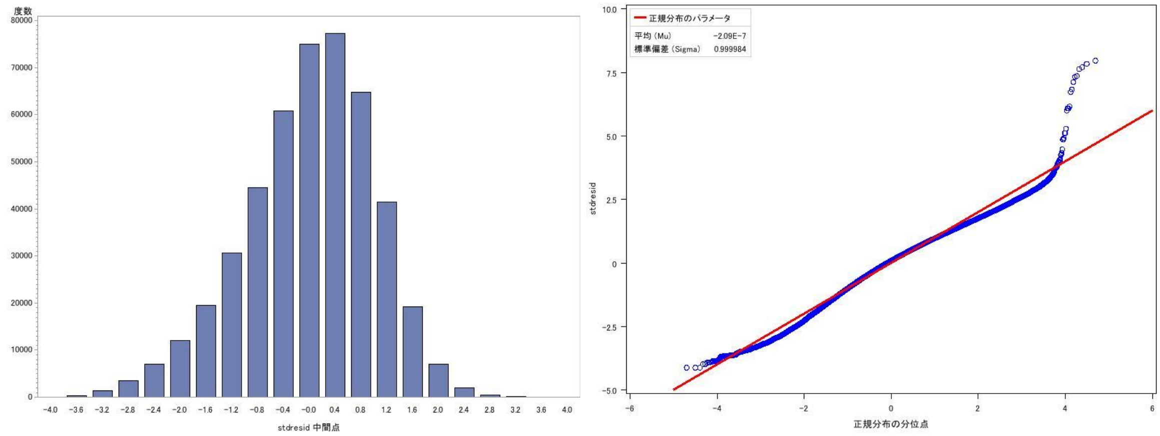


Fig. 6. Standardized residuals of area aggregated annual CPUE standardization.

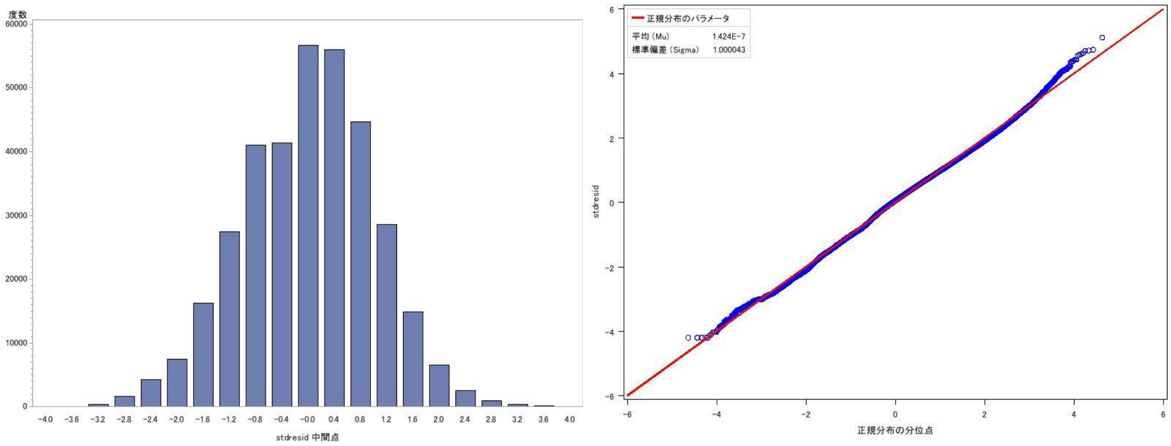
1960-2015 quarter based

Tropical area



1960-2015 quarter based

South area



1960-2015 quarter based

Whole area

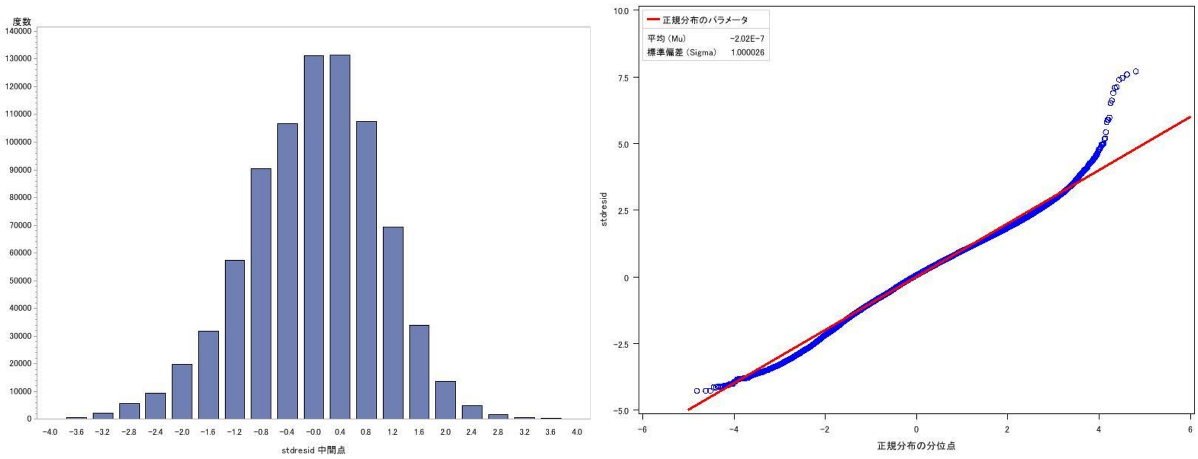


Fig. 7. Standardized residuals of area aggregated quarterly CPUE standardization.

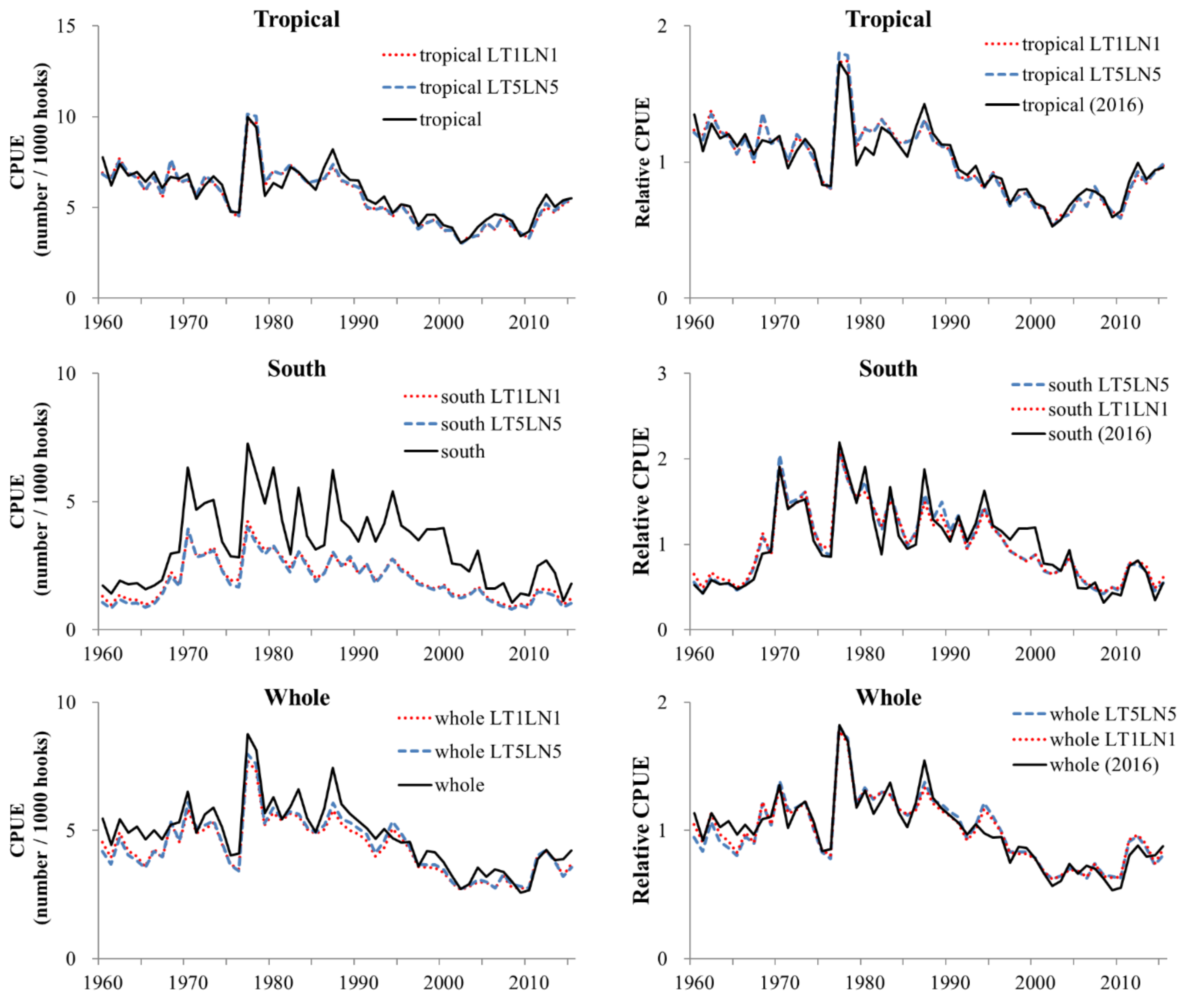


Fig. 8. Comparison of area aggregated CPUE series of bigeye between the model including subarea effect and that including LT5LN5 or LT1LN1 effect. Left: real scale, right: relative scale.

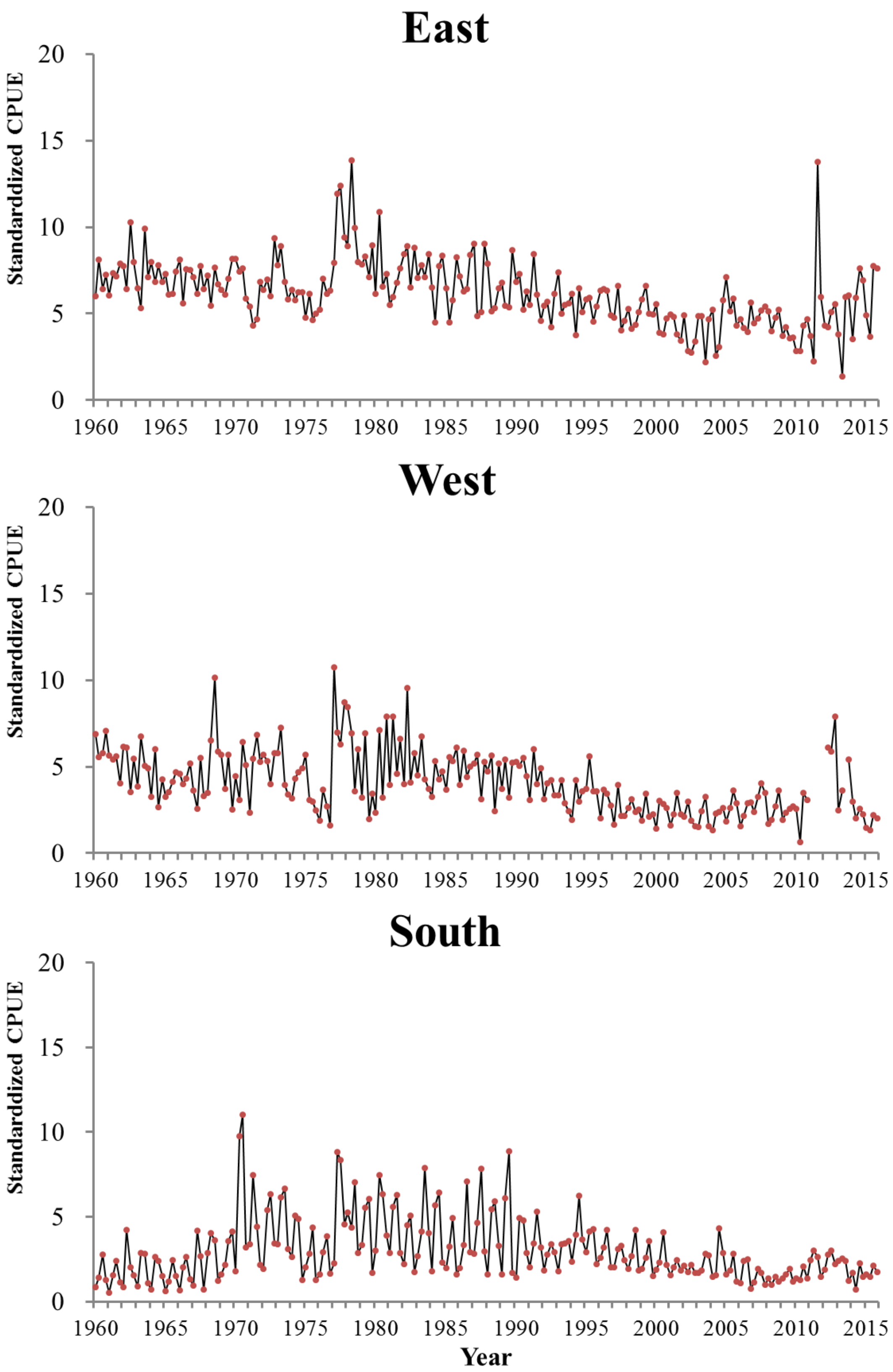
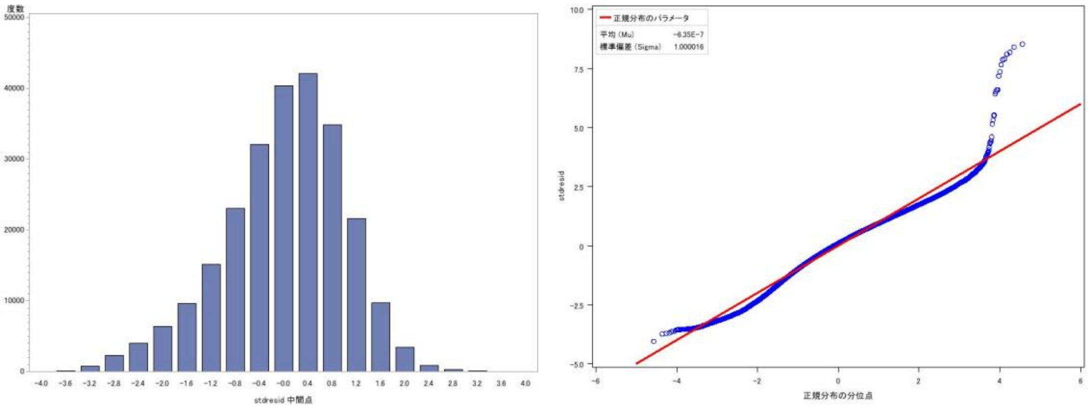


Fig. 9. Comparison of area specific quarterly CPUE series of bigeye tuna by Japanese longline for the east (top), west (middle) and south (bottom) area.

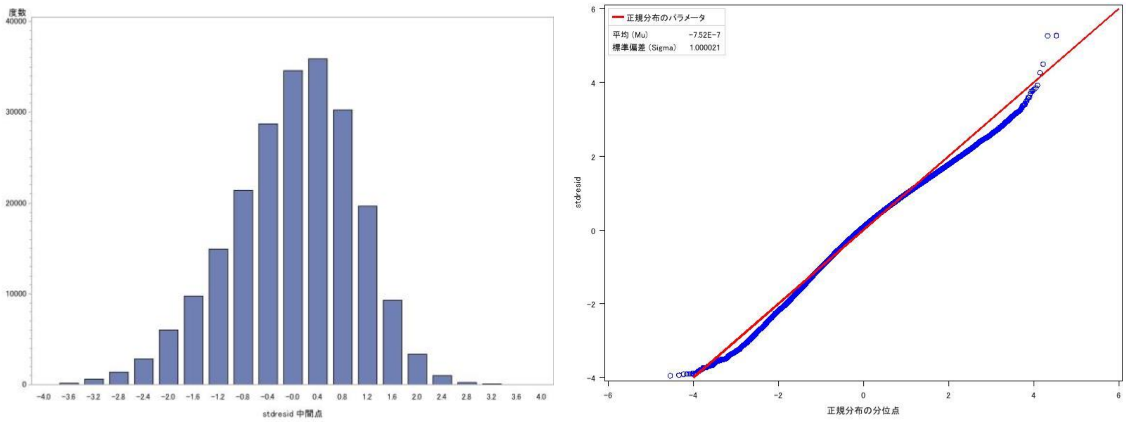
1960-2015 quarter based

East area



1960-2015 quarter based

West area



1960-2015 quarter based

South area

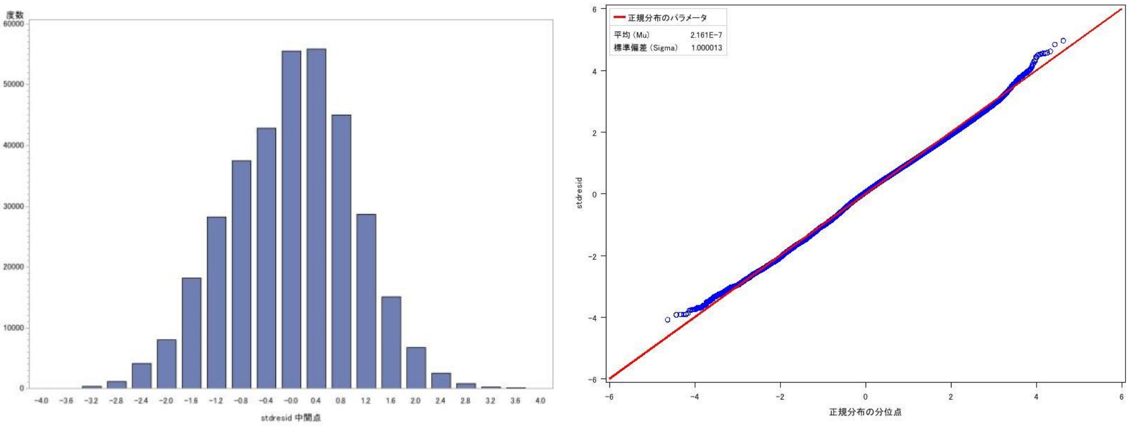


Fig. 10. Standardized residuals of area specific quarterly CPUE standardization.