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Japanese longline CPUE for yellowfin tuna in the Indian Ocean standardized by generalized linear model

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Abstract

Japanese longline CPUE for yellowfin tuna in the Indian Ocean (area aggregated and area-specific) was standardized up to 2016 by GLM based on similar method to thaose in the previous studies. Basically, standardized CPUEs showed similar trends among areas. CPUE continuously decreased from early 1960s to 1974, and kept in the same level until 1990. Thereafter, it declined to historical low level in recent years. The stable trend in recent years at all models indicates decreased effort caused by piracy activity in area 2 (northwest) has little effect on overall CPUE trends. Applying 5 degree latitude/longitude effect showed large effect on the CPUE trend for Area 3 (southwest) and 4 (south). There was some difference of area aggregated CPUE between the model with subarea and with 5 degree latitude/longitude.

1. Introduction

Yellowfin tuna is one of main target species for Japanese longline fishery in the Indian Ocean. Its abundance indices are very important for stock assessment or stock indicator of this species. Yellowfin tuna is mainly caught in the tropical and subtropical areas especially in the western Indian Ocean (Matsumoto and Satoh, 2012; Matsumoto 2014). Since 2007, piracy activities off Somalia has increased and spread to whole northwestern Indian Ocean. Japanese longline effort in the Indian Ocean, especially in the northwestern part, has rapidly decreased to avoid the piracy attack. In the IOTC WPTT meeting in 2010, a concern about the effect of the decreased effort on the CPUE trend of the longline fishery was recognized. Okamoto (2011b) estimated the regional effect of the decreased longline effort on the CPUE trend in the Indian Ocean, and suggested that the decreased effort in northwestern Indian Ocean has no more been able to represent the CPUE trend in this region. Therefore, Okamoto (2011a) calculated CPUE trends for both scenarios including and excluding Area 2 (northwestern area) and found that the trends were similar. At 2012-2015 IOTC WPTT meetings, Matsumoto et al. (2012, 2013) and Ochi et al. (2014, 2015) conducted CPUE standardization by using area rate without northwest area because no effort was observed in this area in 2011 due to piracy activities, and the indices were used for stock assessment in 2012 and 2015. Matsumoto et al. (2016) also reported standardization of yellowfin tuna CPUE based on similar methods as those in the previous studies with additionally using the effect of LT1LN1 (1 degree latitude/longitude effect). They found that there was only small difference of CPUE between with LT5LN5 and with LT1LN1. Matsumoto et al. (2016) also relieved tha concern that CPUE got higher as the number of hooks between floats (NHF) increases, which does not agree to expected result, by using LT5LN5 instead of subareas for the effect of fishing ground.

In this study, Japanese longline CPUE for yellowfin tuna in the Indian Ocean was standardized by Generalized Linear Model which is equivalent to those by Okamoto and Shono (2010), Okamoto (2011a), Matsumoto et al. (2012, 2013, 2016) and Ochi et al. (2014, 2015). As with these studies, number of hooks between floats (NHF) and material of main and branch lines were applied in the model to standardize the change of the catchability which has been derived by fishing gear configuration.

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

Generalized linear model (GLM) was applied to standardize the Japanese longline CPUE for yellowfin tuna. Principally, the model used for the standardization in this paper is equivalent to that used in the previous studies (Okamoto and Shono, 2010; Okamoto, 2011a; Matsumoto et al., 2012; 2013; 2016, Ochi et al., 2014). In the standardization, no environmental factor was applied in the model.

Area definition:

Area definition in this study which consists of five areas is the same as that used in the yellowfin assessment in IOTC WPTT 2010 – 2012 or the analyses in 2013-2016 (Fig. 1), although Area 1 was not used because of too little effort. CPUE was standardized for main fishing ground (Area 2, 3 and 5) and whole fishing grounds (Area 2, 3, 4 and 5) and for both areas excluding Area 2. Ochi et al (2015) additionally used the area which combined area 2 and area 3 (named as area 3') for standardization in whole fishing ground and for area specific CPUE, but is was not used in this study because it was not used for stock assessment in 2016.

Catch and effort data used:

The Japanese longline catch (in number) and effort statistics from 1963 up to 2016 were used. Data for 2016 are preliminary. Start year is the same as that in the previous studies. Original (operational level) logbook data were used, which include the number of hooks between floats (NHF) and main and branch line materials, were used for the analysis. 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 and branch line material was classified into two categories, 1 = Nylon and 2 = other. Although the information on the materials has been collected since 1994, the nylon material was started to be used by distant water longliner in the tropical Indian Ocean around the late 1980s and spread quickly in the early 1990s (Okamoto, 2005). And it seems that the NHF larger than 17 or 18 would have become possible to be used as a result of introduction of the new material. Therefore, the material of NHF 18 or larger was assumed to be nylon since 1990.

GLM (Generalized Linear Model):

CPUE based on the catch in number was used. CPUE is calculated as "the number of fish caught / the number of hooks * 1000". As the model for standardizing CPUE, GLM-LogNormal error structure was used. The followings are the initial model for each analysis. Based on the result of ANOVA (type III SS), non-significant effects were removed in backward stepwise from the initial model based on the F-value ($p < 0.05$). In the cases in which the factor is not significant as main factor but is significant as interaction with other factor, the main factor was kept in the model.

Annual CPUE was standardized for main (Area 2, 3 and 5) and whole (Area 2-5) fishing grounds for 1963-2016. In addition, area specific annual and quarterly CPUE was also standardized for each of four subareas for 1963-2016 in order to provide CPUE index used for assessment using Multifan-CL software and Stock Synthesis 3 (SS3). In the previous studies, subareas were mainly used for the effect of fishing ground in the CPUE standardization for main and whole fishing grounds. However, subareas seem to be too broad, and so in this stury only the factor of each 5 degree latitude and longitude square (LT5LN5) was used. Also, in the previous studies, as for area specific CPUE, the models with and without LT5LN5 were examined. We considered that the effect of LT5LN5 was essential, and so we used models only with LT5LN5.

- Initial Model for year based CPUE standardization in the main and whole fishing grounds

Log (CPUE+const)=μ+YR +QT +LT5LN5 +NHFCL +ML +BL +YR*QT + NHFCL*ML +NHFCL*BL + e

- Initial Model for year or quarter based CPUE standardization in each area (including explanatory factor of each latitude 5 degree and longitude 5 degree square)

Log (CPUE+const)=μ+YR +QT + NHFCL +ML +BL +LT5LN5 +NHFCL*ML +NHFCL*BL + e

where Log : natural logarithm,
CPUE : catch in number of bigeye per 1000 hooks,
const : 10% of overall mean of CPUE

μ : over all mean (intercept),
YR : effect of year,
QT : effect of fishing season (quarter),
NHFCL : effect of number of hooks between floats (categorized),
ML : effect of material of main line,
BL : effect of material of branch line,
LT5LN5: effect of each latitude 5 degree and longitude 5 degree square
YR*QT : interaction term between year and quarter,
NHFCL*ML: interaction term between effect of number of hooks between floats and main line material,
NHFCL*BL: interaction term between effect of number of hooks between floats and branch line material,
e : error term.

The number of hooks between float (NHF) was divided into 6 classes (NHFCL 1: 5-7, NHFCL 2: 8-10, NHFCL 3: 11-13, NHFCL 4: 14-16, NHFCL 5: 17-19, NHFCL 6: 20 or more) as later explanation. In the past analyses, NHFCL 6 was set to 20-21, but it was changed to 20 or more because substantial fishing effort is deployed for the NHF >21.

Effect of year was obtained by the method used in Ogura and Shono (1999) that uses Lsmean of Year-Area interaction as the following equation.

CPUEi = Σ Wj * (exp(lsmean(Year i*Area j))-const)
where CPUEi = CPUE in year i,
Wj = Area proportion of Area j , (ΣWj = 1),
lsmean(Year*Areaij) = least square mean of Year-Area interaction in Year i and Area j (As for the quarter based CPUE, least square mean of Year*Quarter*Area was used instead),
const= 10% of overall mean of CPUE.

As for standardized CPUE in the main and whole fishing grounds which includes Area 2, CPUE in 2011 was calculated using area rate without Area 2 because no effort was observed in the Area 2 due to piracy activities. The yellowfin CPUEs (catch in number per 1000 hooks) in year and quarter bases were standardized by GLM (CPUE-LogNormal error structured model) for each of area categories, main (Area 2, 3 and 5 or Area 3 and 5) and whole (Areas 2, 3, 4 and 5 or area 3, 4 and 5) fishing grounds. To see effects of each component (fishing gear, season and area), the model for year based CPUE in the whole fishing ground without 2011 data was used only for this purpose.

3. Results and discussion

CPUE standardizations by GLM

Trends of annual CPUEs for main and whole fishing grounds (with and without Area 2, respectively) are shown in Fig. 2 in real and relative scale overlaying nominal CPUE. Basically, standardized CPUE including and excluding Area 2 showed similar trend. In the main fishing ground, CPUE continuously decreased from 1960s to around 1974, and kept in the same level until 1990 with jump in 1977. Thereafter, it declined and has been kept in a low level with fluctuation until 2007. After that, the CPUE declined to historical low level and was almost constant. As this declining trend in the resent years was detected in both models including and excluding Area 2 where the piracy activity had been increasing since 2007, the recent declining trend would be reflecting actual change in abundance rather than change in CPUE derived from shift of fishing ground and/or decreased effort caused by increased piracy activity. The trend of standardized CPUE for whole fishing ground was similar to that of main fishing ground.

Results of ANOVA and distributions of the standardized residual for main and whole fishing grounds are shown in Table 1 and Fig. 3, respectively. ANOVA tables indicate that the effect of LT5LN5 was largest or second largest, indicating that the effect of fishing area is important. In all cases, standardized residuals did not show remarkable difference from the normal distribution.

Comparison of CPUE trend with that which incorporated subarea for the effect of fishing ground (Matsumoto et al.,

2016) indicates that there is comparatively large difference of the trend of CPUE especially in the whole fishing ground, and the CPUE with the effect of subarea shows steeper declining than those with LT5LN5 (Fig. 4). This is probably because subareas used in the past studies are a bit too broad and so there is some difference of catch rate within subarea, which was incorporated by using the effect of LT5LN5.

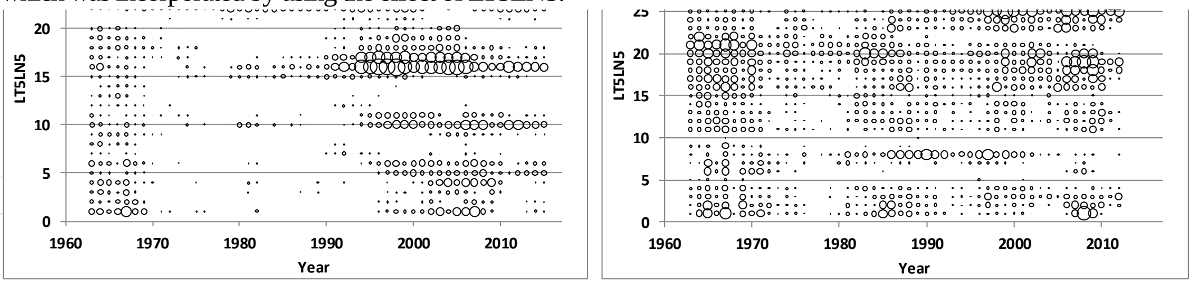

Fig. 9 Fig. 9 indicates that distribution of fishing efforts differs depending on period especially in the Area 3 and 4. It may have caused large difference of CPUE between with and without LT5LN5. **Fig. 11** indicates that the proportion of fishing effort in each area differs depending on period.

Effect of each explanatory factor in the model

Historical changes in the proportion of effort by fishing gear (NHFCL and gear materials) are shown in Fig. 12. NHFCL 5-7 was dominant in each area in the early period. NHF increased with time and sudden increase occurred during early 1990s in each area. In recent years, NHFCL 11-13 is dominant in Area 3 and 4, and NHFCL 17-19 and/or 20 or more in Area 2 and 5. Nylon material for both main and branch lines developed rapidly around mid-1990s, which almost coincided with the change in NHF. Trends of CPUE standardized for each of quarter, NHFCL and gear (main-line and branch-line) materials are shown in Fig. 12. CPUE was highest in 1st quarter followed by 4th quarter. NHFCL2 (8-10) or 3 (11-13) got highest CPUE. As for the gear materials of both of branch and main-lines, nylon showed higher CPUE than other material. In the previous studies with the model with subarea, CPUE by NHFCL demonstrated increasing trend However, as for the model with LT5LN5, NHFCL2 (8-10) or 3 (11-13) got highest CPUE, which seems more realistic.

4. References

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Table 1. ANOVA table of GLM for year based CPUE standardization for main and whole fishing grounds (with and without Area2) for 1963-2016.

1963-2016 Year base (with LT5LN5)
Main Fishing Ground (Area 2&3&5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	163	460251.6	2823.6	3296.1	<.0001	0.43
						CV =
yr	53	39908.6	753.0	879.0	<.0001	62.53
qt	3	6448.6	2149.5	2509.2	<.0001	
LT5LN5	90	191131.1	2123.7	2479.0	<.0001	
nhfcl	5	6491.6	1298.3	1515.6	<.0001	
bl	1	47.9	47.9	55.9	<.0001	
ml	1	714.7	714.7	834.3	<.0001	
nhfcl*ml	5	1410.3	282.1	329.3	<.0001	
nhfcl*bl	5	508.3	101.7	118.7	<.0001	

1963-2016 Year base (with LT5LN5)
Main Fishing Ground (Area 3&5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	133	345993.7	2601.5	2838.9	<.0001	0.45
						CV =
yr	53	21178.8	399.6	436.1	<.0001	82.77
qt	3	8200.8	2733.6	2983.1	<.0001	
LT5LN5	60	146081.9	2434.7	2656.9	<.0001	
nhfcl	5	6556.2	1311.2	1430.9	<.0001	
bl	1	76.5	76.5	83.5	<.0001	
ml	1	449.7	449.7	490.8	<.0001	
nhfcl*ml	5	1459.2	291.8	318.5	<.0001	
nhfcl*bl	5	266.1	53.2	58.1	<.0001	

1963-2016 Year base (with LT5LN5)
Whole Indian (Area 2-5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	230	1077186	4683.42	5743.08	<.0001	0.56
						CV =
yr	53	32981.3	622.3	763.1	<.0001	96.58
qt	3	4121.7	1373.9	1684.8	<.0001	
LT5LN5	157	649056.6	4134.1	5069.5	<.0001	
nhfcl	5	12079.2	2415.8	2962.4	<.0001	
bl	1	100.5	100.5	123.2	<.0001	
ml	1	651.7	651.7	799.1	<.0001	
nhfcl*ml	5	1786.6	357.3	438.2	<.0001	
nhfcl*bl	5	748.7	149.7	183.6	<.0001	

1963-2016 Year base (with LT5LN5)
Whole Indian (Area 3-5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	200	877647.5	4388.24	5062.68	<.0001	0.57
						CV =
yr	53	17742.2	334.8	386.2	<.0001	202.52
qt	3	5678.8	1892.9	2183.9	<.0001	
LT5LN5	127	582078.9	4583.3	5287.7	<.0001	
nhfcl	5	12114.6	2422.9	2795.3	<.0001	
bl	1	168.1	168.1	193.9	<.0001	
ml	1	421.6	421.6	486.4	<.0001	
nhfcl*ml	5	1800.9	360.2	415.5	<.0001	
nhfcl*bl	5	434.4	86.9	100.2	<.0001	

Table 2. ANOVA table of GLM for year and quarterly based area specific CPUE standardization for each area for 1963-2016.

1963-2016 annual with LT5LN5
Area 2

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	101	87749.57	868.81	1131.63	<.0001	0.315
						CV =
yr	52	22007.50	423.22	551.25	<.0001	43.955
qt	3	989.61	329.87	429.66	<.0001	
nhfcl	5	436.37	87.27	113.68	<.0001	
bl	1	5.63	5.63	7.33	0.0068	
ml	1	2.24	2.24	2.92	0.0873	
LT5LN5	29	17254.34	594.98	774.97	<.0001	
nhfcl*ml	5	190.48	38.10	49.62	<.0001	
nhfcl*bl	5	96.30	19.26	25.09	<.0001	

1963-2016 annual with LT5LN5
Area 3

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	100	257667.44	2576.67	2758.95	<.0001	0.477
						CV =
yr	53	15054.261	284.043	304.14	<.0001	80.388
qt	3	12786.75	4262.25	4563.77	<.0001	
nhfcl	5	1168.78	233.76	250.29	<.0001	
bl	1	0.67	0.67	0.71	0.3987	
ml	1	3.13	3.13	3.35	0.0672	
LT5LN5	27	93570.67	3465.58	3710.74	<.0001	
nhfcl*ml	5	999.73	199.95	214.09	<.0001	
nhfcl*bl	5	20.12	4.02	4.93	0.0002	

1963-2016 annual with LT5LN5
Area 4

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	139	307908.59	2215.17	2140.91	<.0001	0.493
						CV =
yr	53	11017.96	207.89	200.92	<.0001	-66.251
qt	3	1830.28	610.09	589.64	<.0001	
nhfcl	5	418.57	83.71	80.91	<.0001	
bl	1	38.52	38.52	37.22	<.0001	
ml	1	89.97	89.97	86.96	<.0001	
nhfcl*ml	66	231270.13	3504.09	3386.63	<.0001	
nhfcl*bl	5	521.24	104.25	100.75	<.0001	
nhfcl*bl	5	616.78	123.36	119.22	<.0001	

1963-2016 annual with LT5LN5
Area 5

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	105	107675.16	1025.48	1422.40	<.0001	0.474
						CV =
yr	53	15392.52	290.42	402.84	<.0001	78.491
qt	3	1043.64	347.88	482.53	<.0001	
nhfcl	5	113.11	22.62	31.38	<.0001	
bl	1	76.82	76.82	106.56	<.0001	
ml	1	12.40	12.40	17.20	<.0001	
nhfcl*ml	32	4829.05	150.91	209.32	<.0001	
nhfcl*bl	5	94.79	18.96	26.30	<.0001	
nhfcl*bl	5	115.46	23.09	32.03	<.0001	

1963-2016 quarterly with LT5LN5
Area 2

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	251	97878.00	389.95	536.11	<.0001	0.352
						CV =
yr	52	18795.26	361.45	496.92	<.0001	42.784
qt	3	176.39	58.80	80.83	<.0001	
nhfcl	5	374.08	74.82	102.86	<.0001	
bl	1	11.94	11.94	16.41	<.0001	
ml	1	0.36	0.36	0.5	0.4809	
LT5LN5	29	14545.06	501.55	689.54	<.0001	
yr*qt*area	150	10128.43	67.52	92.83	<.0001	
nhfcl*ml	5	117.29	23.46	32.25	<.0001	
nhfcl*bl	5	74.46	14.89	20.47	<.0001	

1963-2016 quarterly with LT5LN5
Area 3

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	259	274917.32	1061.46	1209.73	<.0001	0.509
						CV =
yr	53	11975.47	225.95	257.52	<.0001	77.919
qt	3	11955.04	3985.01	4541.68	<.0001	
nhfcl	5	1090.35	218.07	248.53	<.0001	
bl	1	0.16	0.16	0.18	0.6728	
ml	1	6.11	6.11	6.96	0.0083	
LT5LN5	27	72166.79	2672.84	3046.22	<.0001	
yr*qt*area	159	17249.88	108.49	123.64	<.0001	
nhfcl*ml	5	896.38	179.28	204.32	<.0001	
nhfcl*bl	5	92.79	18.56	21.15	<.0001	

1963-2016 quarterly with LT5LN5
Area 4

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	298	325689.88	1092.92	1118.51	<.0001	0.521
						CV =
yr	53	8592.96	162.13	165.93	<.0001	-64.381
qt	3	1547.63	515.88	527.96	<.0001	
nhfcl	5	344.55	68.91	70.52	<.0001	
bl	1	43.77	43.77	44.79	<.0001	
ml	1	105.77	105.77	108.24	<.0001	
LT5LN5	66	166380.10	2520.91	2579.93	<.0001	
yr*qt*area	159	17781.28	111.83	114.45	<.0001	
nhfcl*ml	5	497.48	99.50	101.83	<.0001	
nhfcl*bl	5	550.63	110.13	112.7	<.0001	

1963-2016 quarterly with LT5LN5
Area 5

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	263	112745.17	428.69	620.37	<.0001	0.496
						CV =
yr	53	11628.46	219.40	317.51	<.0001	-64.381
qt	3	457.13	152.38	220.51	<.0001	
nhfcl	5	104.08	20.82	30.12	<.0001	
bl	1	86.08	86.08	124.57	<.0001	
ml	1	8.38	8.38	12.12	0.0005	
LT5LN5	32	4563.84	142.62	206.39	<.0001	
yr*qt*area	158	5070.01	32.09	46.44	<.0001	
nhfcl*ml	5	93.50	18.70	27.06	<.0001	
nhfcl*bl	5	118.52	23.70	34.3	<.0001	

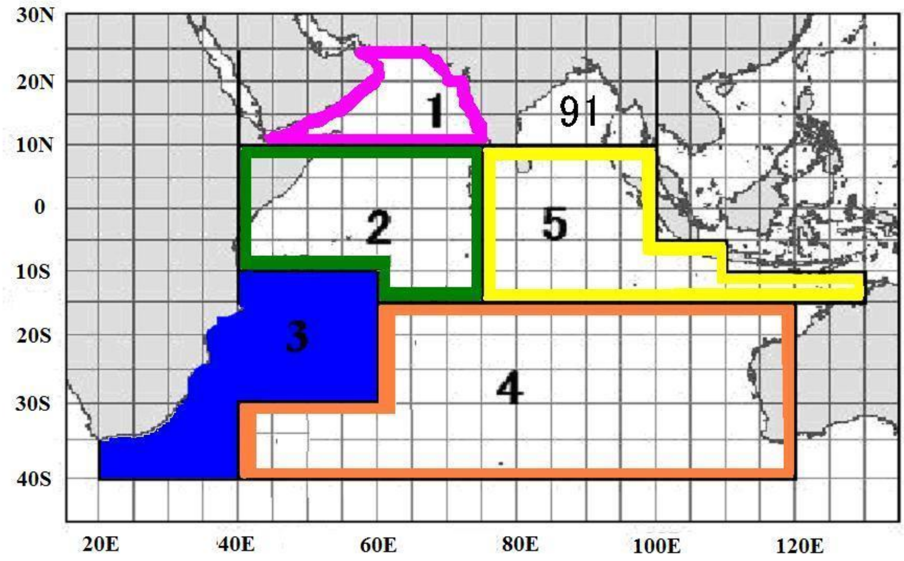


Fig. 1. Definition of areas used in this study. Main (areas 2, 3 and 5) and whole (areas 2-5) fishing ground categories in this study.

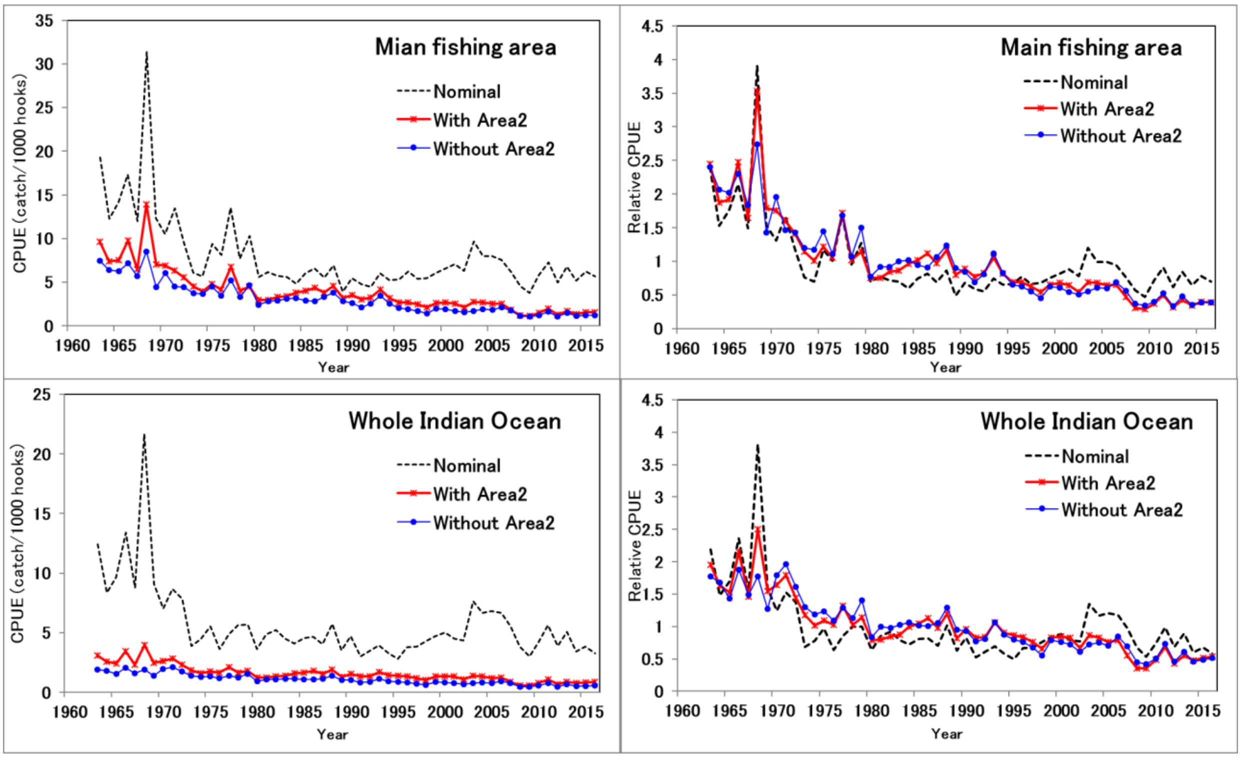
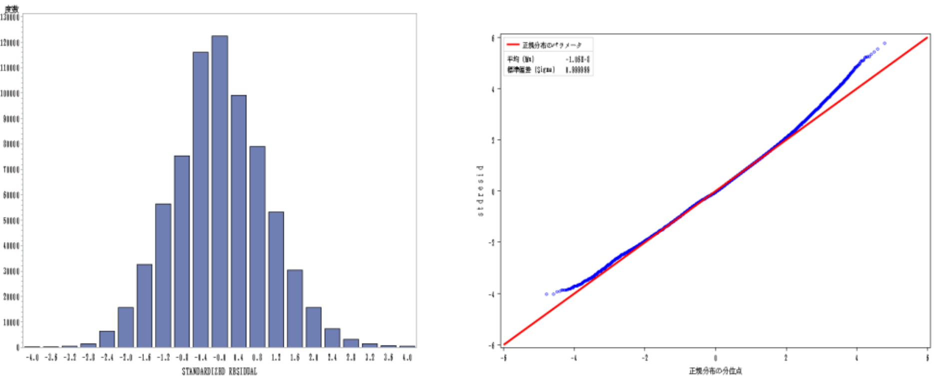
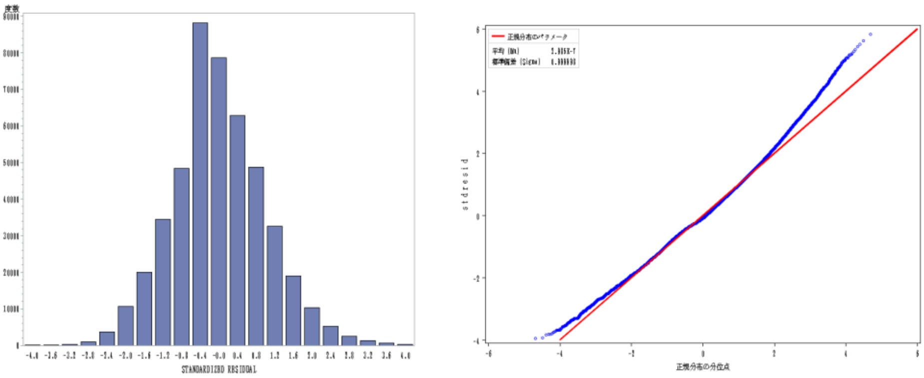


Fig. 2. Annual based area aggregated CPUE in number for 1963-2016 standardized for main (top) and whole (bottom) fishing grounds expressed in real (left figure) and relative (right figure) scale overlaid with nominal CPUE.

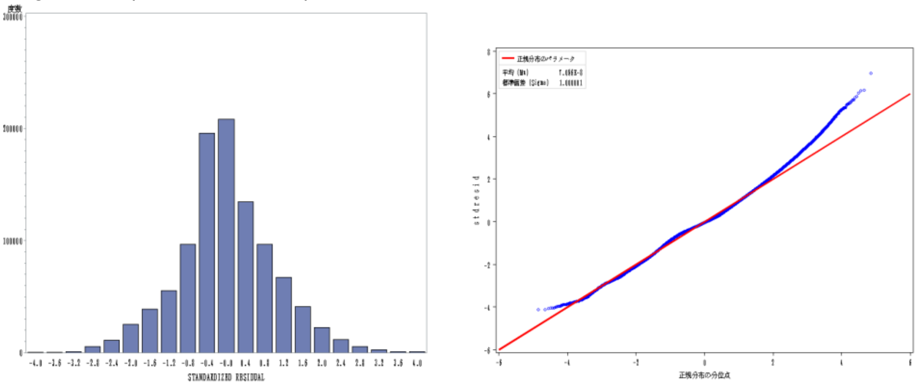
1663-2016 Year based
Main Fishing Ground (Area 2, 3 and 5)



1663-2016 Year based
Main Fishing Ground (Area 3 and 5)



1663-2016 Year based
Whole Fishing Ground (Area 2, 3, 4 and 5)



1663-2016 Year based
Whole Fishing Ground (Area 3, 4 and 5)

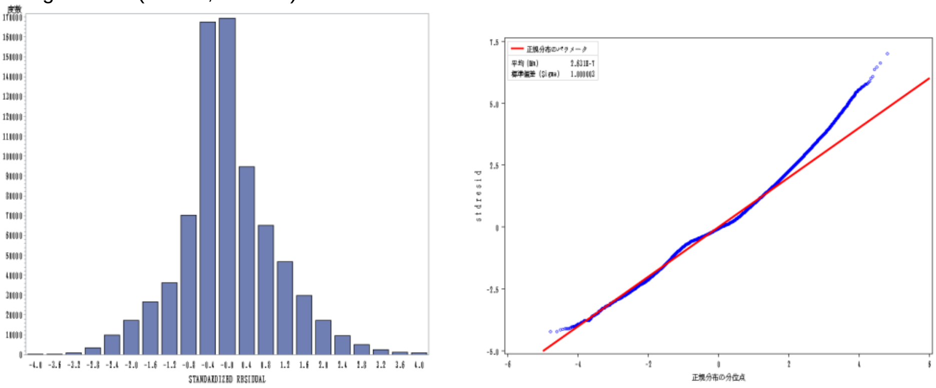


Fig. 3. Standardized residuals of annual based CPUE standardization for main and whole (with and without area 2) fishing ground.

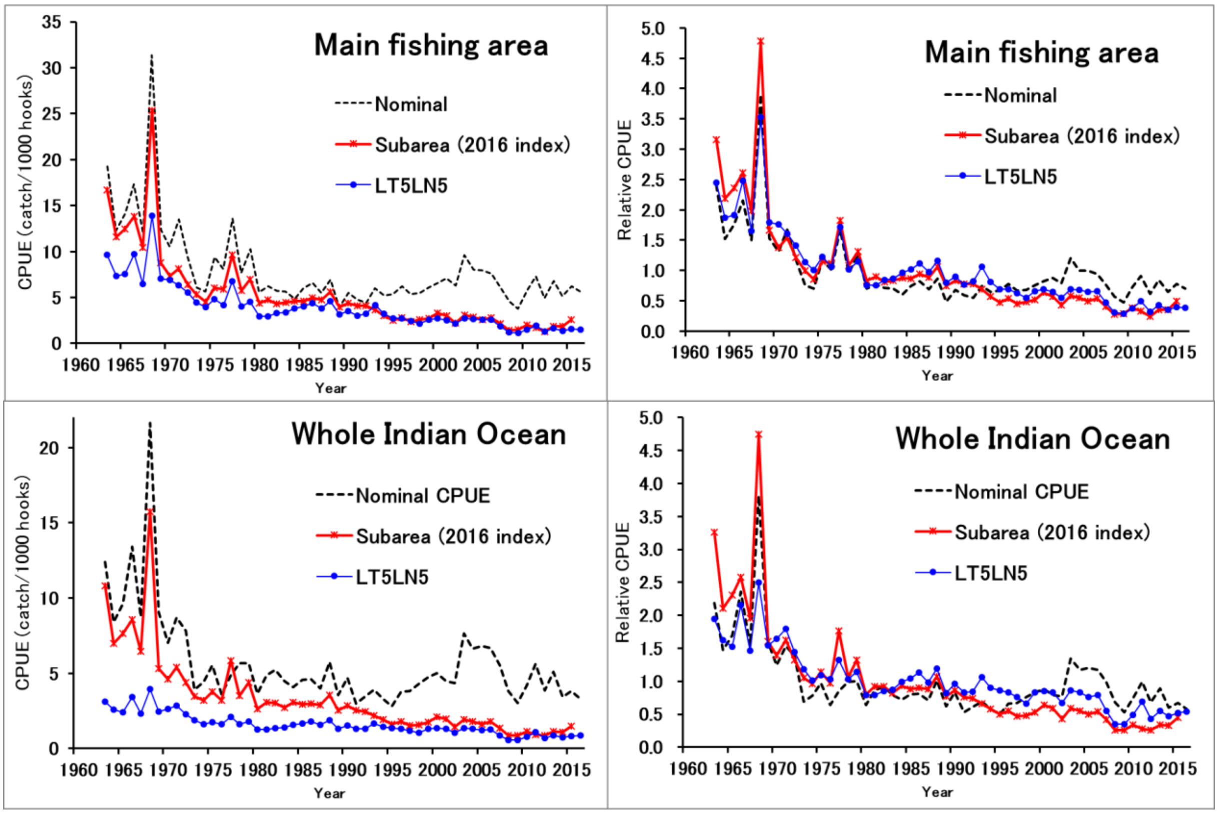


Fig. 4. Comparison of annual based area aggregated CPUE with the effect of subarea (Matsumoto et al., 2016) and LT5LN5 (present study), standardized for main (top) and whole (bottom) fishing grounds expressed in real (left figure) and relative (right figure) scale overlaid with nominal CPUE.

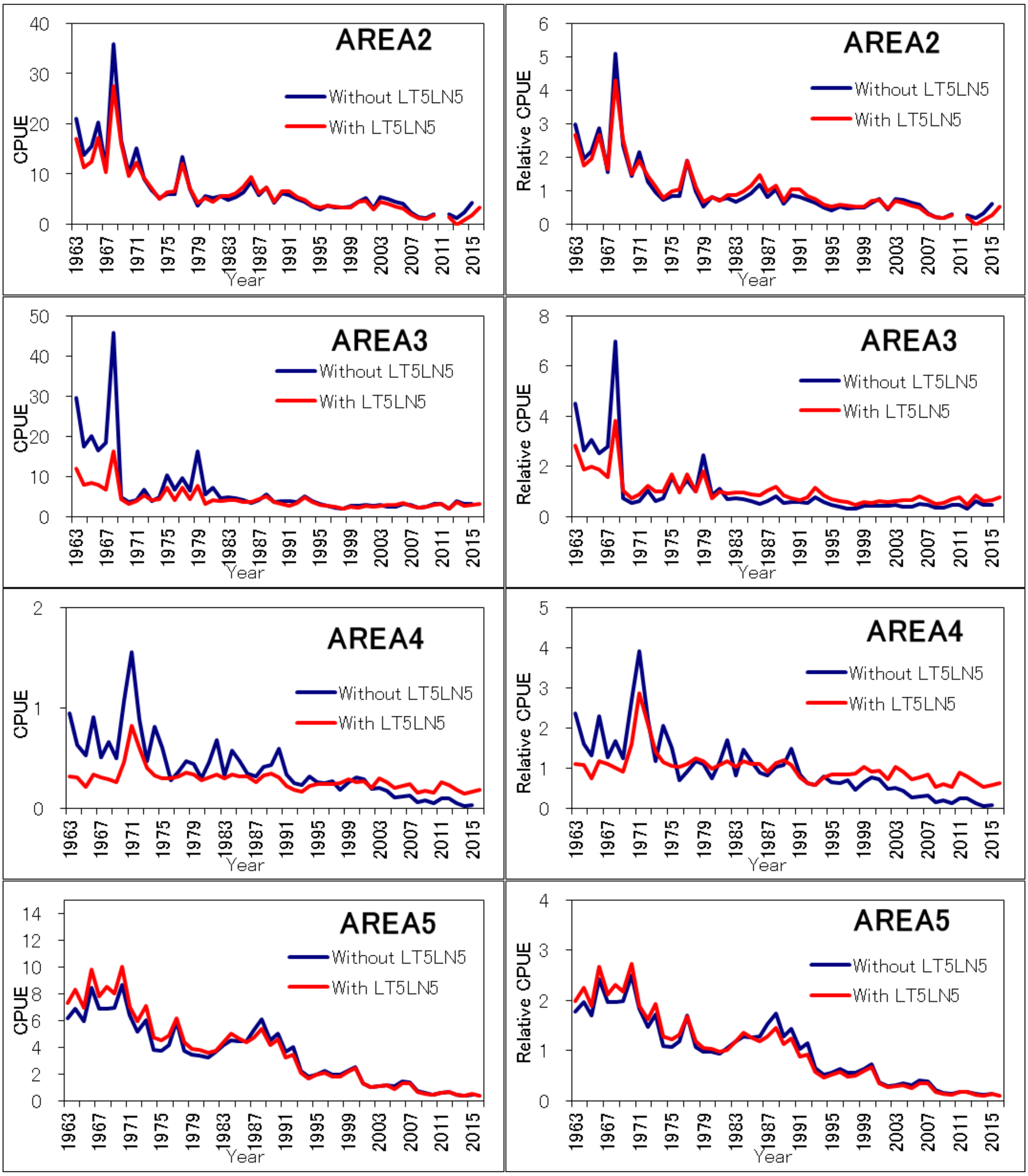


Fig. 5. Standardized year based CPUE in number for 1963-2016 for each four areas expressed in relative (left figure) and real (right figure) scale with comparison of CPUE without LT5LN5 reported in 2016 (Matsumoto et al., 2016).

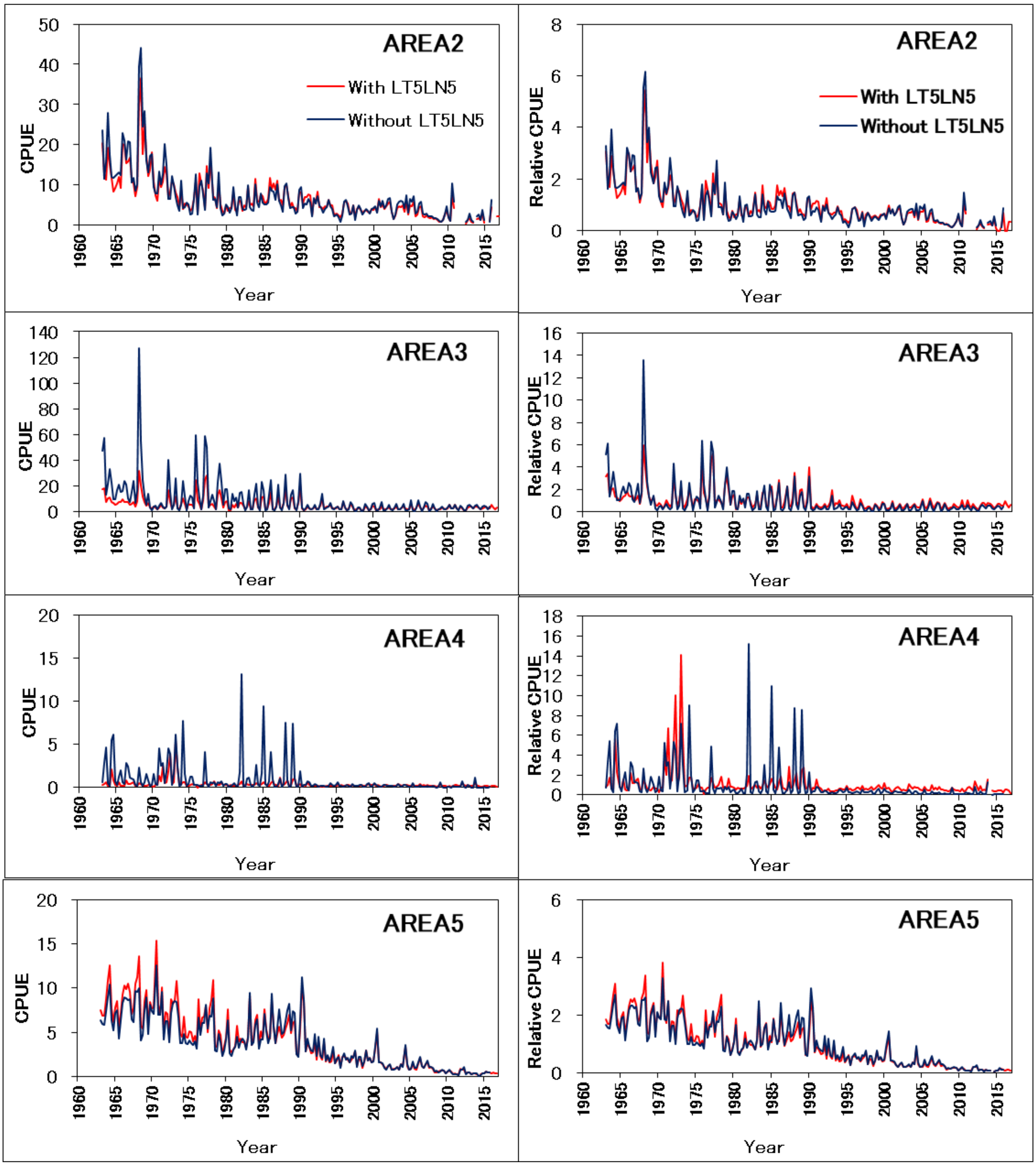
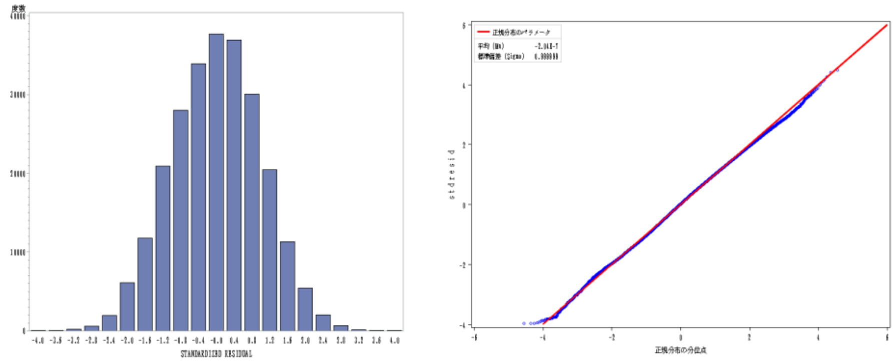
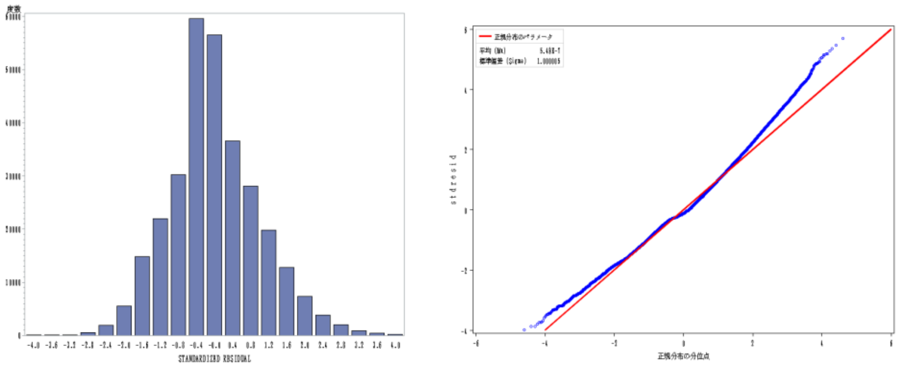


Fig. 6. Standardized quarter based CPUE in number for 1963-2016 for each four areas expressed in relative (left figure) and real (right figure) scale with comparison of CPUE without LT5LN5 reported in 2016 (Matsumoto et al., 2016).

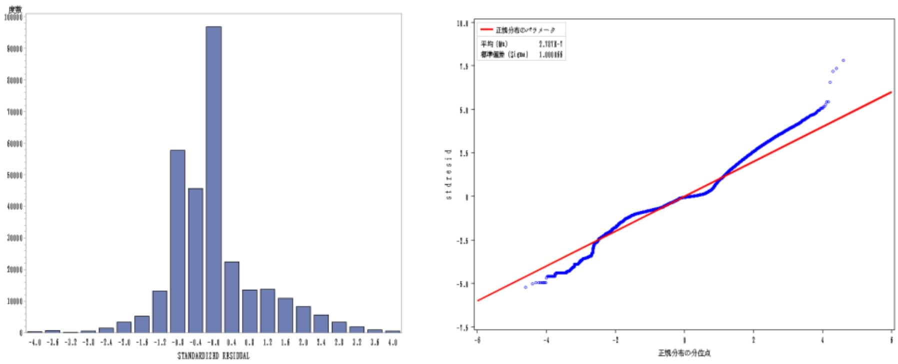
Area 2



Area 3



Area 4



Area 5

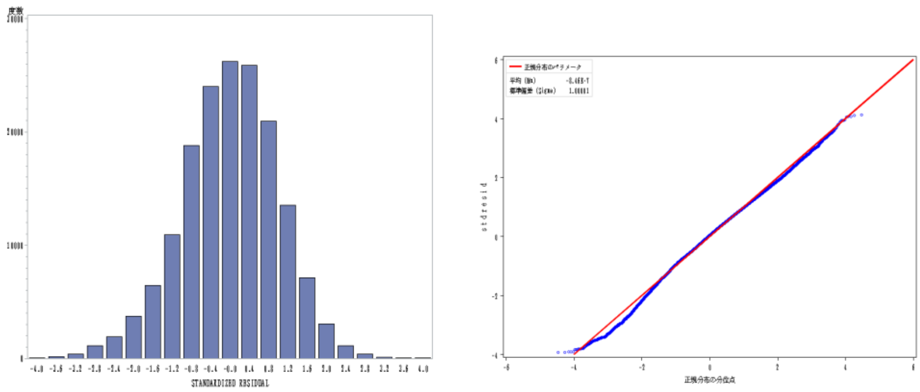
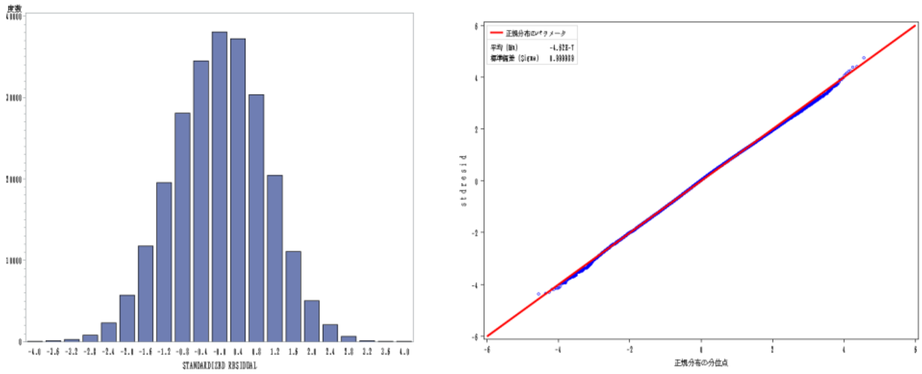
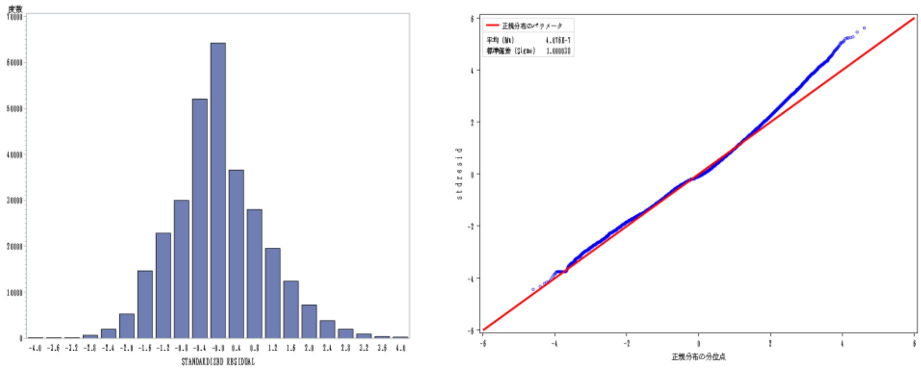


Fig. 7. Standardized residuals of year based CPUE standardization for each of four areas expressed as histograms and QQ plots.

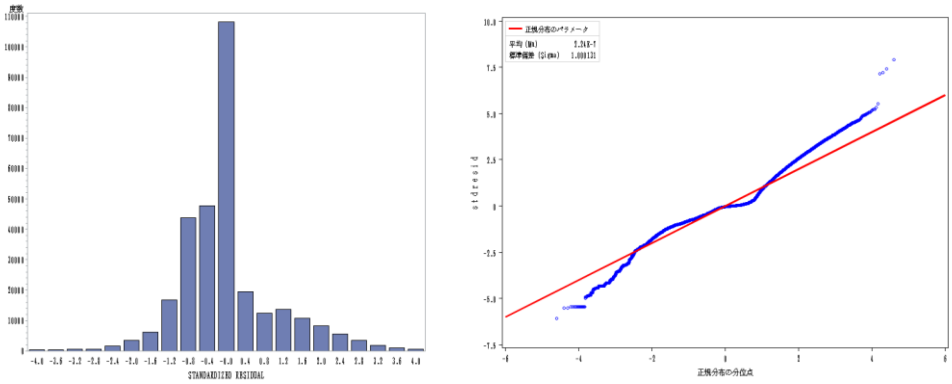
Area 2



Area 3



Area 4



Area 5

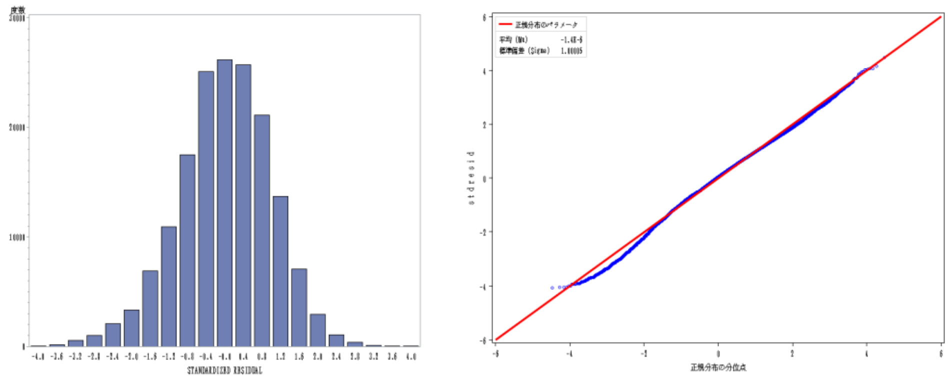


Fig. 8. Standardized residuals of quarter based CPUE standardization for each of four areas expressed as histograms and QQ plots.

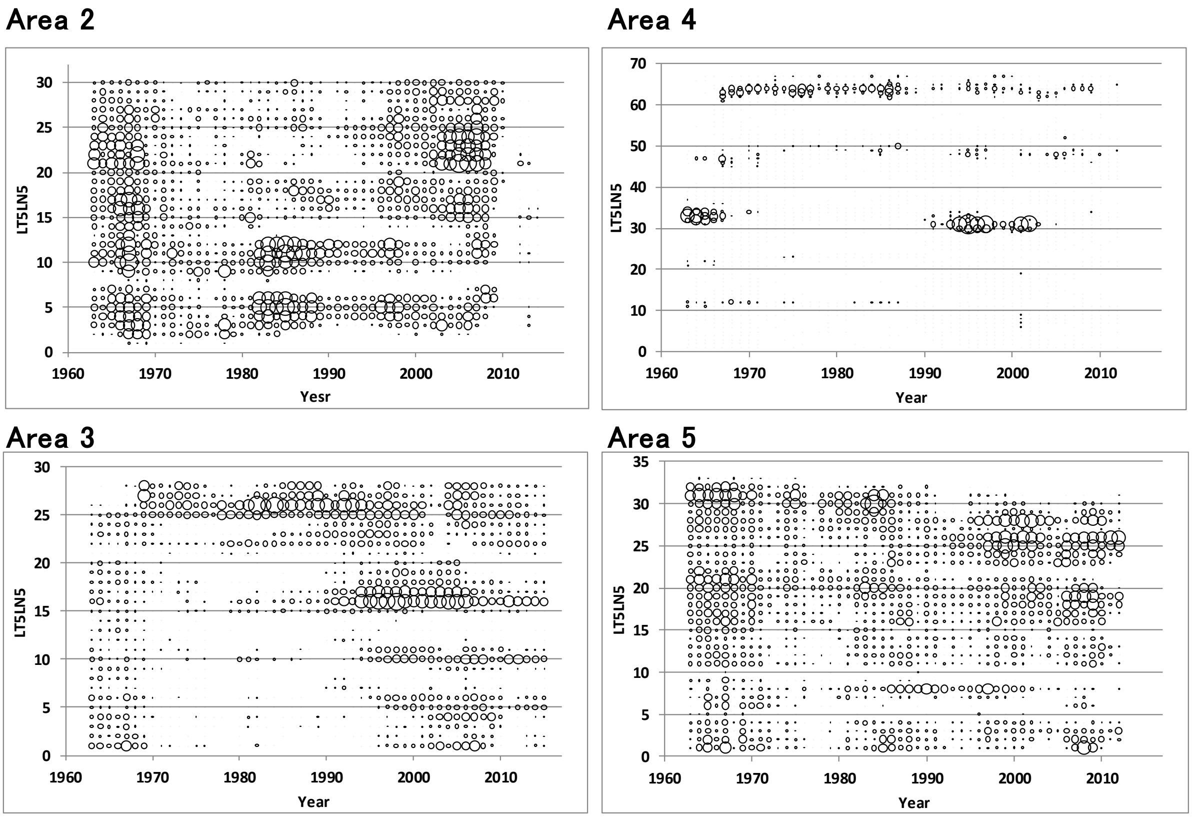


Fig. 9. Historical change in the number of observation of each LT5LN5 factor in each area.

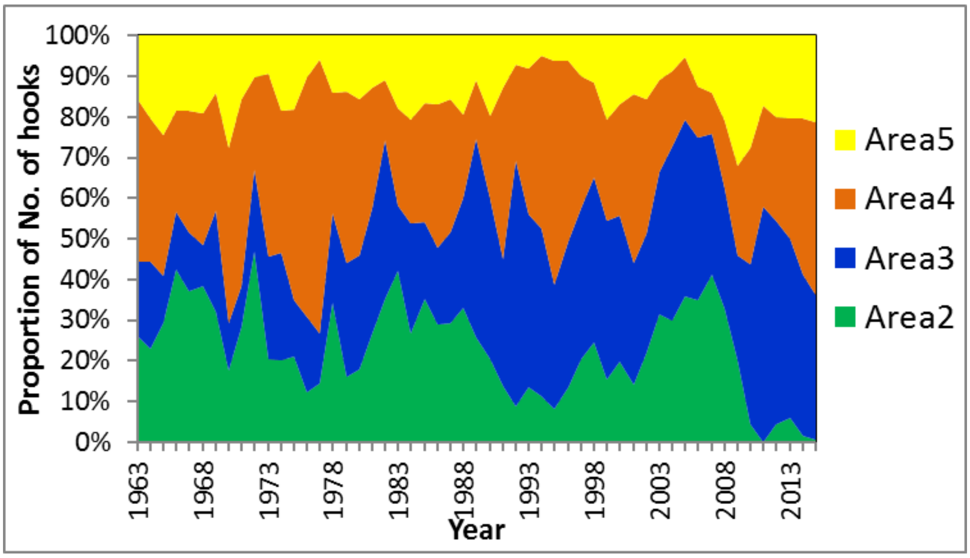


Fig. 10. Historical change in the proportion of fishing effort (number of hooks) in each area.

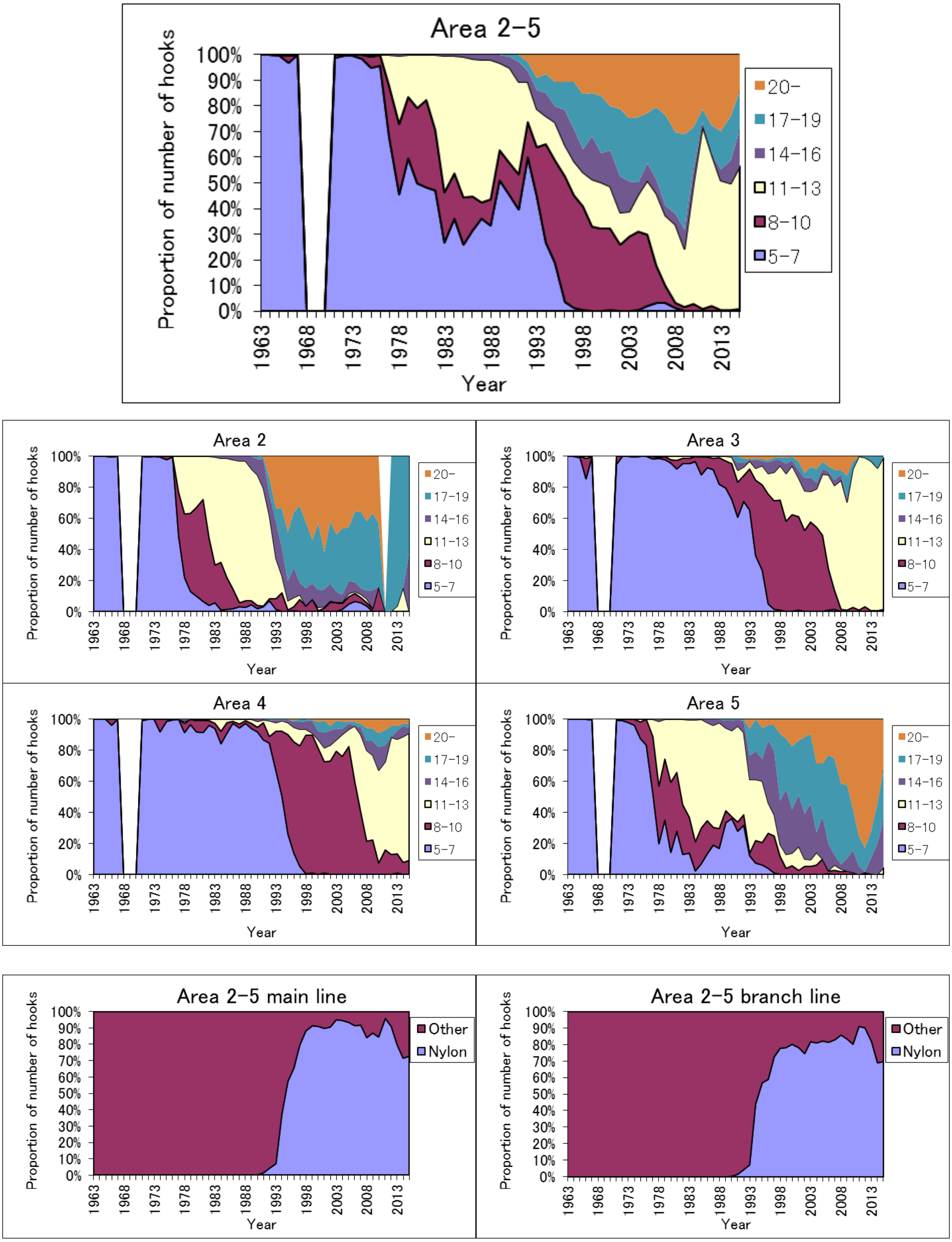


Fig. 11. Historical changes in the proportion of fishing effort by fishing gear (NHFCL and gear materials (main-line and branch-line)).

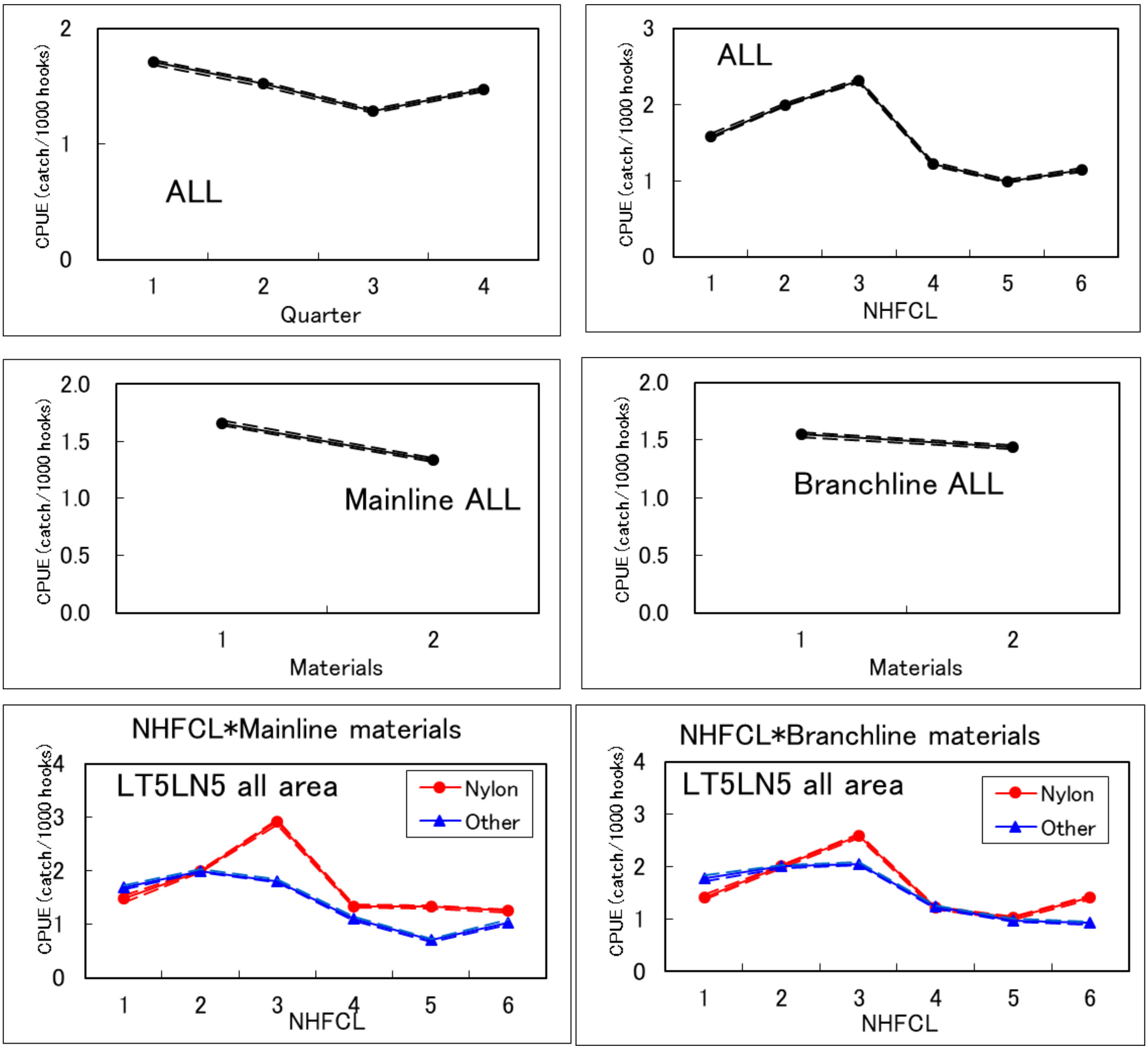


Fig. 12. Trends of CPUE standardized for each quarter, NHFCL (with gear material as well) and gear (main-line and branch-line) materials.