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

Takayuki Matsumoto[1]

[1]National Research Institute of Far Seas Fisheries (NRIFSF), Japan Fisheries Research and Education Agency, 5-7-1, Orido, Shimizu, Shizuoka, 424-8633, Japan

Abstract

Japanese longline CPUE for yellowfin tuna in the Indian Ocean (area aggregated and area-specific) was standardized up to 2017 by GLM mainly based on similar methods used in the previous studies. Basically, standardized CPUEs showed similar trends among areas. CPUE continuously decreased from 1950s to around 1974, and kept in the same level until 1990. Thereafter, it declined to a historically low level and then slightly increased in recent years. A vessel effect was also used in a part of analyses, and it has some extent of influence on CPUE trend. Decline in CPUE got less steep by using the vessel effect. There was somewhat difference between the trend of CPUEs in this study and those created in the collaborative analysis (with cluster analysis and vessel ID).

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 recent years IOTC collaborative analyses for CPUE of tuna species including yellowfin were conducted (e.g. Hoyle et al., 2016; 2017). In these analyses, vessel effect was used for one of the effects (covariates) in the CPUE standardization. Okamoto (2014) also used similar approach for Indian Ocean yellowfin and bigeye tuna CPUE. The same method was applied in this study.

In this study, Japanese longline CPUE for yellowfin tuna in the Indian Ocean was standardized by Generalized Linear Model which is equivalent to or minor revision from those by Okamoto and Shono (2010), Okamoto (2011a), Matsumoto et al. (2012, 2013, 2016), Ochi et al. (2014, 2015) and Matsumoto (2017). 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.

In the IOTC collaborative CPUE analysis, joint CPUEs for 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); Matsumoto, 2017 except that vessel ID was used. 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 2013-2017 (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 1952 up to 2017 were used. Data for 2017 were preliminary. Start year was usually 1963 in the previous studies for using in the stock assessment models. In this study it is 1952 (longest series) for comparing the trend of CPUE with those by collaborative analyses. 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. Vessel call signs were available from 1979 onward and were used for the vessel identifier in a part of the models (start year is 1979).

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 1952 -2017. In addition, area specific annual and quarterly CPUE was also standardized for each of four subareas for 1952 -2017 in order to provide CPUE index used for assessment using Multifan-CL software and Stock Synthesis 3 (SS3). In the past 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 past 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 based CPUE standardization in the main and whole fishing grounds with vessel ID

Log (CPUE+const)=μ+YR +QT +LT5LN5 +NHFCL +ML +BL + vessel ID+ 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 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
Vessel ID: vessel identifier based on call sign
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.

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 1950s to around 1974, and kept in the same level until 1990 with small 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 slightly increased with fluctuation. 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. 5 shows the comparison of annual based area aggregated CPUE in the main and whole fishing ground with and without the effect of vessel ID. Overall trend is similar among models, but the model with vessel ID shows less steep declining trend. Baesd on ANOVA table for the model with vessel ID (Table **2**), the effect of vessel ID seems intermediate level.

The annual and quarterly CPUEs for each area with comparison of CPUE without LT5LN5 reported in 2016 (Matsumoto et al., 2016) are shown in Fig. 6 and Fig. 7, respectively, in real and relative scale. ANOVA tables and standardized residuals are shown in Table 3 and Fig. 8-Fig. 9, respectively. Trends of CPUEs of each area were relatively similar, i.e. large decline until middle 1970s, relatively stable trend until around 1991 and steadily declining trend thereafter. Applying LT5LN5 factor in the model showed relatively large effect on the CPUE trend for area 3 and 4 in which the declining trend until around 1990 was steeper in the model without LT5LN5. Then, the CPUE trend derived from the model with LT5LN5 caused relatively flat trend throughout period analyzed.

Fig. 10 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. 13. 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.

Comparison of CPUE with those by collaborative analysis

Fig. 14 shows comparison of yellowfin CPUE in each area in the present study with those created at this year's collaborative analysis (Matsumoto et al., 2018), which incorporated vessel effect and cluster analysis. The trend of both CPUEs was similar, but there are some differences especially in the early period in region 2 and 4. This is probably because of the results of incorporating vessel effect and/or targeting.

4. References

Hoyle, S., Chang, Y., Kim, D. N., Lee, S., Matsumoto, T., Satoh, K. and Yeh, Y. (2016) Collaborative study of tropical tuna CPUE from multiple Indian Ocean longline fleets in 2016. IOTC-2016-WPTT18-14.

Hoyle S., Assan C., Chang, S. T., Fu. D, Govinden R., Kim D, N, Lee S. I., Lucas J., Matsumoto T. Satoh K., Yeh Y. M., and Kitakado T. (2017) Collaborative study of tropical tuna CPUE from multiple Indian Ocean longline fleets in 2017. IOTC-2017-WPTT19-32. 52p.

Matsumoto, T. (2014): Review of Japanese fisheries and tropical tuna catch in the Indian Ocean. IOTC 2014/WPTT16/10. 28pp.

Matsumoto, T. (2017) Japanese longline CPUE for yellowfin tuna in the Indian Ocean standardized by generalized linear model. IOTC-2017-WPTT19–48. pp 17.

Matsumoto, T. Okamoto, H. and Kitakado, T. (2012): Japanese longline CPUE for yellowfin tuna in the Indian Ocean up to 2011 standardized by general linear model. IOTC 2012/WPTT14/35. 34pp.

Matsumoto, T. and Satoh, K. (2012): Review of Japanese fisheries and tropical tuna catch in the Indian Ocean. IOTC 2012/WPTT14/17. 28pp.

Matsumoto, T., Okamoto, H. and Kitakado, T. (2013): Japanese longline CPUE for yellowfin tuna in the Indian Ocean up to 2012 standardized by generalized linear model. IOTC-2013-WPTT15-37, p. 43.

Matsumoto, T., Nishida, H., Satoh, K and Kitakado, T. (2016): Japanese longline CPUE for yellowfin tuna in the Indian Ocean standardized by generalized linear model. IOTC-2016-WPTT18-25, p. 22.

Matsumoto, T., Satoh, K. and Hoyle, S. (2018): Standardization of bigeye and yellowfin tuna CPUE by Japanese longline in the Indian Ocean which includes cluster analysis. IOTC-2018-WPTT20-37.

Ochi, D., Matsumoto, T., Okamoto, H. and Kitakado, T. (2014): Japanese longline CPUE for yellowfin tuna in the Indian

Ocean up to 2013 standardized by generalized linear model. IOTC-2014-WPTT16-47, 37pp.

Ochi, D., Matsumoto, T., Okamoto, H., T. Nishida and Kitakado, T. (2015): Update of standardized Japanese longline CPUE for yellowfin tuna in the Indian Ocean and consideration of standardization methods. IOTC-2014/WPTT16/26, 53pp.

Okamoto, H. (2005): Recent trend of Japanese longline fishery in the Indian Ocean with special reference to the targeting Is the target shifting from bigeye to yellowfin? IOTC 2005/WPTT/11. 15 pp.

Okamoto, H. and Shono, H. (2010): Japanese longline CPUE for yellowfin tuna in the Indian Ocean up to 2009 standardized by general linear model. IOTC 2010/WPTT12/30. 27 pp.

Okamoto, H. (2011a): Japanese longline CPUE for yellowfin tuna in the Indian Ocean up to 2010 standardized by general linear model. IOTC 2011/WPTT13/34. 45 pp.

Okamoto, H. (2011b): Preliminary analysis of the effect of the Piracy activity in the northwestern Indian Ocean on the CPUE trend of bigeye and yellowfin. IOTC 2011/ WPTT13/44. 9pp.

Okamoto, H. (2014): CPUE of bigeye and yellowfin tuna caught by Japanese longliner in the Indian Ocean standardized by GLM considering several aspects of area, catchability and data resolution. IOTC 2014/WPTT16/31. 23 pp.

Table 1. ANOVA table of GLM for year based CPUE standardization for main and whole fishing grounds (with and without Area2) for 1952-2017.

1952-2017 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	175	565858.9	3233.5	4227.8	<.0001	0.49
						CV =
yr	65	86583.1	1332.0	1741.7	<.0001	52.36
qt	3	7017.9	2339.3	3058.7	<.0001	
LT5LN5	90	183170.0	2035.2	2661.1	<.0001	
nhfcl	5	6254.8	1251.0	1635.7	<.0001	
bl	1	42.5	42.5	55.6	<.0001	
ml	1	656.8	656.8	858.7	<.0001	
nhfcl*ml	5	1297.0	259.4	339.2	<.0001	
nhfcl*bl	5	506.3	101.3	132.4	<.0001	

1952-2017 Year base (with LT5LN5)
Whole Indian (Area 2-5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	242	########	5043.3	6816.9	<.0001	0.60
						CV =
yr	65	86389.9	1329.1	1796.5	<.0001	75.66
qt	3	4755.1	1585.0	2142.5	<.0001	
LT5LN5	157	642122.3	4090.0	5528.3	<.0001	
nhfcl	5	12816.8	2563.4	3464.8	<.0001	
bl	1	89.1	89.1	120.5	<.0001	
ml	1	590.5	590.5	798.2	<.0001	
nhfcl*ml	5	1752.2	350.4	473.7	<.0001	
nhfcl*bl	5	762.1	152.4	206.0	<.0001	

1952-2017 Year base (with LT5LN5)
Main Fishing Ground (Area 3&5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	145	414443.7	2858.2	3460.3	<.0001	0.49
						CV =
yr	65	51830.6	797.4	965.4	<.0001	67.10
qt	3	8454.9	2818.3	3412.0	<.0001	
LT5LN5	60	136779.2	2279.7	2759.9	<.0001	
nhfcl	5	6726.8	1345.4	1628.8	<.0001	
bl	1	71.6	71.6	86.6	<.0001	
ml	1	439.8	439.8	532.4	<.0001	
nhfcl*ml	5	1379.1	275.8	333.9	<.0001	
nhfcl*bl	5	262.2	52.4	63.5	<.0001	

1952-2017 Year base (with LT5LN5)
Whole Indian (Area 3-5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	212	993773.9	4687.61	5887.72	<.0001	0.60
						CV =
yr	65	55496.5	853.8	1072.4	<.0001	132.89
qt	3	5929.7	1976.6	2482.6	<.0001	
LT5LN5	127	572144.2	4505.1	5658.5	<.0001	
nhfcl	5	13747.3	2749.5	3453.4	<.0001	
bl	1	161.7	161.7	203.0	<.0001	
ml	1	422.4	422.4	530.6	<.0001	
nhfcl*ml	5	1825.3	365.1	458.5	<.0001	
nhfcl*bl	5	415.9	83.2	104.5	<.0001	

Table 2. ANOVA table of GLM for year based CPUE standardization for main and whole fishing grounds (with vessel ID) for 1979-2017.

1979-2017 Year base (with LT5LN5 and vessel ID)
Main Fishing Ground (Area 2&3&5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	1076	356629.7	331.4	367.4	<.0001	0.43
yr	38	8276.5	217.8	241.4	<.0001	CV =
qt	3	6032.6	2010.9	2228.8	<.0001	84.33
LT5LN5	89	106595.3	1197.7	1327.5	<.0001	
nhfcl	5	2130.7	426.1	472.3	<.0001	
bl	1	13.9	13.9	15.4	<.0001	
ml	1	267.9	267.9	296.9	<.0001	
vessel ID	929	45894.1	49.4	54.8	<.0001	
nhfcl*ml	5	1113.3	222.7	246.8	<.0001	
nhfcl*bl	5	46.9	9.4	10.4	<.0001	

1979-2017 Year base (with LT5LN5 and vessel ID)
Whole Indian (Area 2-5)

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	1191	767043.2	644.0	758.3	<.0001	0.56
yr	38	8884.5	233.8	275.3	<.0001	CV =
qt	3	5151.8	1717.3	2022.0	<.0001	148.33
LT5LN5	155	241751.6	1559.7	1836.5	<.0001	
nhfcl	5	4587.2	917.4	1080.3	<.0001	
bl	1	0.5	0.5	0.6	0.4394	
ml	1	295.1	295.1	347.5	<.0001	
vessel ID	978	51046.3	52.2	61.5	<.0001	
nhfcl*ml	5	1299.3	259.9	306.0	<.0001	
nhfcl*bl	5	55.9	11.2	13.2	<.0001	

Table 3. ANOVA table of GLM for year and quarterly based area specific CPUE standardization for each area for 1952-2017.

1954-2017 annual with LT5LN5
Area 2

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	111	130917.92	1179.44	1750.2	<.0001	0.420
						CV =
yr	62	39436.64	636.07	943.89	<.0001	37.760
qt	3	1015.17	338.39	502.15	<.0001	
nhfcl	5	387.01	77.40	114.86	<.0001	
bl	1	4.67	4.67	6.93	0.0085	
ml	1	2.07	2.07	3.07	0.0796	
LT5LN5	29	15794.43	544.64	808.2	<.0001	
nhfcl*ml	5	166.32	33.26	49.36	<.0001	
nhfcl*bl	5	86.60	17.32	25.7	<.0001	

1955-2017 annual with LT5LN5
Area 3

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	109	266529.03	2445.22	2679.77	<.0001	0.484
						CV =
yr	62	21459.399	346.119	379.32	<.0001	76.458
qt	3	12801.40	4267.13	4676.45	<.0001	
nhfcl	5	1128.14	225.63	247.27	<.0001	
bl	1	0.59	0.59	0.65	0.4213	
ml	1	2.61	2.61	2.87	0.0905	
LT5LN5	27	92727.46	3434.35	3763.78	<.0001	
nhfcl*ml	5	952.71	190.54	208.82	<.0001	
nhfcl*bl	5	20.12	4.02	4.93	0.0002	

1952-2017 annual with LT5LN5
Area 4

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	151	351709.08	2329.2	2338.79	<.0001	0.515
						CV =
yr	65	17642.45	271.42	272.54	<.0001	−77.805
qt	3	1807.07	602.36	604.84	<.0001	
nhfcl	5	411.93	82.39	82.73	<.0001	
bl	1	32.50	32.50	32.63	<.0001	
ml	1	90.26	90.26	90.63	<.0001	
nhfcl*ml	66	219567.61	3326.78	3340.47	<.0001	
nhfcl*bl	5	499.73	99.95	100.36	<.0001	
nhfcl*bl	5	533.99	106.80	107.24	<.0001	

1952-2017 annual with LT5LN5
Area 5

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	117	166015.84	1418.94	2419.59	<.0001	0.582
						CV =
yr	65	30707.99	472.43	805.60	<.0001	50.709
qt	3	1217.13	405.71	691.83	<.0001	
nhfcl	5	91.64	18.33	31.25	<.0001	
bl	1	53.43	53.43	91.11	<.0001	
ml	1	8.32	8.32	14.20	0.0002	
nhfcl*ml	32	8132.67	254.15	433.37	<.0001	
nhfcl*bl	5	63.87	12.77	21.78	<.0001	
nhfcl*bl	5	83.42	16.68	28.45	<.0001	

1954-2017 quarterly with LT5LN5
Area 2

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	289	140549.76	486.33	761.83	<.0001	0.451
						CV =
yr	62	34545.11	557.18	872.81	<.0001	36.752
qt	3	200.93	66.98	104.92	<.0001	
nhfcl	5	336.41	67.28	105.4	<.0001	
bl	1	9.99	9.99	15.64	<.0001	
ml	1	0.33	0.33	0.52	0.4711	
LT5LN5	29	13366.91	460.93	722.03	<.0001	
yr*qt*area	178	9631.84	54.11	84.76	<.0001	
nhfcl*ml	5	103.78	20.76	32.51	<.0001	
nhfcl*bl	5	65.14	13.03	20.41	<.0001	

1955-2017 quarterly with LT5LN5
Area 3

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	294	283933.30	965.76	1126.83	<.0001	0.516
						CV =
yr	62	14801.00	238.73	278.54	<.0001	74.100
qt	3	2101.07	700.36	817.16	<.0001	
nhfcl	5	1057.12	211.42	246.69	<.0001	
bl	1	0.14	0.14	0.16	0.6849	
ml	1	5.16	5.16	6.02	0.0142	
LT5LN5	27	70920.38	2626.68	3064.76	<.0001	
yr*qt*area	185	17404.27	94.08	109.77	<.0001	
nhfcl*ml	5	840.19	168.04	196.06	<.0001	
nhfcl*bl	5	92.34	18.47	21.55	<.0001	

1952-2017 quarterly with LT5LN5
Area 4

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	343	372287.34	1085.39	1161.49	<.0001	0.546
						CV =
yr	65	10695.72	164.55	176.09	<.0001	−75.367
qt	3	353.88	117.96	126.23	<.0001	
nhfcl	5	318.55	63.71	68.18	<.0001	
bl	1	38.91	38.91	41.63	<.0001	
ml	1	103.41	103.41	110.66	<.0001	
LT5LN5	66	158048.94	2394.68	2562.59	<.0001	
yr*qt*area	192	20578.26	107.18	114.69	<.0001	
nhfcl*ml	5	473.48	94.70	101.34	<.0001	
nhfcl*bl	5	471.64	94.33	100.94	<.0001	

1952-2017 quarterly with LT5LN5
Area 5

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	307	171891.34	559.91	1003.38	<.0001	0.603
						CV =
yr	65	25444.58	391.46	701.51	<.0001	−75.367
qt	3	432.69	144.23	258.47	<.0001	
nhfcl	5	78.53	15.71	28.14	<.0001	
bl	1	57.87	57.87	103.71	<.0001	
ml	1	6.53	6.53	11.71	0.0006	
LT5LN5	32	7148.62	223.39	400.33	<.0001	
yr*qt*area	190	5875.50	30.92	55.42	<.0001	
nhfcl*ml	5	66.11	13.22	23.69	<.0001	
nhfcl*bl	5	83.34	16.67	29.87	<.0001	

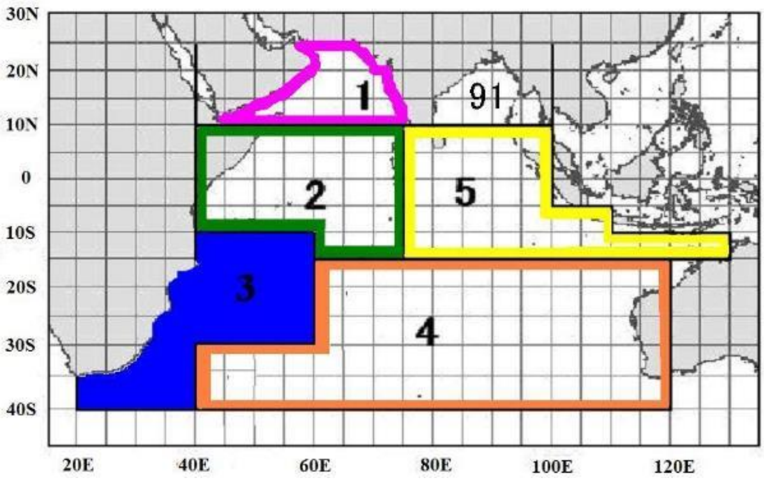


Fig. 1. Definition of areas used in this study. Main (areas 2, 3 and 5) and whole (areas 2-5) fishing ground categories in this study.

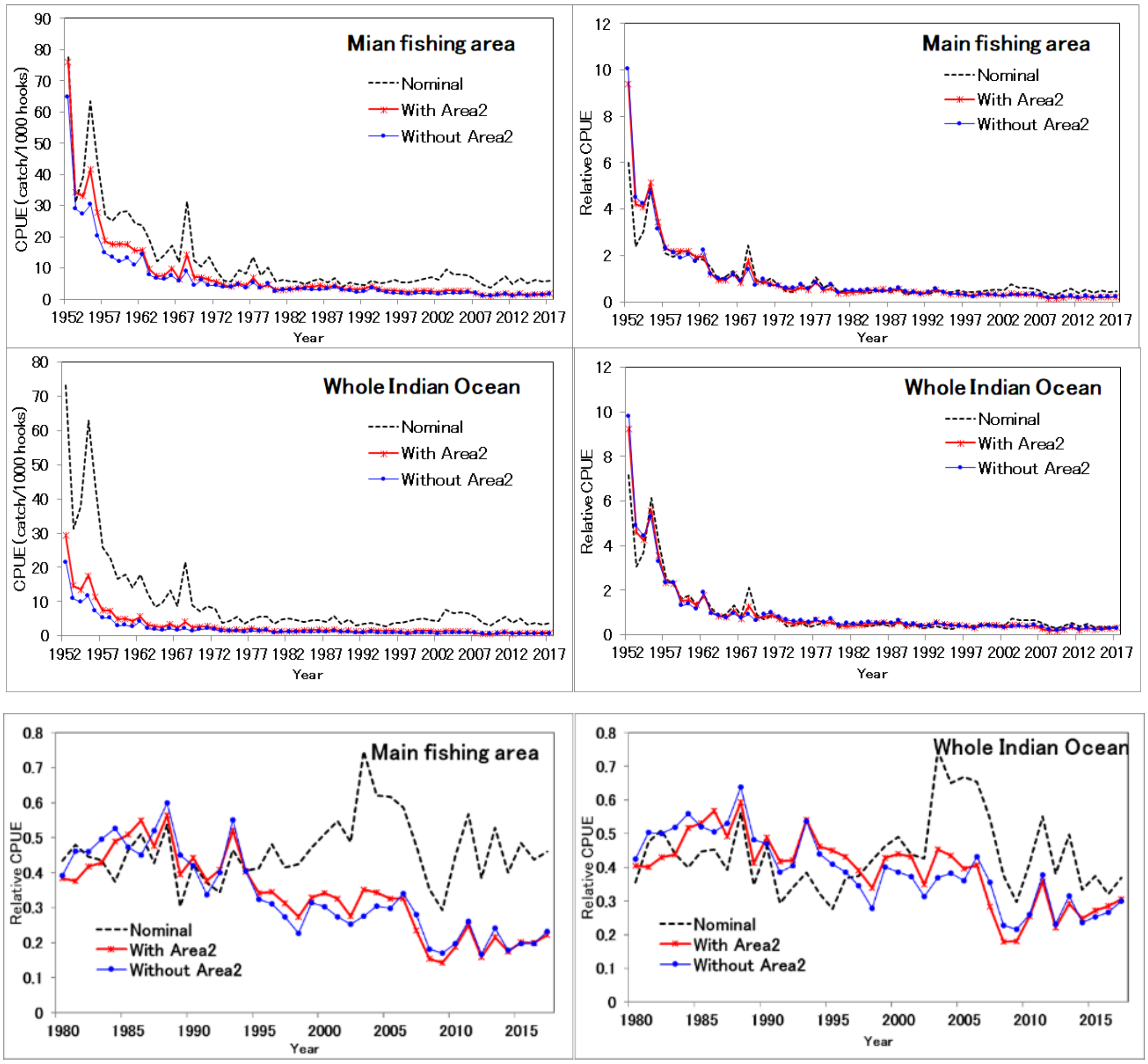
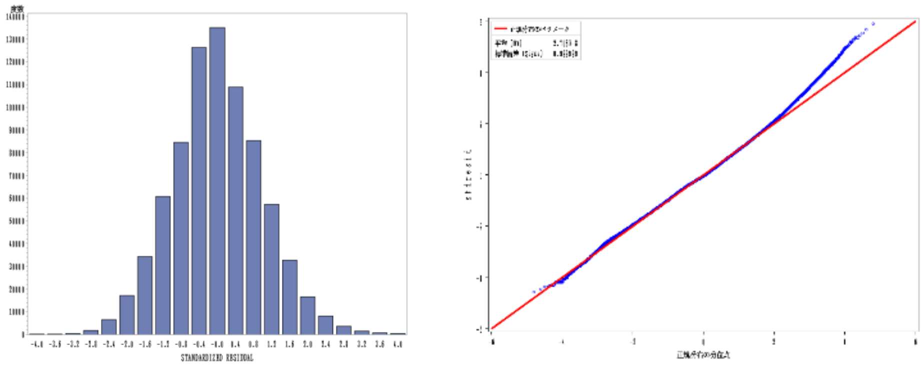
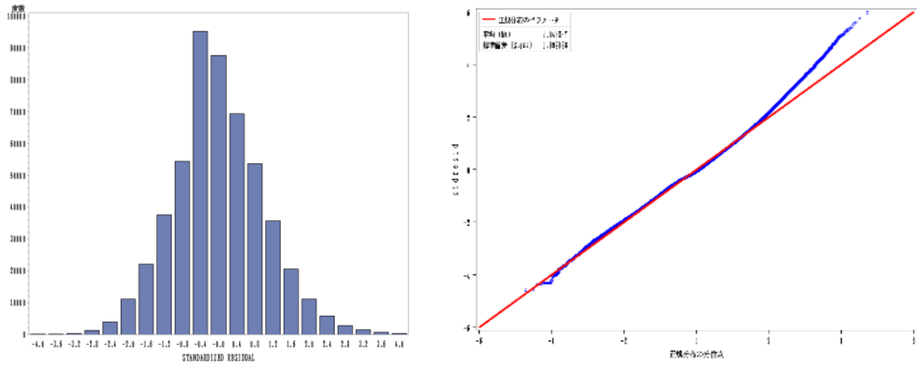


Fig. 2. Annual based area aggregated CPUE in number for 1952-2017 standardized for main (top) and whole (middle) fishing grounds expressed in real (left figure) and relative (right figure) scale overlaid with nominal CPUE. Bottom graphs how relative CPUE for main (left) and whole (right) fishig ground after 1980.

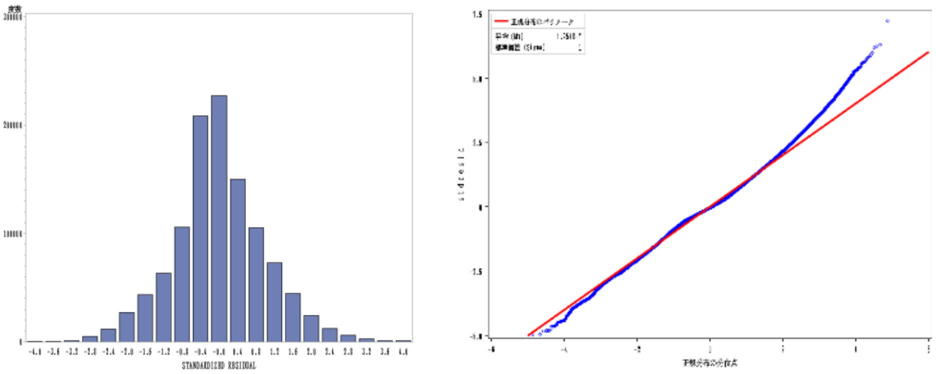
1952-2017 Year based
Main Fishing Ground (Area 2, 3 and 5)



1952-2017 Year based
Main Fishing Ground (Area 3 and 5)



1952-2017 Year based
Whole Fishing Ground (Area 2, 3, 4 and 5)



1952-2017 Year based
Whole Fishing Ground (Area 3, 4 and 5)

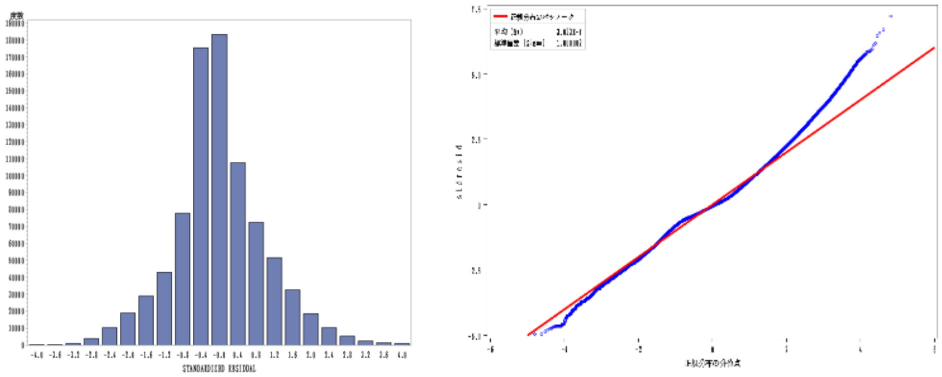


Fig. 3. Standardized residuals of annual based CPUE standardization for main and whole (with and without area 2) fishing ground.

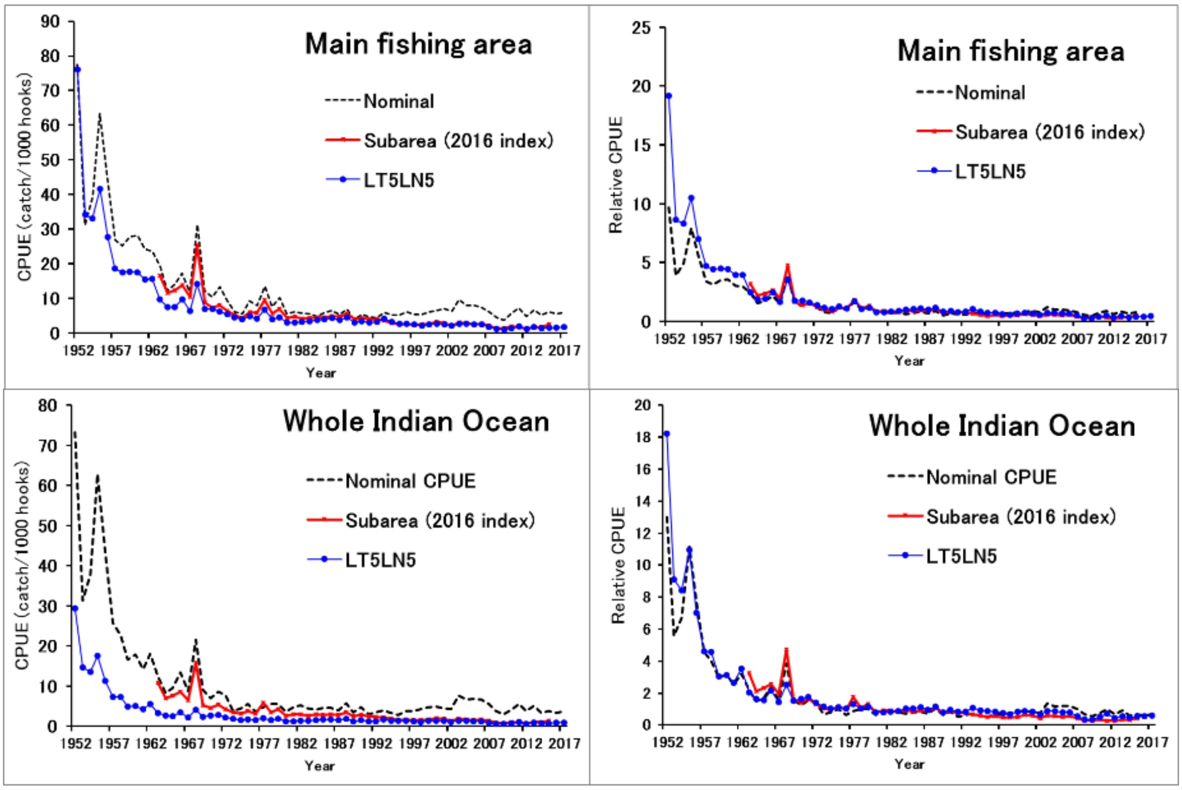


Fig. 4. Comparison of annual based area aggregated CPUE with the effect of subarea (Matsumoto et al., 2016) and LT5LN5 (present study), standardized for main (top) and whole (bottom) fishing grounds expressed in real (left figure) and relative (right figure) scale overlaid with nominal CPUE.

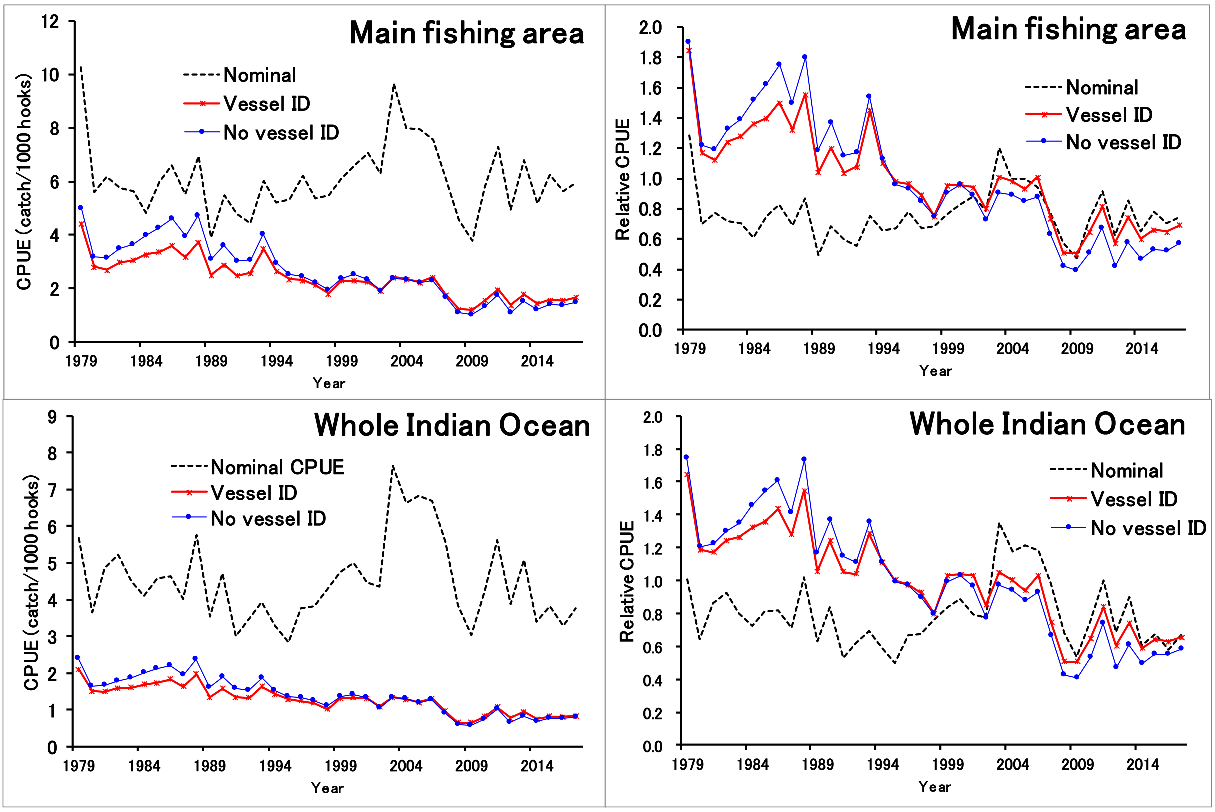


Fig. 5. Comparison of annual based area aggregated CPUE with and without the effect of vessel ID, standardized for main (top) and whole (bottom) fishing grounds expressed in real (left figure) and relative (right figure) scale overlaid with nominal CPUE.

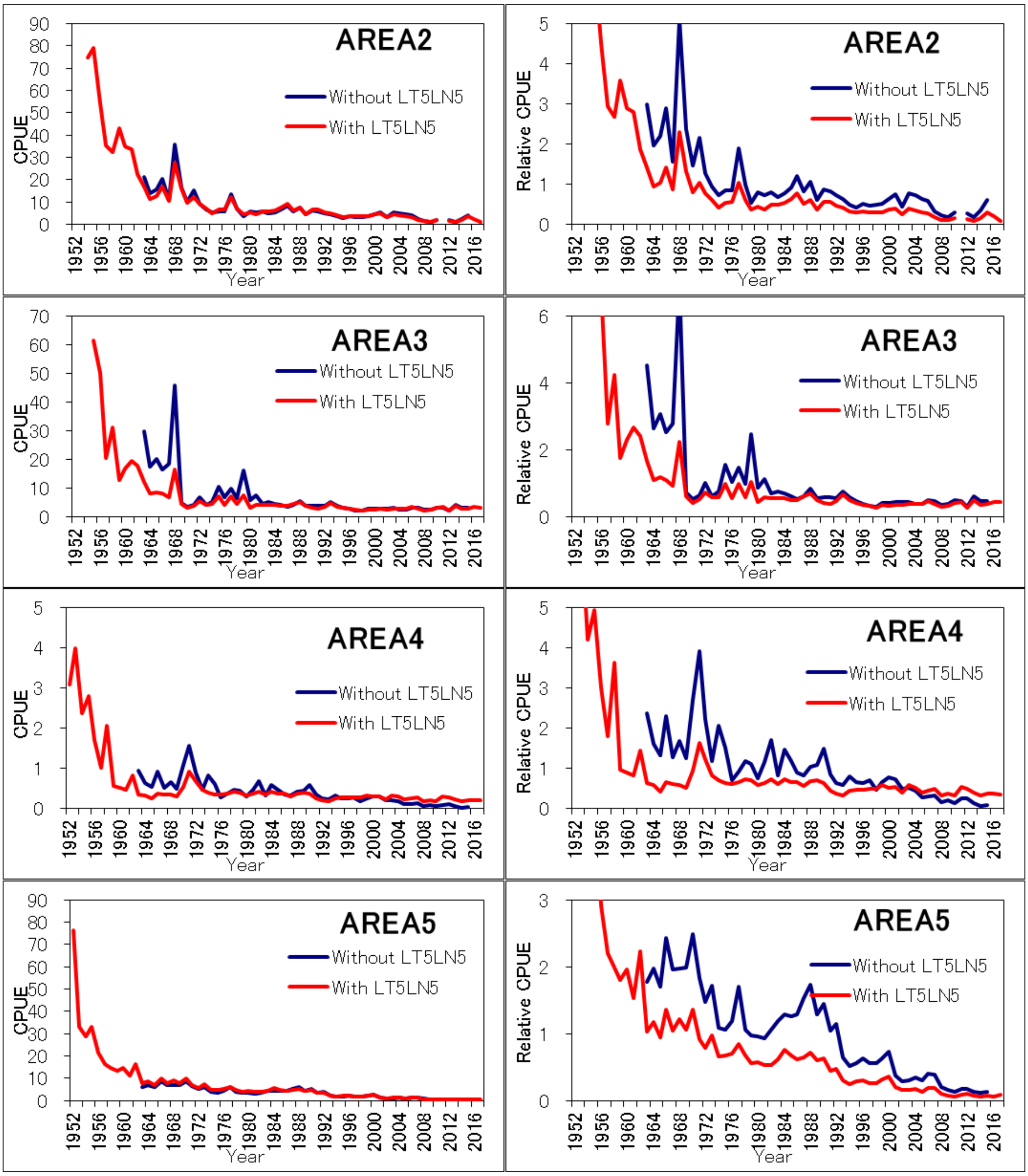


Fig. 6. Standardized year based CPUE in number for 1952-2017 for each four areas expressed in relative (left figure) and real (right figure) scale with comparison of CPUE without LT5LN5 reported in 2016 (Matsumoto et al., 2016).

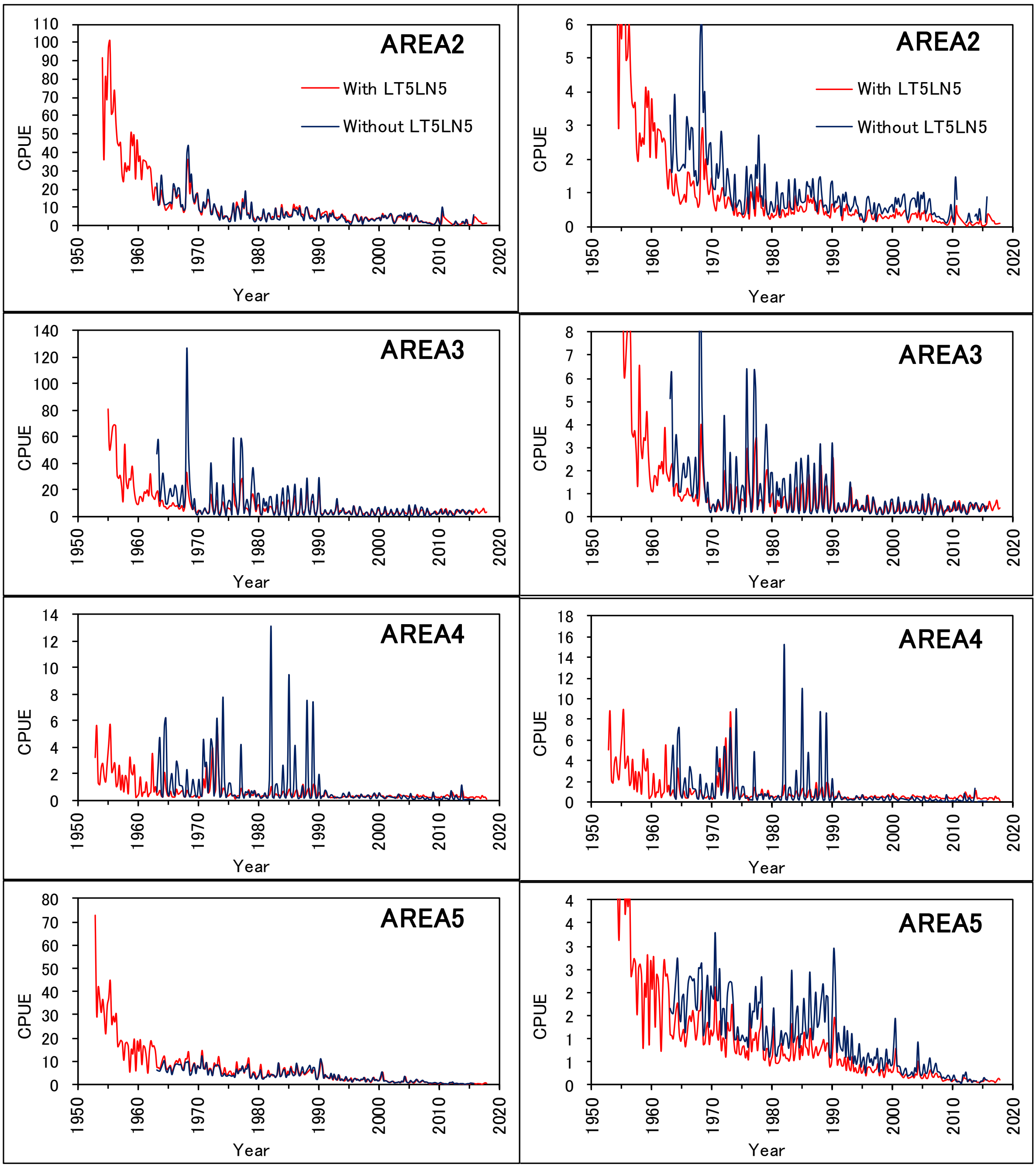
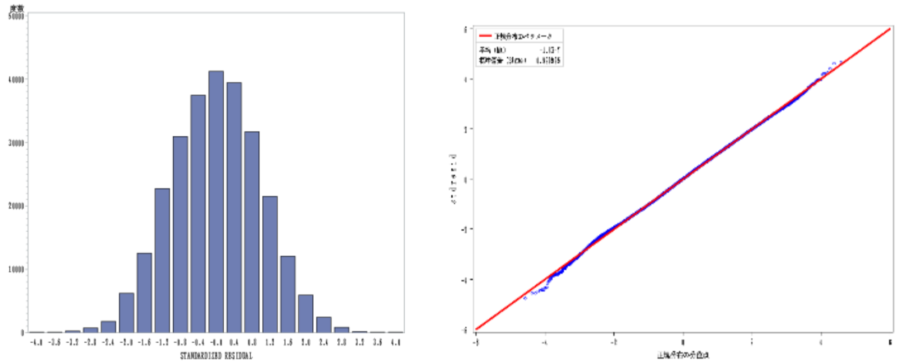
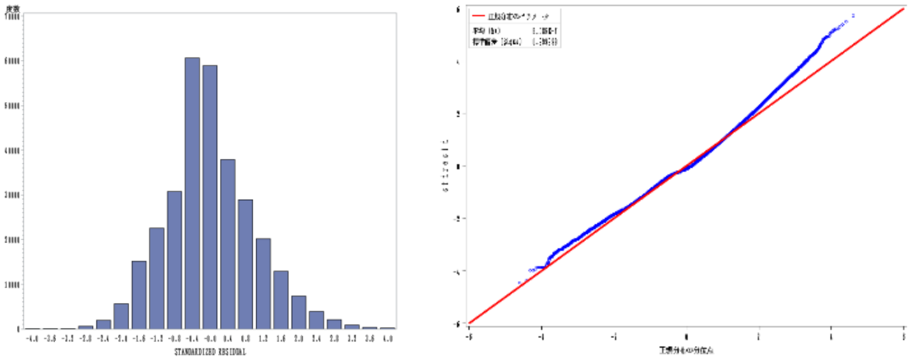


Fig. 7. Standardized quarter based CPUE in number for 1952-2017 for each four areas expressed in relative (left figure) and real (right figure) scale with comparison of CPUE without LT5LN5 reported in 2016 (Matsumoto et al., 2016).

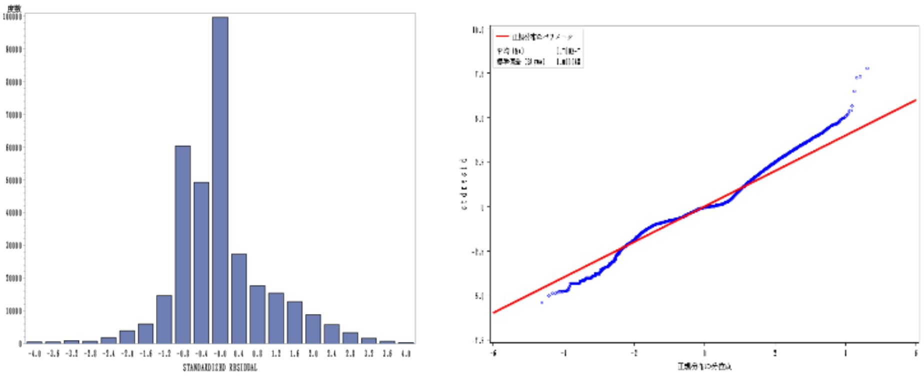
Area 2



Area 3



Area 4



Area 5

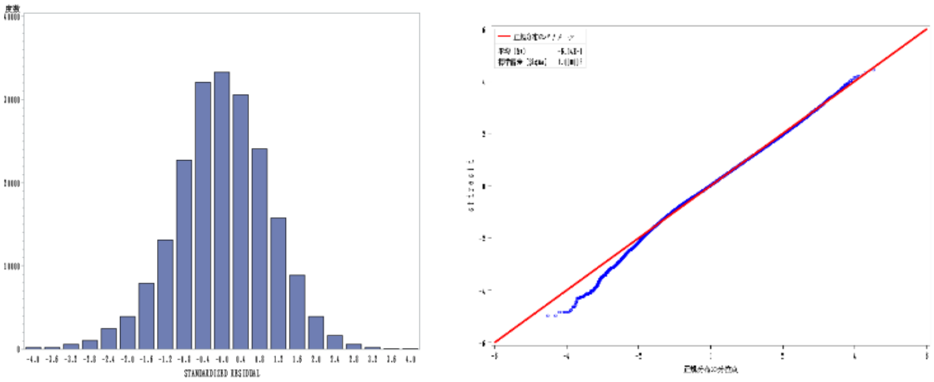
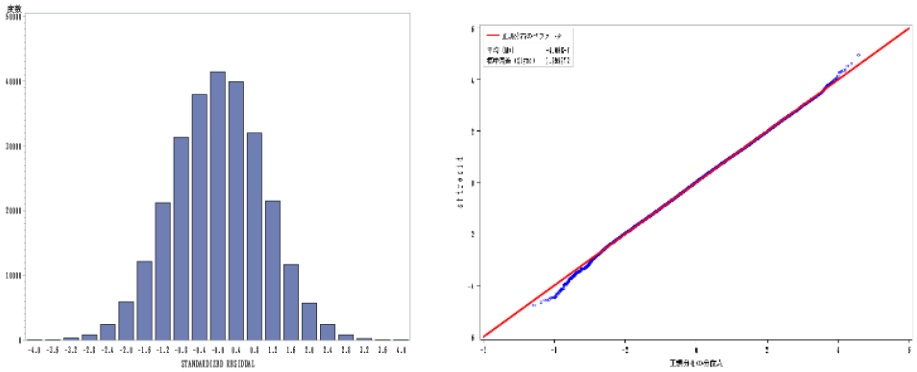
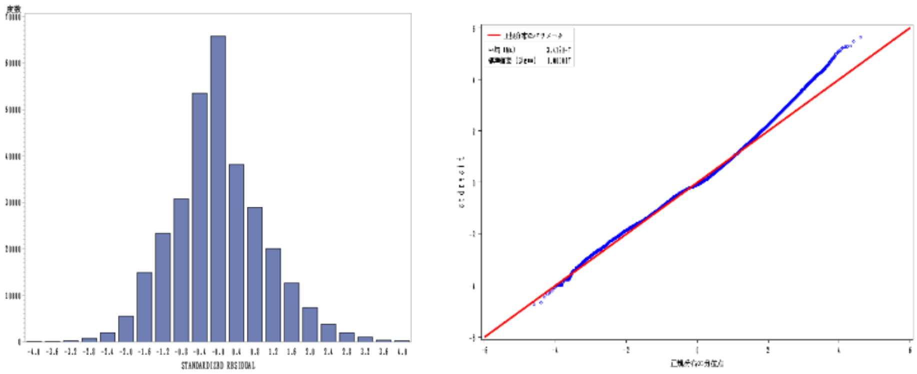


Fig. 8. Standardized residuals of year based CPUE standardization for each of four areas expressed as histograms and QQ plots.

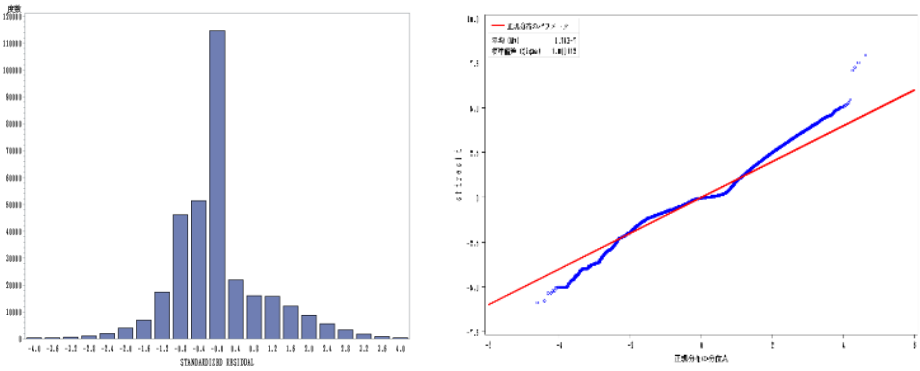
Area 2



Area 3



Area 4



Area 5

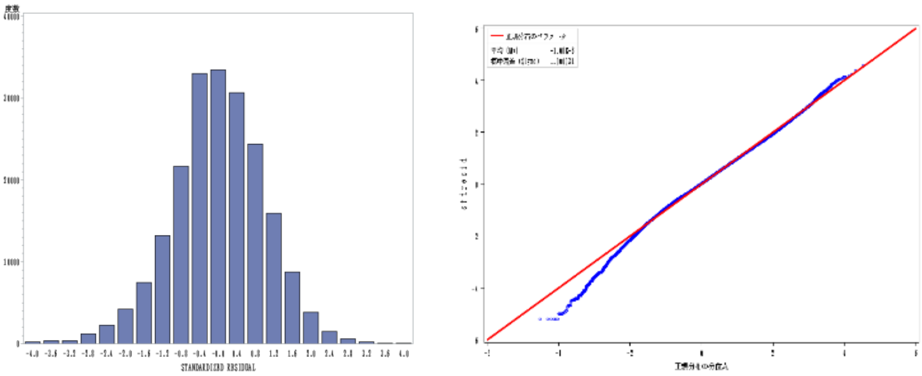


Fig. 9. Standardized residuals of quarter based CPUE standardization for each of four areas expressed as histograms and QQ plots.

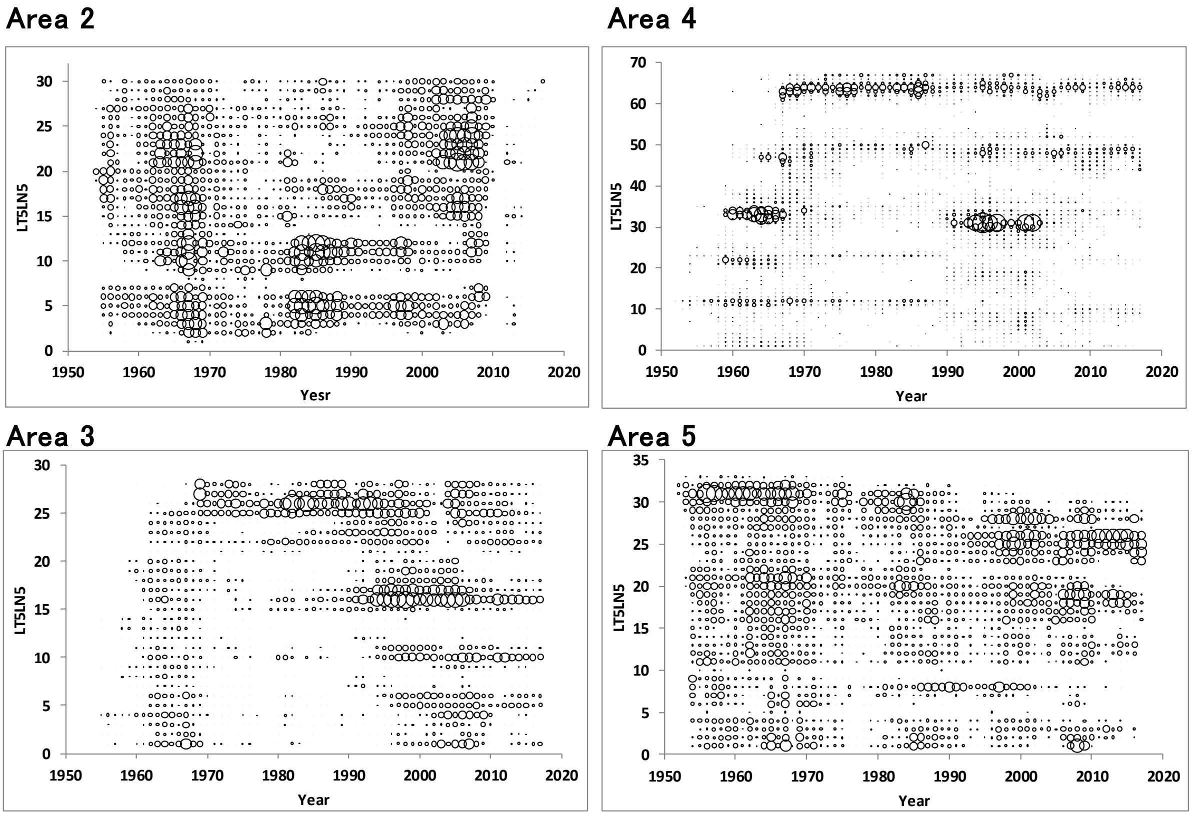


Fig. 10. Historical change in the number of observation of each LT5LN5 factor in each area.

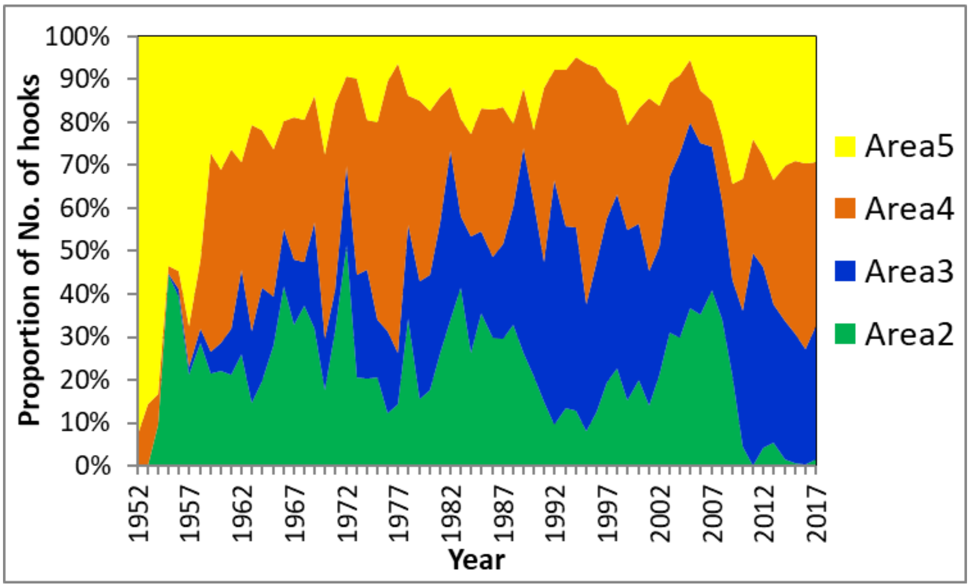


Fig. 11. Historical change in the proportion of fishing effort (number of hooks) in each area.

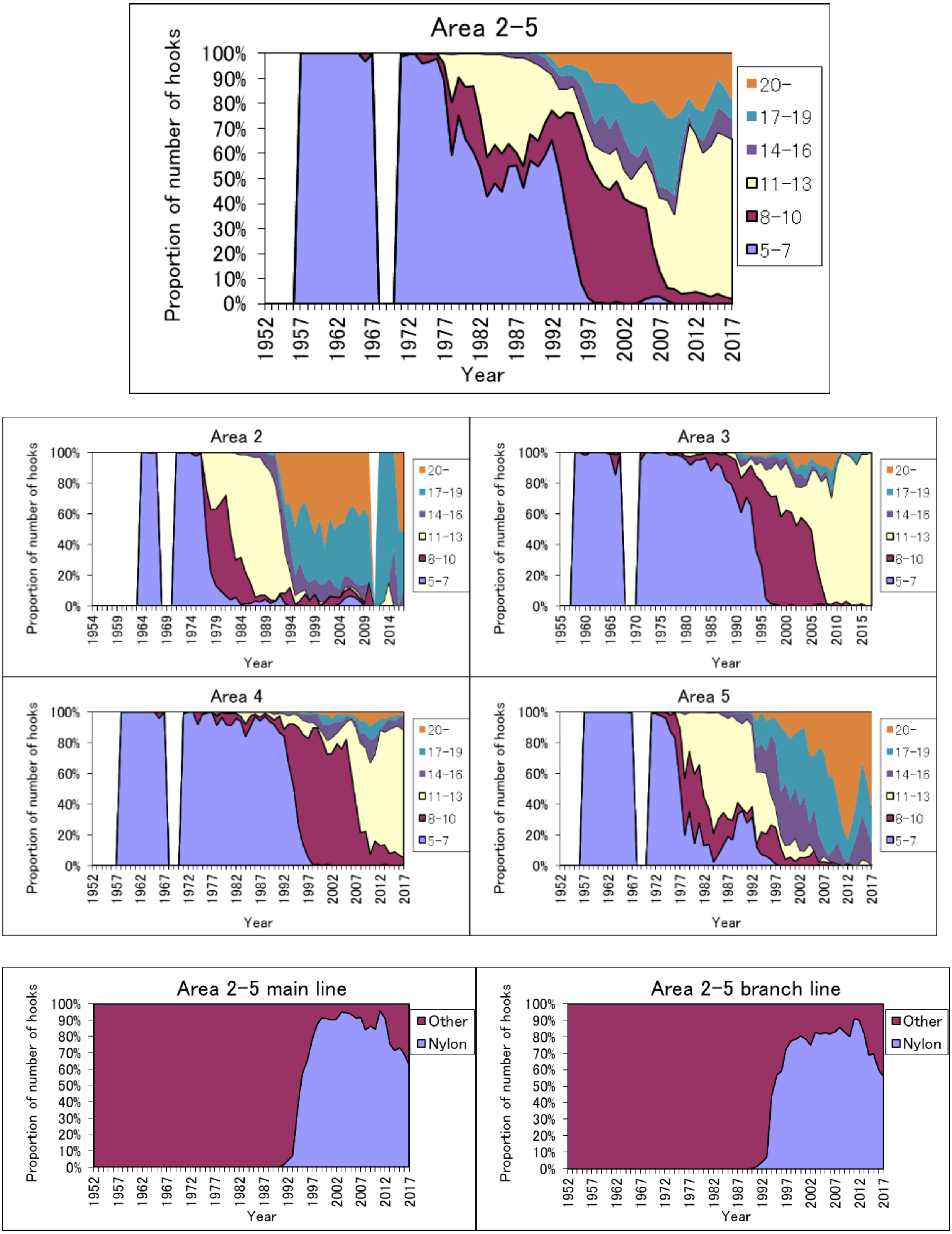


Fig. 12. Historical changes in the proportion of fishing effort by fishing gear (NHFCL and gear materials (main-line and branch-line)).

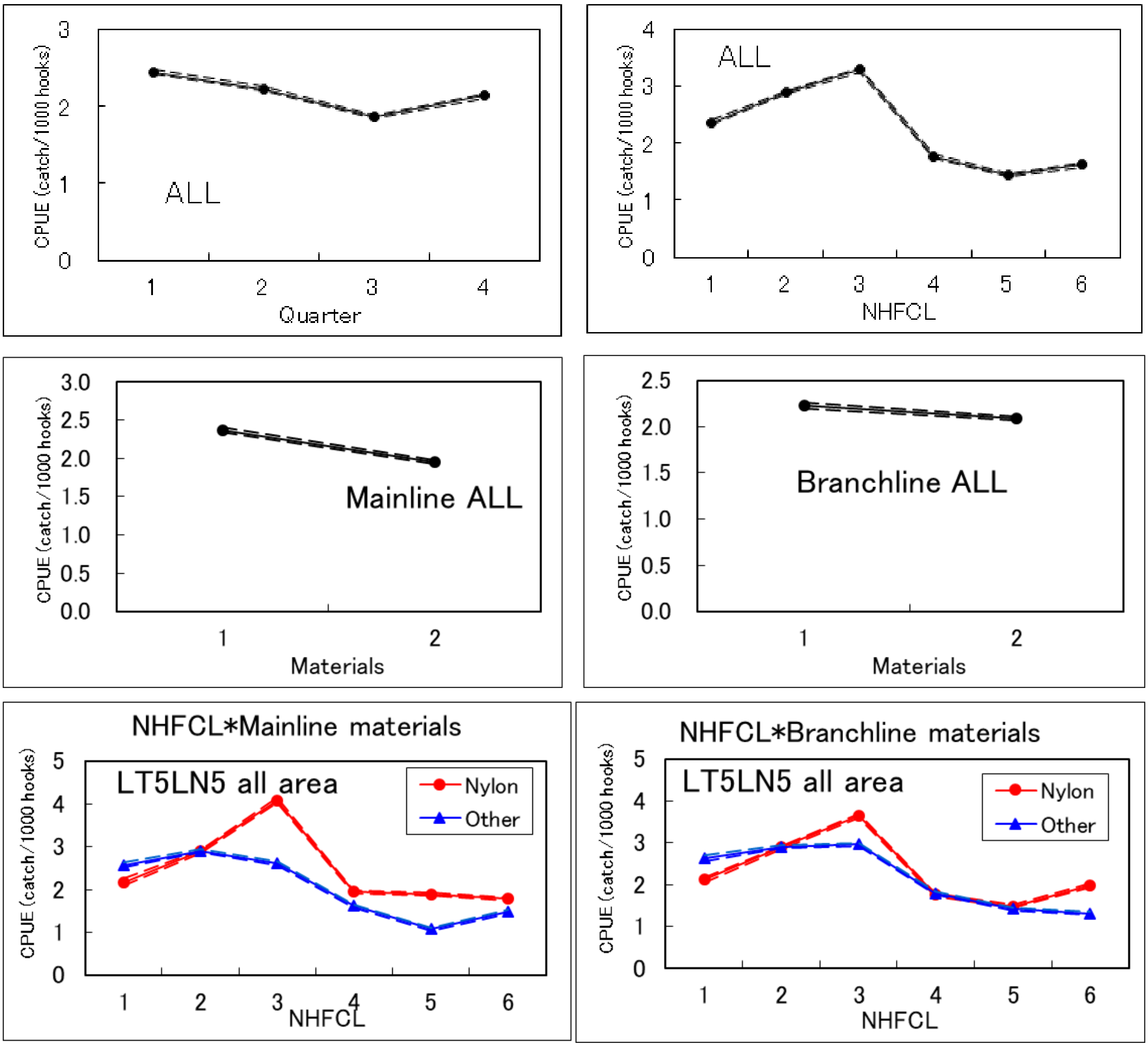


Fig. 13. Trends of CPUE standardized for each quarter, NHFCL (with gear material as well) and gear (main-line and branch-line) materials in whole Indian Ocean.

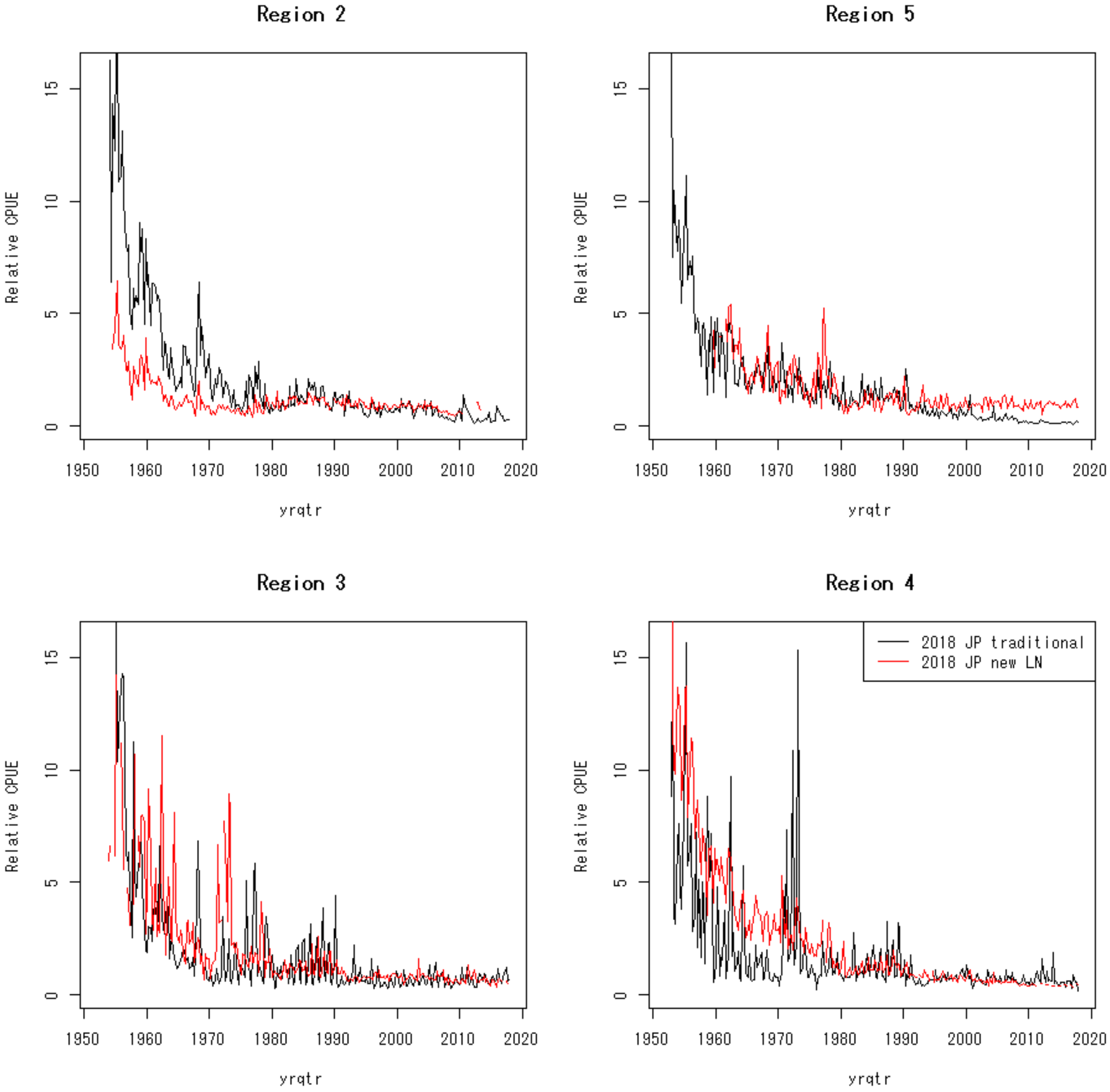


Fig. 14. Comparison of area specific CPUE series of yellowfin tuna with new method in the CPUE collaborative analysis (Matsumoto et al., 2018). "2018 JP traditional" and "2018 JP new LN" show the indices by traditional (this study) and new method (collaborative analysis, lognormal model) conducted this year, respectively.