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

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**

Standardization of Japanese longline CPUE for bigeye tuna was conducted up to 2018 by using GLM (generalized linear model, log normal error structured). The effects of season (month or quarter), subarea or LT5LN5 (five degree latitude-longitude block), SST (sea surface temperature), NHF (number of hooks between floats) and material of main line, and several interactions between them were used for standardization. The trend of CPUE slightly differed by area, but high jump in 1977 and 1978, slight decrease after that, and increasing trend in the recent few years were observed.

## 1. Introduction

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

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

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. This year bigeye tuna CPUE by Japanese longline based on the same method was also updated (Matsumoto and Hoyle, 2019). 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 - 2018 IOTC WPTT meetings (Satoh and Okamoto 2012, Matsumoto et al. 2013, Ochi et al. 2014a, Matsumoto et al. 2015; 2016, Matsumoto

2017; 2018). 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) has been changed from previous studies, and it harmonized with that for joint longline CPUE analysis. Fishing ground was divided into four areas: R1 (northwest area), R2 (northeast area), R3 (southwest area) and R4 (southeast area).

**Environmental factors:**

As environmental factors, which are available for the period of 1952-2018, SST (sea surface temperature) was used. The original SST data, whose resolution is 1-degree latitude and 1-degree longitude by month, were downloaded from NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA) http://near-goos1.jodc.go.jp/index_j.html. The SST data for several month during 2014-2017 were replaced by SST data for the same month for nearest past year because these data were unreleased in the data base. The SST in integer value was used as a continuous variable in the GLM models with subareas.

**Catch and effort data used:**

The Japanese longline catch (in number) and effort statistics from 1952 up to 2018 (all available period) were used. Data for 2018 were preliminary. Start year was usually 1960 in the previous studies for using in the stock assessment models. In this study it is 1952 (longest series) for comparing the trend of CPUEs with those by collaborative analyses, which uses longest series. Operational level (set by set) logbook data were used, which include the number of hooks between floats (NHF), were used for the analysis. CPUE was defined as the number of fish caught per 1,000 hooks. As the NHF information is only partly available for the period before 1975, NHF was regarded to be 5 in this period if there is no information. Main line material was categorized into two: 1 = Nylon and 2 = other, which is not available before 1993. The main line material was assumed as 'other' from 1975 to 1993 except as NHF was over 18 from 1990 to 1993, in which it was assumed as 'Nylon'.

**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

Area specific CPUE (quarterly):

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

where

- Log: natural logarithm,
- CPUE: catch in number of bigeye per 1000 hooks,
- const: 10% of overall mean of CPUE,
- μ: intercept,
- year: effect of year,
- month: effect of fishing season (month),
- area: effect of sub-area,
- NHFC: effect of gear type (class of the number of hooks between floats). The number of hooks between floats (NHF) was divided into 6 classes (NHFC 1: 5-7, NHFC 2: 8-10, NHFC 3: 11-13, NHFC 4: 14-16, NHFC 5: 17-19, NHFC 6: 20-21),
- SST: effect of SST (sea surface temperature),
- ML: effect of material of main line,
- LT5LN5: effect of each latitude 5 degree and longitude 5 degree square,
- quarter: effect of fishing season (quarter),
- error ~ normal (0, $\sigma^2$).

Input variables for the model was selected by a backwards stepwise F-test with a criterion of $P < 0.05$. In the cases in which the factor was not significant as main factor but was significant as interaction with another factor, the main factor was kept in the model.

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

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

where $CPUE_i$ = CPUE in year i, $W_j$ = area rate of Area j, ($\Sigma W_j = 1$), lsmean ($year*area_{ij}$) = least square mean of year-area interaction in year i and area j, constant = 10% of overall mean of CPUE. As for area aggregated CPUE in the tropical and whole Indian Ocean which includes Areas 1 and 3, CPUE in 2010, 2011 2015-2016 and 2017was calculated using area rate without Area 1, Area 1 & 3 Area 1 and Area 1 & 2, respectively because no effort was observed in these year and area due to piracy activities (Fig. 4, **Fig. 5**). Time period of standardization was 1952-2018 for all CPUEs.

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

Area aggregated CPUE (annual, with LT5LN5):

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

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

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

**3. Results and discussion**

**Area aggregated CPUE**

Trends of area aggregated CPUE in each region (tropical, south and whole of the Indian Ocean) are shown in Fig. 6 (annual) and Fig. 7 (quarterly). In the tropical Indian Ocean, CPUE increased from around 5.1 (real scale) in 1952 to 8.8 in 1956, and slightly decreased to 4.8 in 1976. It suddenly jumped up to around 10 in 1977 and 1978 and then it declined and became stable until around 1990 with some fluctuation, after which it had continuously decreased to 3.0 in 2002. CPUE after 2009 shows increasing trend with fluctuation. The standardized CPUE in the south region was stable during 1959-1967, sharply increased during 1968-1970 and then showed fluctuation or decreasing trend. As a result, CPUE in the whole Indian Ocean, which had been in the same level around 4 to 7 until 1976 and suddenly increased around 8 in 1977 and 1978 and after that showed slightly decreasing trend. It increased after 2009 with fluctuation, and was comparatively stable after 2013. 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. 8 and Fig. 9, respectively. Distributions of the standardized residual did not show remarkable difference from the normal distribution.

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

**Area specific CPUE**

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

**Comparison of CPUE with those by collaborative analysis**

**Fig. 13** shows comparison of bigeye CPUE in each area in the present study with those created at this year's collaborative analysis (Matsumoto and Hoyle, 2019), which incorporated vessel effect and cluster analysis. The trend of both CPUEs was mostly similar, but there are some differences especially in the region 4. This is probably because of the results of incorporating vessel effect and/or targeting. The difference in the region 1 (early period) is mainly because of discontinuity of CPUE before and after 1979 (without and with vessel ID, and resultant different vessel effect) for the CPUE created at collaborative analysis, and so actual difference may be smaller.

**4. References**

Matsumoto, T. (2017) Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM. IOTC-2017-WPTT19-28. pp 17.

Matsumoto, T. (2018) Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM. IOTC–2018–WPTT20–29. pp 22.

Matsumoto, T., Satoh, K. and Okamoto, H. (2013): Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM. IOTC-2013-WPTT15-25, p. 28.

Matsumoto, T., Ochi, D. and Satoh, K. (2015): Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM. IOTC–2015–WPTT17–34, p. 26.

Matsumoto, T., Nishida, T., Satoh, K. and Kitakado, T. (2016) Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM. IOTC-2016-WPTT18-13. pp 17.

Matsumoto, T. and Hoyle, S. (2019): Standardization of bigeye and yellowfin tuna CPUE by Japanese longline in the Indian Ocean which includes cluster analysis. IOTC-2019-WPTT21-20.

Matsumoto, T. and Hoyle, S. (2019): Standardization of bigeye and yellowfin tuna CPUE by Japanese longline in the Indian Ocean which includes cluster analysis. IOTC-2019-WPTT21-20.

Ochi, D., Matsumoto, T., Okamoto, H. and Kitakado, T. (2014a): Japanese longline CPUE for yellowfin tuna in the Indian Ocean up to 2014 standardized by generalized linear model. IOTC-2014/WPTT16/47, p.37.

Ochi, D., Matsumoto, T., Satoh, K. and Okamoto, H. (2014b): Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM. IOTC-2014/WPTT16/29, p.25.

Okamoto, H. and Shono, H. (2006): Japanese longline CPUE for bigeye tuna in the Indian Ocean up to 2004 standardized by GLM applying gear material information in the model. IOTC-2006/WPTT/17, p. 17.

Okamoto, H. and Shono, H. (2010): Japanese longline CPUE for bigeye tuna in the Indian Ocean up to 2009 standardized by GLM. IOTC-2010/WPTT/29, p. 14.

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 | 44.74 | | | | |
| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
| Model | 406 | 87616.67 | 215.80 | 334.02 | <.0001 |
| year | 66 | 6200.42 | 93.95 | 145.41 | <.0001 |
| month | 11 | 2197.89 | 199.81 | 309.26 | <.0001 |
| area | 4 | 1700.65 | 425.16 | 658.07 | <.0001 |
| nhfc | 5 | 446.64 | 89.33 | 138.26 | <.0001 |
| sst | 1 | 109.25 | 109.25 | 169.1 | <.0001 |
| ML | 1 | 98.89 | 98.89 | 153.07 | <.0001 |
| year*area | 245 | 9847.83 | 40.20 | 62.21 | <.0001 |
| month*area | 44 | 3161.33 | 71.85 | 111.21 | <.0001 |
| area*nhfc | 20 | 987.72 | 49.39 | 76.44 | <.0001 |
| sst*area | 4 | 1496.21 | 374.05 | 578.96 | <.0001 |
| nhfc*ML | 5 | 554.07 | 110.81 | 171.52 | <.0001 |

south

| RSquare | CV | | | | |
|---|---|---|---|---|---|
| 0.31 | 135.14 | | | | |
| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
| Model | 167 | 153737.20 | 920.58 | 996.44 | <.0001 |
| year | 66 | 26111.98 | 395.64 | 428.24 | <.0001 |
| month | 11 | 13463.64 | 1223.97 | 1324.82 | <.0001 |
| area | 1 | 88.90 | 88.90 | 96.23 | <.0001 |
| nhfc | 5 | 1753.04 | 350.61 | 379.5 | <.0001 |
| sst | 1 | 4580.51 | 4580.51 | 4957.95 | <.0001 |
| ML | 1 | 36.43 | 36.43 | 39.43 | <.0001 |
| year*area | 60 | 6740.34 | 112.34 | 121.6 | <.0001 |
| month*area | 11 | 2407.87 | 218.90 | 236.93 | <.0001 |
| area*nhfc | 5 | 881.09 | 176.22 | 190.74 | <.0001 |
| sst*area | 1 | 350.30 | 350.30 | 379.16 | <.0001 |
| nhfc*ML | 5 | 273.02 | 54.60 | 59.1 | <.0001 |

whole

| RSquare | CV | | | | |
|---|---|---|---|---|---|
| 0.37 | 60.02 | | | | |
| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
| Model | 568 | 361150.98 | 635.83 | 908.33 | <.0001 |
| year | 66 | 11251.40 | 170.48 | 243.54 | <.0001 |
| month | 11 | 3161.39 | 287.40 | 410.57 | <.0001 |
| area | 6 | 2112.02 | 352.00 | 502.86 | <.0001 |
| nhfc | 5 | 1176.14 | 235.23 | 336.04 | <.0001 |
| sst | 1 | 12.60 | 12.60 | 18 | <.0001 |
| ML | 1 | 0.41 | 0.41 | 0.58 | 0.4467 |
| year*area | 371 | 32681.73 | 88.09 | 125.84 | <.0001 |
| month*area | 66 | 14085.73 | 213.42 | 304.89 | <.0001 |
| area*nhfc | 30 | 2586.40 | 86.21 | 123.16 | <.0001 |
| sst*area | 6 | 2545.27 | 424.21 | 606.02 | <.0001 |
| nhfc*ML | 5 | 423.98 | 84.80 | 121.14 | <.0001 |

Quarterly

tropical

| RSquare | CV | | | | |
|---|---|---|---|---|---|
| 0.24 | 43.95 | | | | |
| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
| Model | 1252 | 99557.60 | 79.52 | 127.5 | <.0001 |
| year | 66 | 3046.51 | 46.16 | 74.01 | <.0001 |
| quarter | 3 | 75.06 | 25.02 | 40.12 | <.0001 |
| area | 4 | 730.16 | 182.54 | 292.69 | <.0001 |
| nhfc | 5 | 340.54 | 68.11 | 109.2 | <.0001 |
| sst | 1 | 0.41 | 0.41 | 0.66 | 0.4167 |
| ML | 1 | 88.92 | 88.92 | 142.58 | <.0001 |
| year*quarter*area | 1143 | 26828.25 | 23.47 | 37.63 | <.0001 |
| area*nhfc | 20 | 814.56 | 40.73 | 65.3 | <.0001 |
| sst*area | 4 | 610.91 | 152.73 | 244.88 | <.0001 |
| nhfc*ML | 5 | 483.83 | 96.77 | 155.16 | <.0001 |

south

| RSquare | CV | | | | |
|---|---|---|---|---|---|
| 0.35 | 131.20 | | | | |
| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
| Model | 514 | 173543.76 | 337.63 | 387.75 | <.0001 |
| year | 66 | 13134.96 | 199.01 | 228.56 | <.0001 |
| quarter | 3 | 1239.53 | 413.18 | 474.51 | <.0001 |
| area | 1 | 385.92 | 385.92 | 443.21 | <.0001 |
| nhfc | 5 | 1262.89 | 252.58 | 290.07 | <.0001 |
| sst | 1 | 8284.29 | 8284.29 | 9514 | <.0001 |
| ML | 1 | 6.93 | 6.93 | 7.96 | 0.0048 |
| year*quarter*area | 426 | 33393.05 | 78.39 | 90.02 | <.0001 |
| area*nhfc | 5 | 288.43 | 57.69 | 66.25 | <.0001 |
| sst*area | 1 | 876.16 | 876.16 | 1006.2 | <.0001 |
| nhfc*ML | 5 | 142.23 | 28.45 | 32.67 | <.0001 |

whole

| RSquare | CV | | | | |
|---|---|---|---|---|---|
| 0.40 | 58.67 | | | | |
| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
| Model | 1761 | 389304.69 | 221.07 | 330.55 | <.0001 |
| year | 66 | 4611.84 | 69.88 | 104.48 | <.0001 |
| quarter | 3 | 201.50 | 67.17 | 100.43 | <.0001 |
| area | 6 | 1208.79 | 201.46 | 301.24 | <.0001 |
| nhfc | 5 | 853.69 | 170.74 | 255.29 | <.0001 |
| sst | 1 | 98.00 | 98.00 | 146.53 | <.0001 |
| ML | 1 | 0.22 | 0.22 | 0.32 | 0.57 |
| year*quarter*area | 1638 | 79480.37 | 48.52 | 72.55 | <.0001 |
| area*nhfc | 30 | 1645.79 | 54.86 | 82.03 | <.0001 |
| sst*area | 6 | 1906.95 | 317.83 | 475.22 | <.0001 |
| nhfc*ML | 5 | 326.60 | 65.32 | 97.67 | <.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 | 44.48 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 170 | 91166.88 | 536.28 | 839.49 | <.0001 |
| year | 66 | 9359.48 | 141.81 | 221.99 | <.0001 |
| month | 11 | 2203.86 | 200.35 | 313.63 | <.0001 |
| LT5LN5 | 74 | 40257.84 | 544.02 | 851.62 | <.0001 |
| nhfc | 5 | 153.63 | 30.73 | 48.1 | <.0001 |
| sst | 8 | 1476.07 | 184.51 | 288.83 | <.0001 |
| ML | 1 | 71.05 | 71.05 | 111.22 | <.0001 |
| nhfc*ML | 5 | 379.66 | 75.93 | 118.86 | <.0001 |

**south**

| RSquare | CV |
|---|---|
| 0.33 | 133.04 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 152 | 164219.25 | 1080.39 | 1206.76 | <.0001 |
| year | 66 | 26359.82 | 399.39 | 446.11 | <.0001 |
| month | 11 | 12455.27 | 1132.30 | 1264.74 | <.0001 |
| LT5LN5 | 46 | 14280.92 | 310.45 | 346.77 | <.0001 |
| nhfc | 5 | 694.09 | 138.82 | 155.06 | <.0001 |
| sst | 18 | 7758.21 | 431.01 | 481.43 | <.0001 |
| ML | 1 | 6.05 | 6.05 | 6.76 | 0.0093 |
| nhfc*ML | 5 | 120.74 | 24.15 | 26.97 | <.0001 |

**whole**

| RSquare | CV |
|---|---|
| 0.36 | 60.71 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 228 | 346779.88 | 1520.96 | 2123.9 | <.0001 |
| year | 66 | 19477.52 | 295.11 | 412.1 | <.0001 |
| month | 11 | 4420.33 | 401.85 | 561.15 | <.0001 |
| LT5LN5 | 121 | 139085.18 | 1149.46 | 1605.13 | <.0001 |
| nhfc | 5 | 344.09 | 68.82 | 96.1 | <.0001 |
| sst | 19 | 10404.57 | 547.61 | 764.69 | <.0001 |
| ML | 1 | 71.00 | 71.00 | 99.15 | <.0001 |
| nhfc*ML | 5 | 375.53 | 75.11 | 104.88 | <.0001 |

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

**Northwest(R1)**

| RSquare | CV |
|---|---|
| 0.32 | 49.57 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 309 | 103497.18 | 334.94 | 523.41 | <.0001 |
| year | 64 | 5975.68 | 93.37 | 145.91 | <.0001 |
| quarter | 3 | 439.99 | 146.66 | 229.19 | <.0001 |
| nhfc | 5 | 73.41 | 14.68 | 22.94 | <.0001 |
| ML | 1 | 15.37 | 15.37 | 24.02 | <.0001 |
| LT5LN5 | 1 | 8.29 | 8.29 | 12.95 | 0.0003 |
| year*quarter | 42 | 20994.05 | 499.86 | 781.12 | <.0001 |
| nhfc*ML | 188 | 7407.10 | 39.40 | 61.57 | <.0001 |

**Southwest(R3)**

| RSquare | CV |
|---|---|
| 0.32 | 184.99 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 294 | 82335.25 | 280.05 | 281.17 | <.0001 |
| year | 64 | 6692.72 | 104.57 | 104.99 | <.0001 |
| quarter | 3 | 632.83 | 210.94 | 211.78 | <.0001 |
| nhfc | 5 | 902.30 | 180.46 | 181.18 | <.0001 |
| ML | 1 | 6.91 | 6.91 | 6.93 | 0.0085 |
| sst | 1 | 1441.37 | 1441.37 | 1447.1 | <.0001 |
| LT5LN5 | 33 | 5924.76 | 179.54 | 180.25 | <.0001 |
| year*quarter | 182 | 6744.72 | 37.06 | 37.21 | <.0001 |
| nhfc*ML | 5 | 366.39 | 73.28 | 73.57 | <.0001 |

**Northeast(R2)**

| RSquare | CV |
|---|---|
| 0.16 | 38.54 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 306 | 21197.35 | 69.27 | 118.79 | <.0001 |
| year | 66 | 2802.36 | 42.46 | 72.81 | <.0001 |
| quarter | 3 | 164.84 | 54.95 | 94.22 | <.0001 |
| nhfc | 5 | 139.69 | 27.94 | 47.91 | <.0001 |
| ML | 1 | 33.52 | 33.52 | 57.49 | <.0001 |
| sst | 1 | 3.89 | 3.89 | 6.68 | 0.0098 |
| LT5LN5 | 33 | 9275.96 | 281.09 | 482.04 | <.0001 |
| year*quarter | 192 | 3226.53 | 16.80 | 28.82 | <.0001 |
| nhfc*ML | 5 | 116.98 | 23.40 | 40.12 | <.0001 |

**Southeast(R4)**

| RSquare | CV |
|---|---|
| 0.41 | 91.16 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 307 | 102000.89 | 332.25 | 464.77 | <.0001 |
| year | 66 | 10630.37 | 161.07 | 225.31 | <.0001 |
| quarter | 3 | 845.46 | 281.82 | 394.23 | <.0001 |
| nhfc | 5 | 495.20 | 99.04 | 138.54 | <.0001 |
| ML | 1 | 1.95 | 1.95 | 2.73 | 0.0988 |
| sst | 1 | 30.55 | 30.55 | 42.74 | <.0001 |
| LT5LN5 | 34 | 6265.42 | 184.28 | 257.78 | <.0001 |
| year*quarter | 192 | 15614.66 | 81.33 | 113.76 | <.0001 |
| nhfc*ML | 5 | 165.07 | 33.01 | 46.18 | <.0001 |

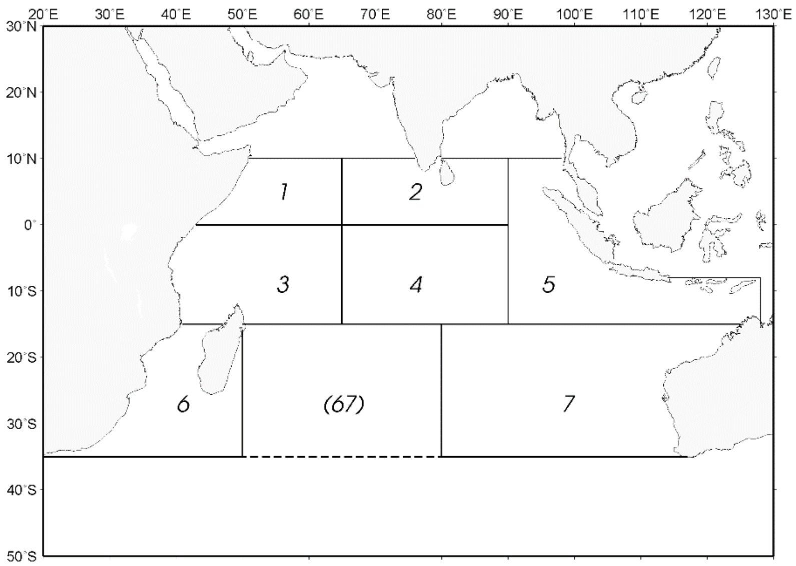



**Fig. 1.** Definition of sub-areas for area aggregated CPUE used in this study. The tropical, south and whole Indian Ocean regions in this paper consist of areas 1-5, areas 6-7 and areas1-7, respectively. Area 67 was not used in this study.

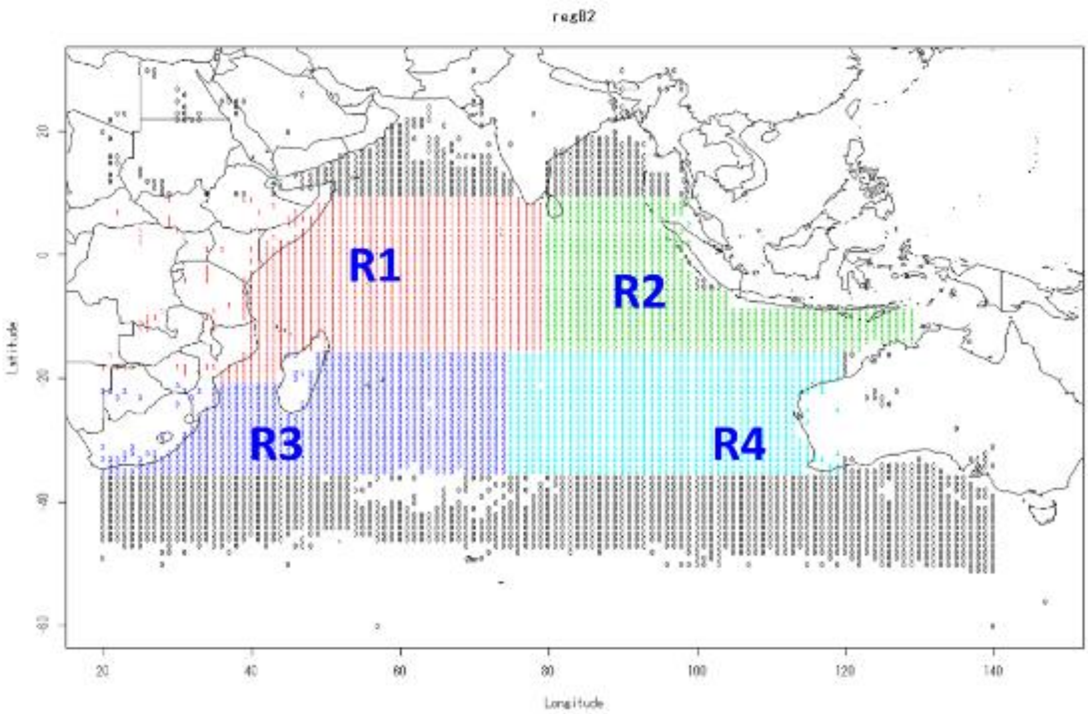



**Fig. 2.** Another definition of areas for area specific CPUE formatted for integrated model.

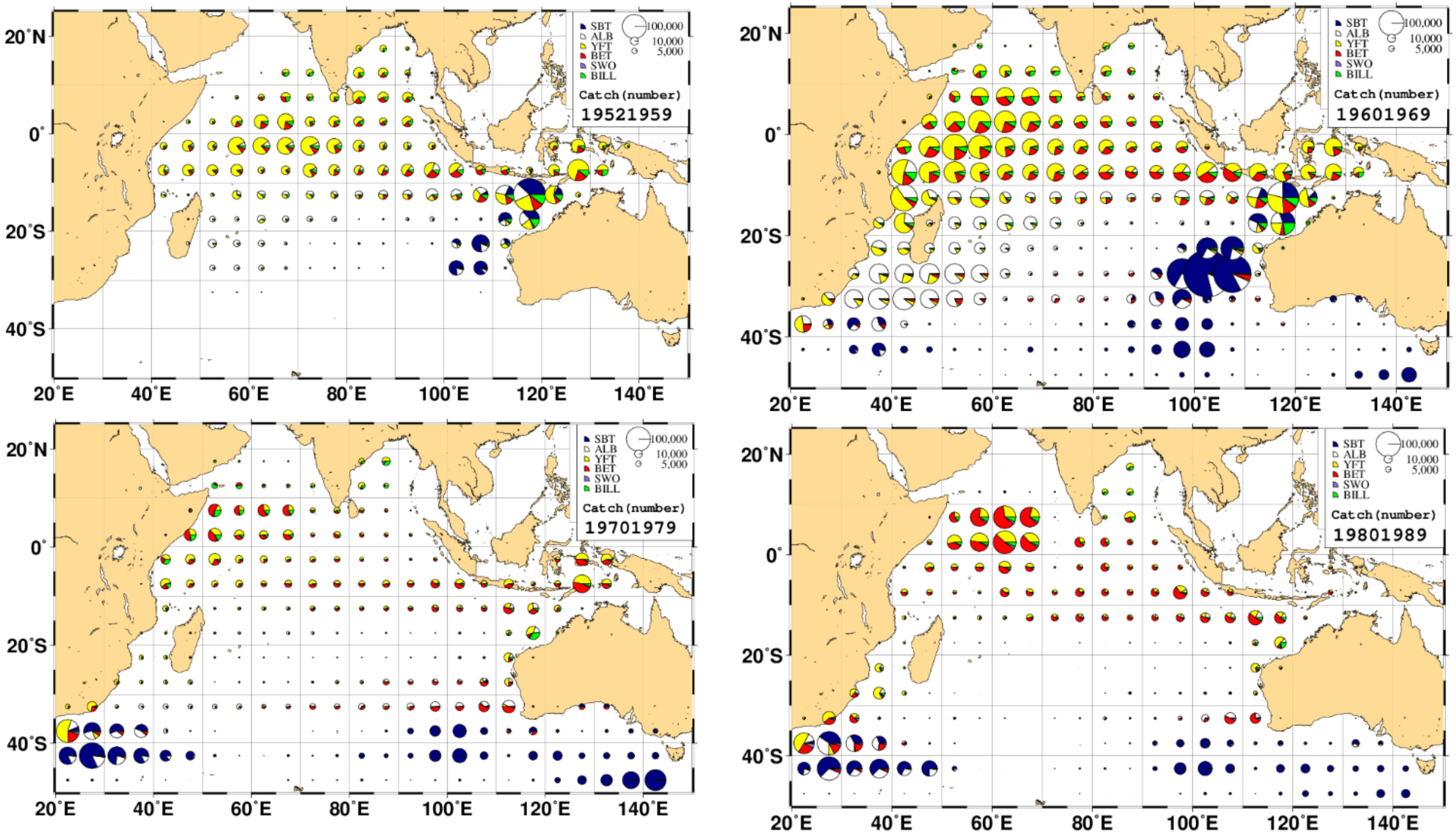



Fig. 3. The averaged distribution of amount of catch in number by species for each decade. Size of circle shows amount of total of catches i.e. southern bluefin tuna (SBT), albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO) and billfishes (Bill).

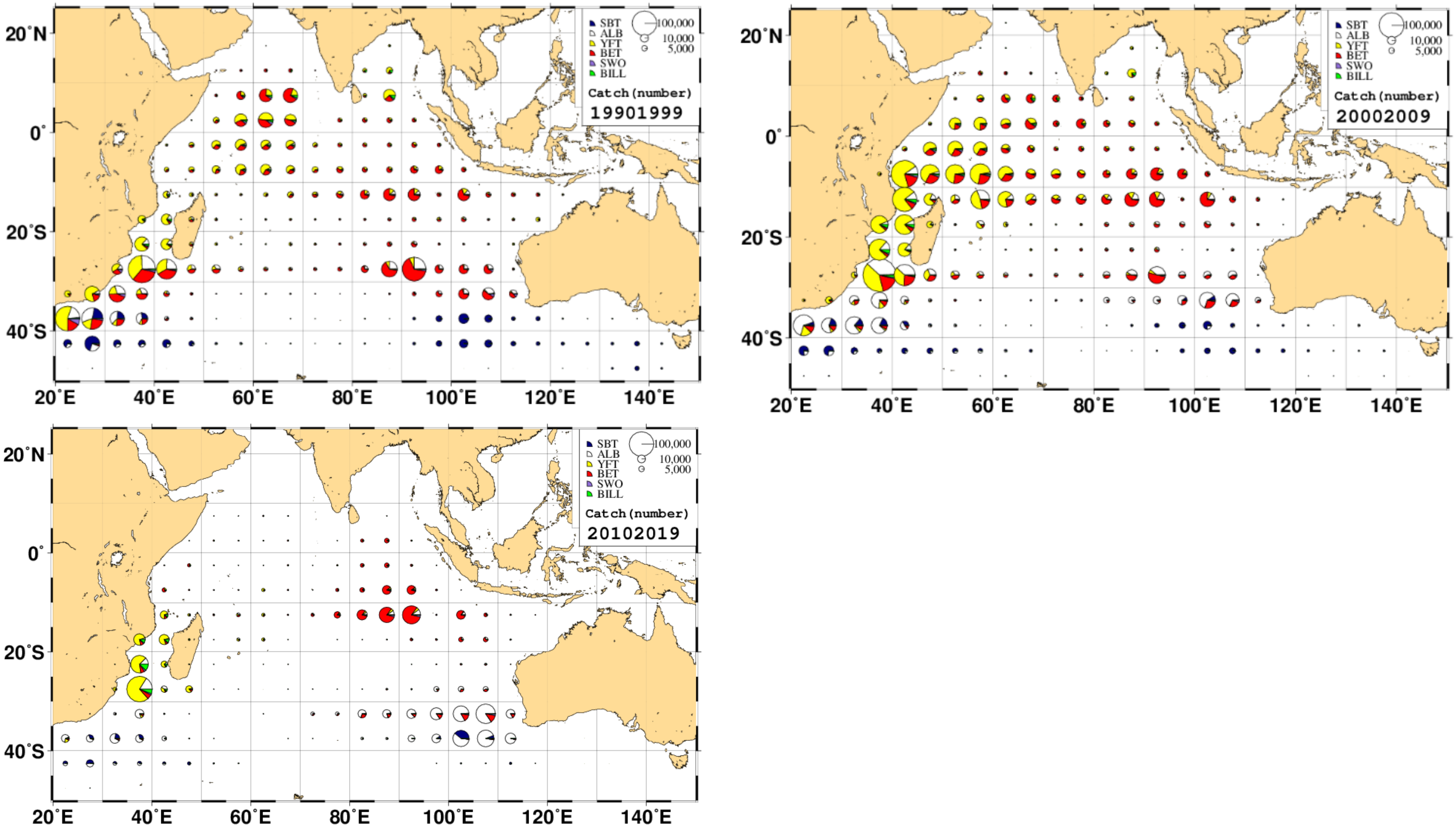



Fig. 3. The averaged distribution of amount of catch in number by species for each decade. Size of circle shows amount of total of catches i.e. southern bluefin tuna (SBT), albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO) and billfishes (Bill). (continued)

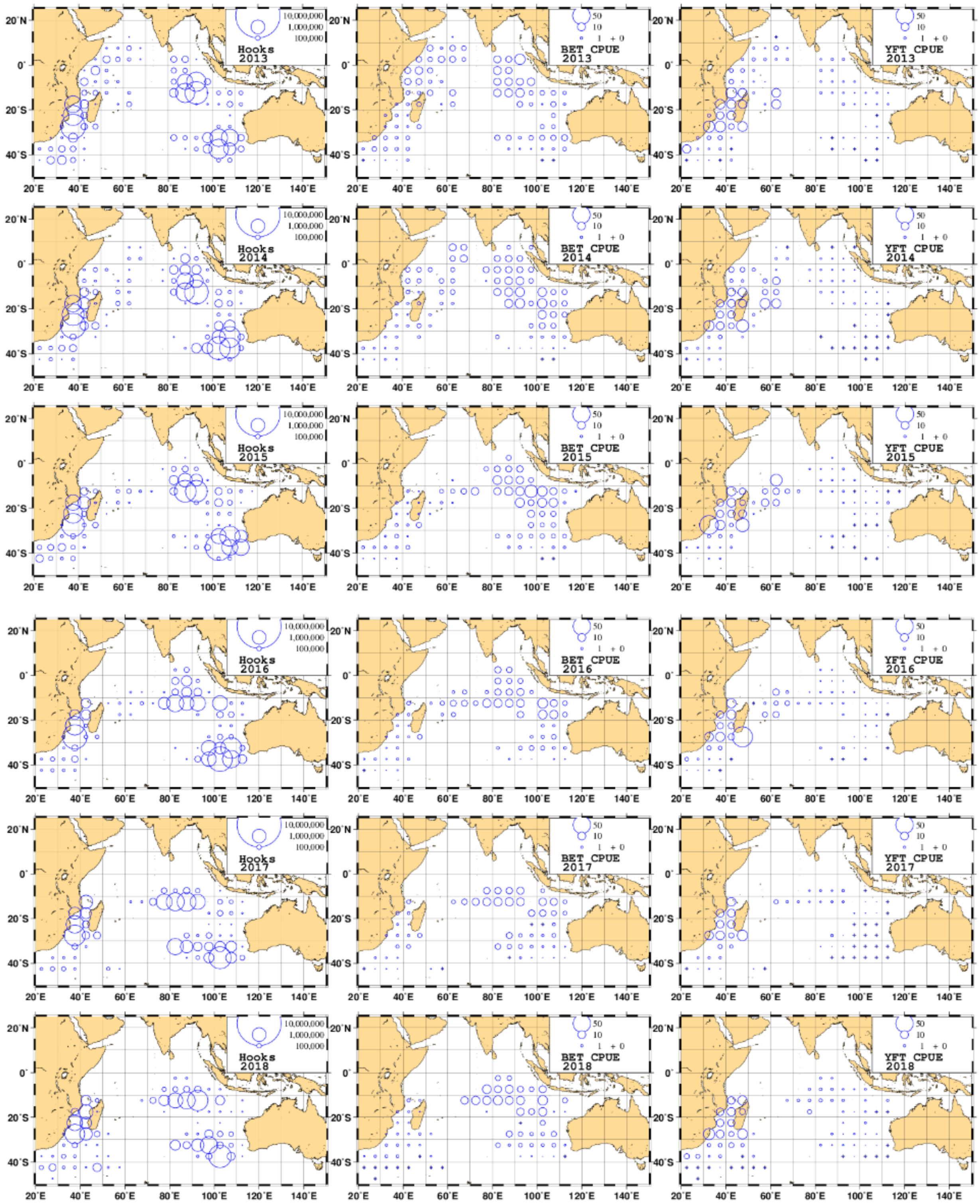


**Fig. 4.** Geographical distribution of fishing effort and nominal CPUE for bigeye and yellowfin tuna by Japanese longline in recent years.

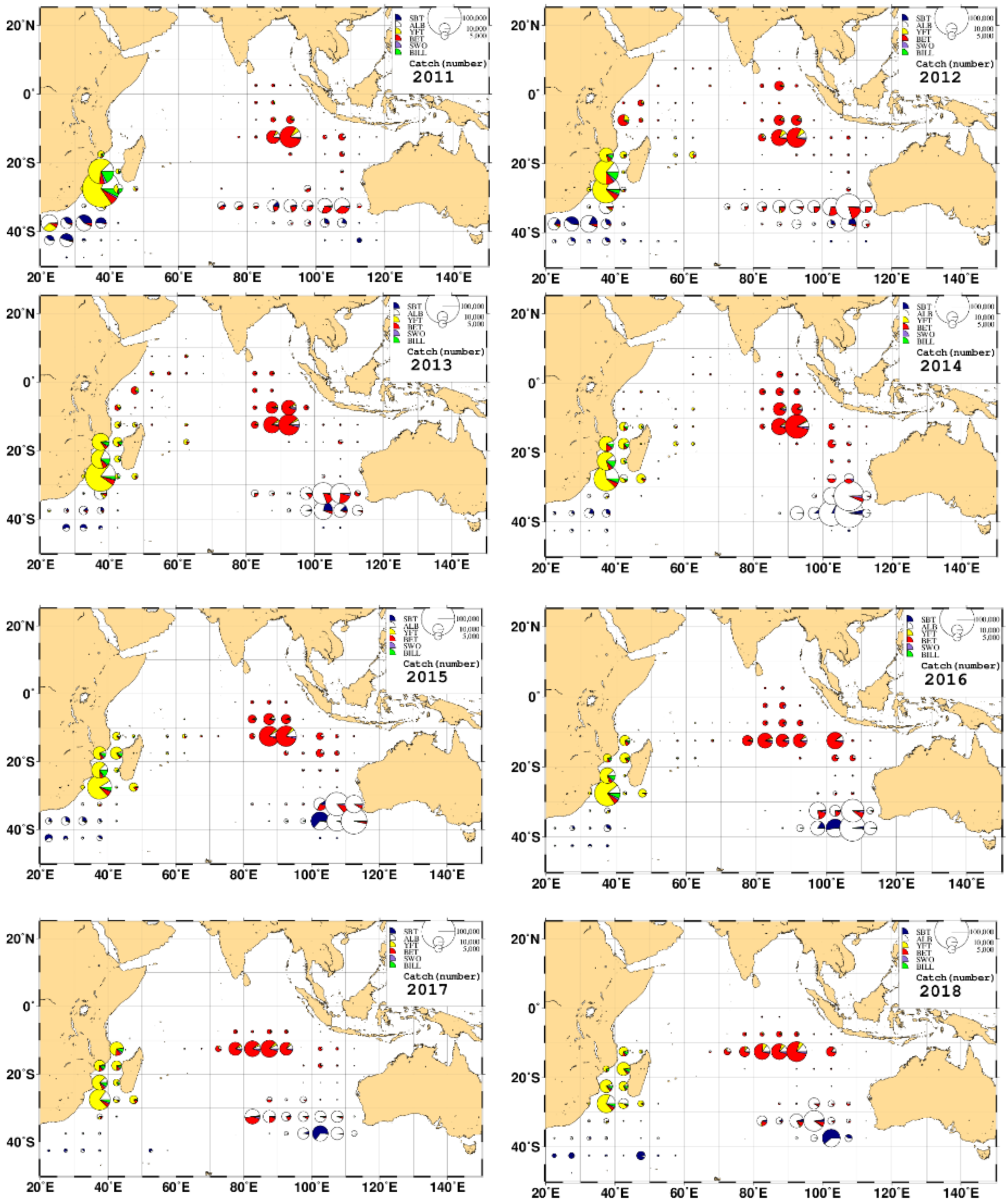



**Fig. 5.** Geographical distribution of species composition of catch for tuna and billfish species by Japanese longline in recent years. Size of circle shows amount of total of catches i.e. southern bluefin tuna (SBT), albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO) and billfishes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

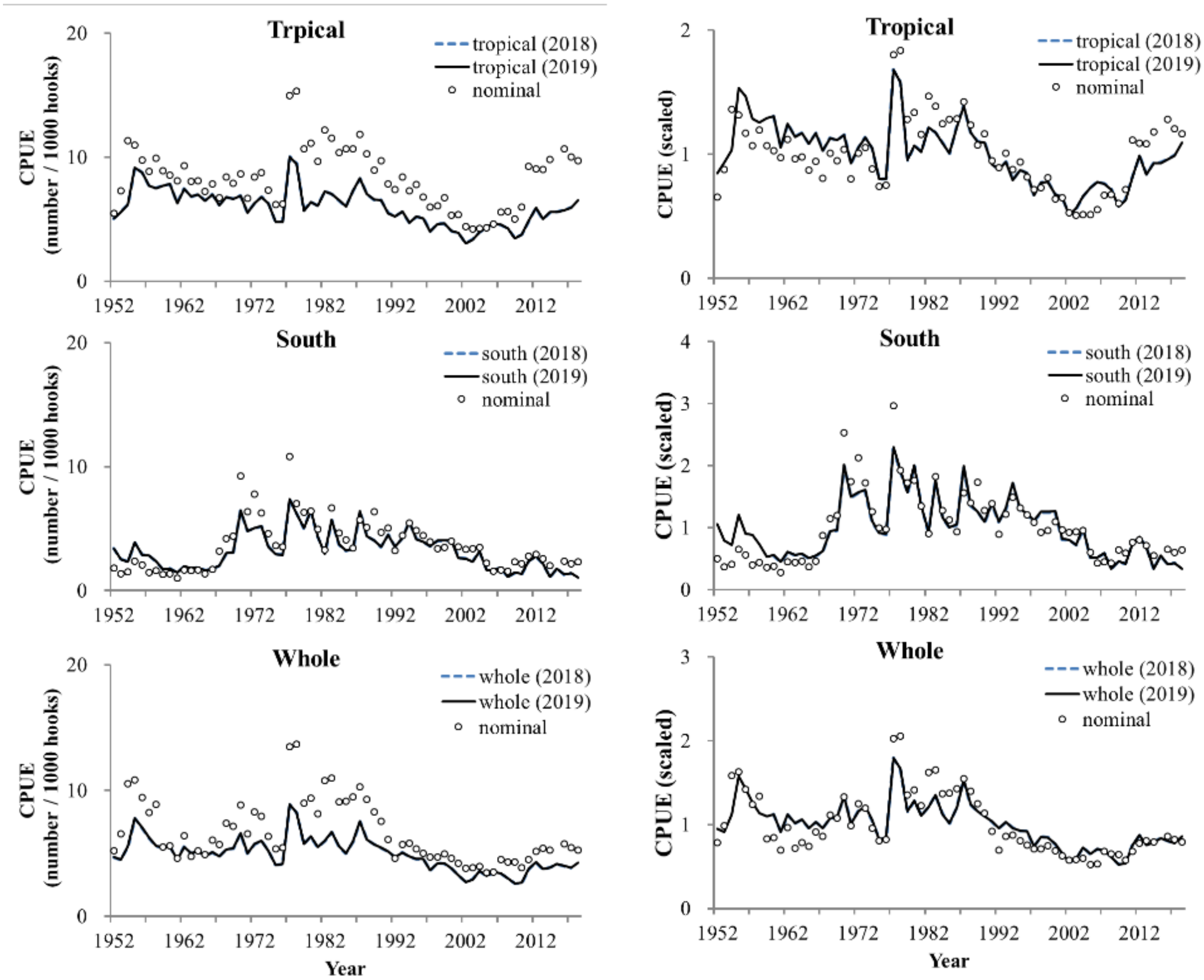



**Fig. 6**. Trend of area aggregated annual CPUE (left: real scale, right: relative scale) of bigeye. Standardized CPUE created in 2019 (solid line), nominal CPUE (open circle), and standardized CPUE created in 2018 (dashed line: Matsumoto el al., 2018) of Japanese longline for the tropical (top), south (middle) and whole (bottom) Indian Ocean.

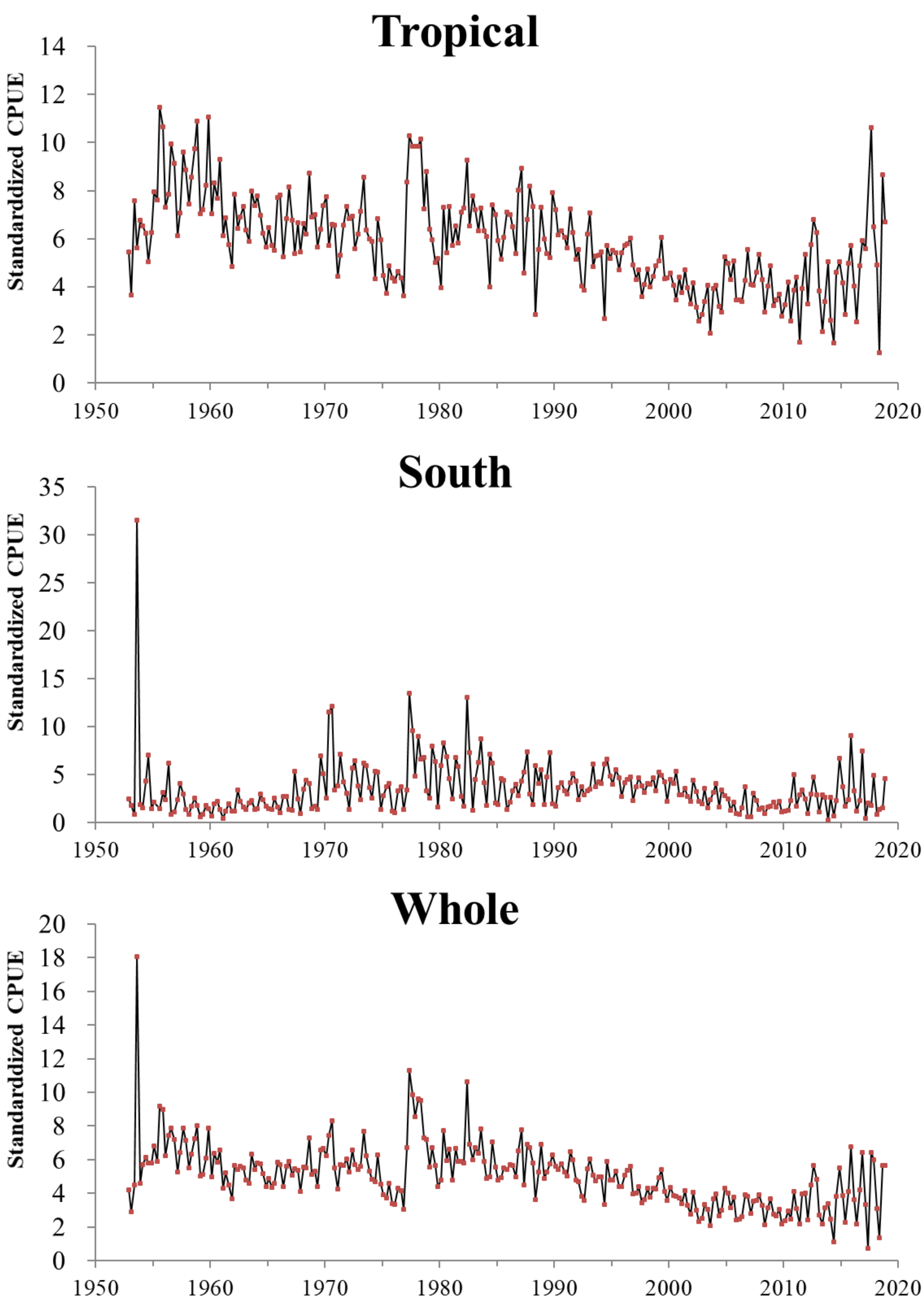
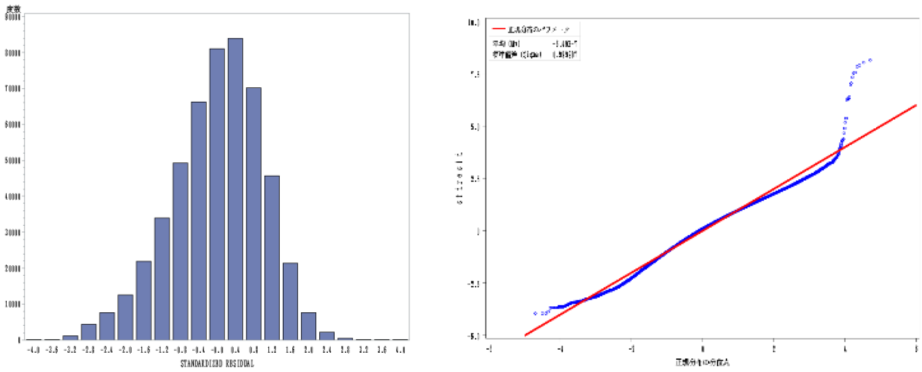



**Fig. 7**. Trend of area aggregated quarterly CPUE series of bigeye for tropical (top), south (middle) and whole (bottom) Indian Ocean

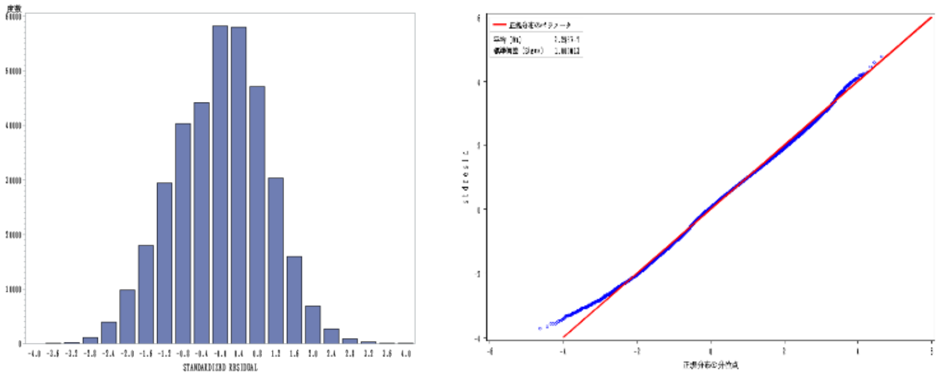
Year based

Tropical area



Year based

South area



Year based

Whole area

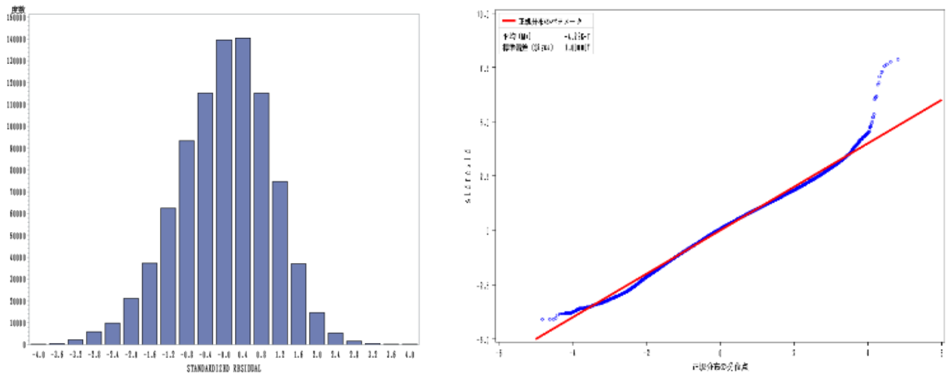
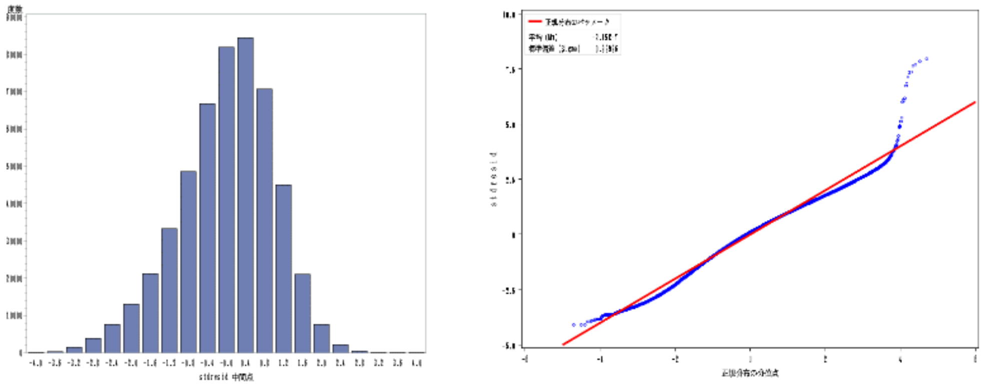


**Fig. 8**. Standardized residuals of area aggregated annual CPUE standardization.

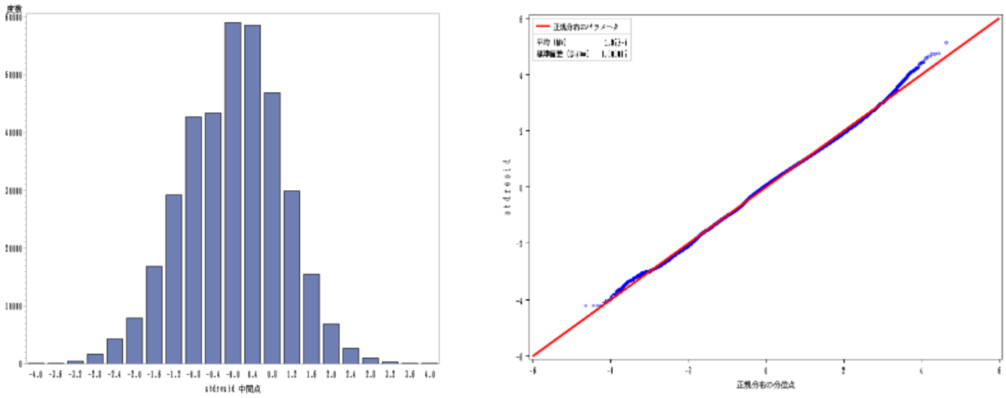
Quarter based

Tropical area



Quarter based

South area



Quarter based

Whole area

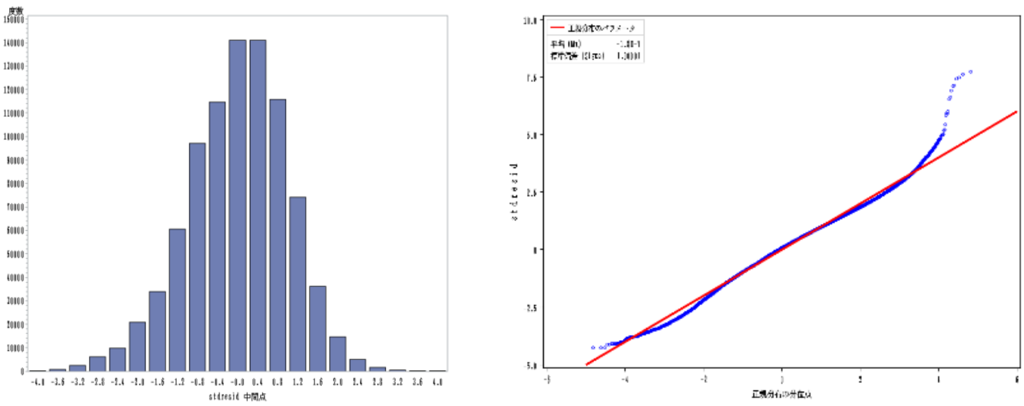


**Fig. 9**. Standardized residuals of area aggregated quarterly CPUE standardization.

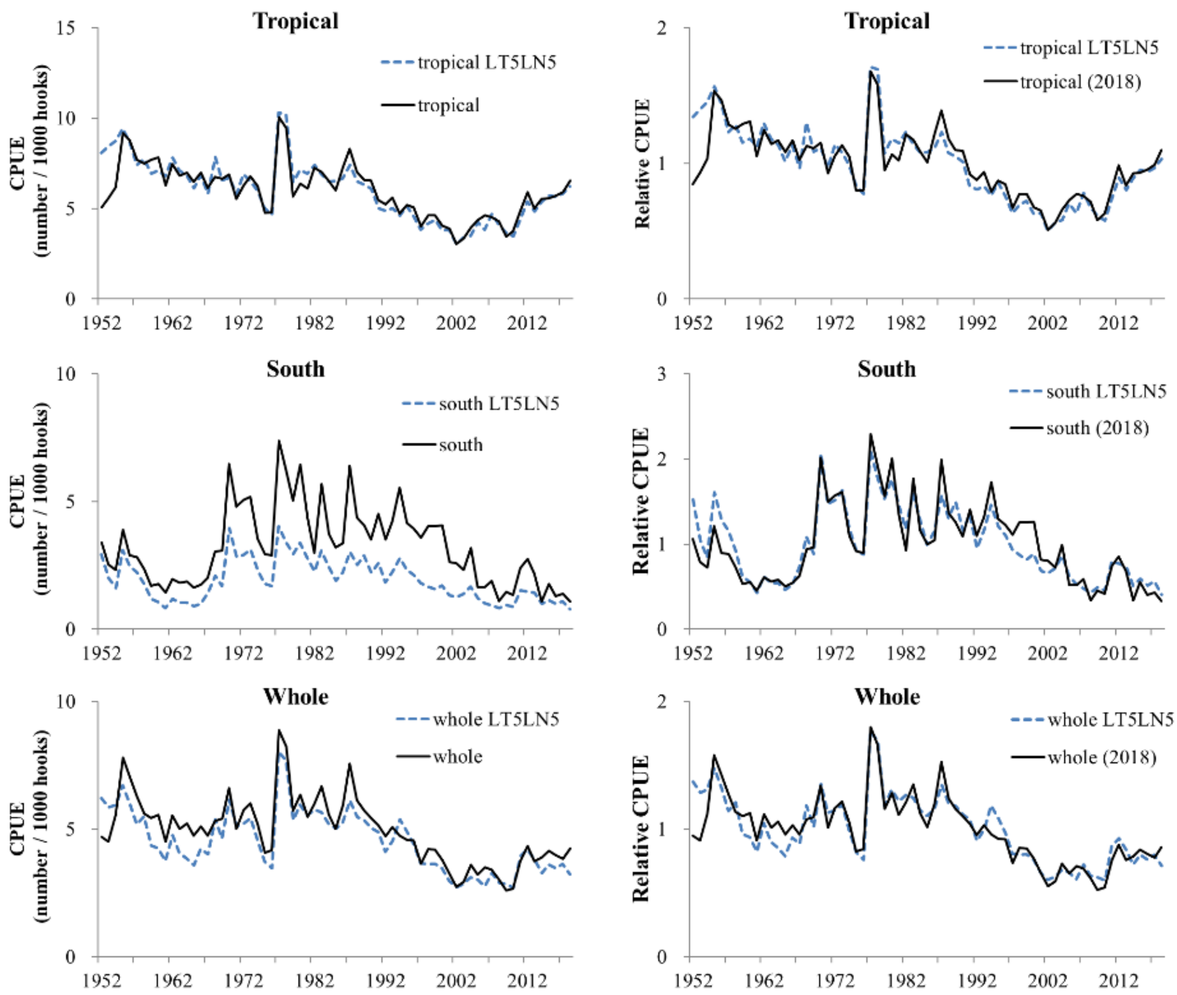



**Fig. 10**. Comparison of area aggregated CPUE series of bigeye between the model including subarea effect and that including LT5LN5 effect. Left: real scale, right: relative scale.

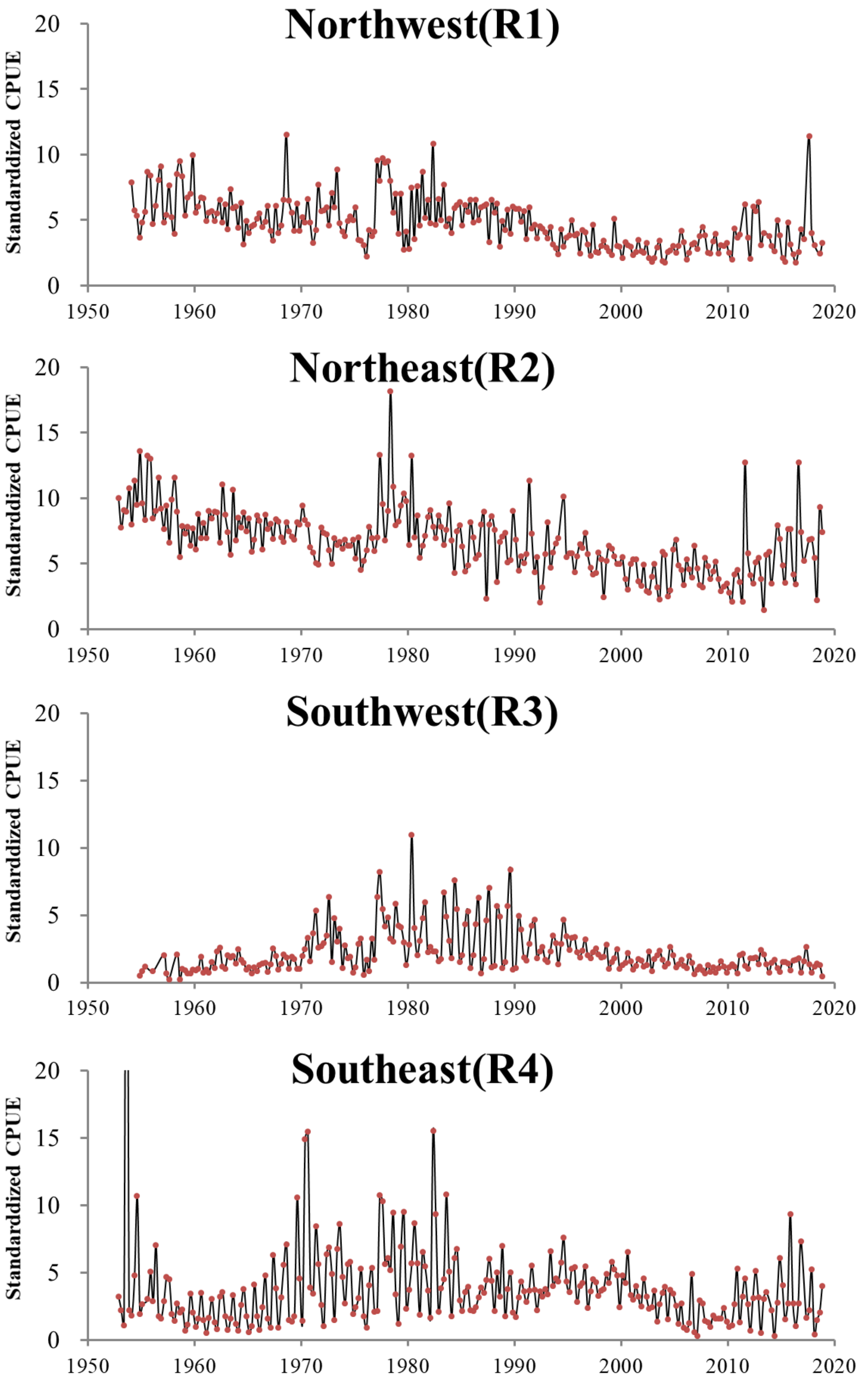
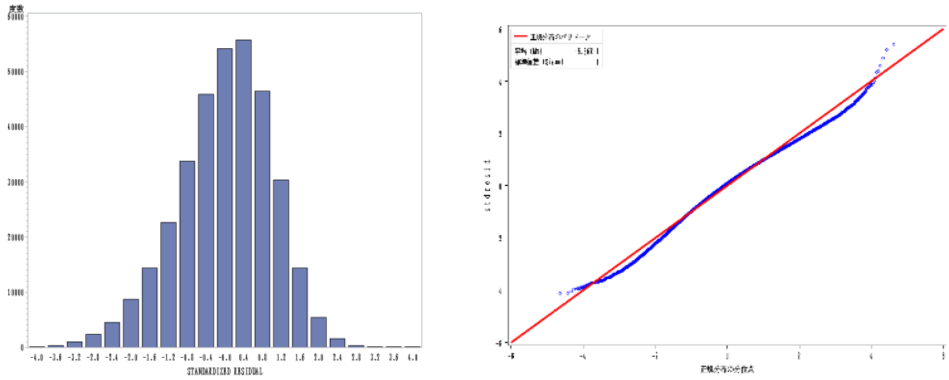
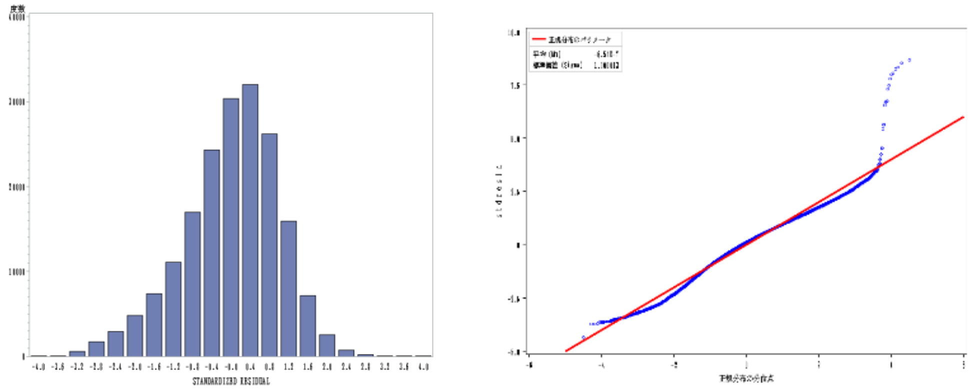



**Fig. 11**. Comparison of area specific quarterly CPUE series of bigeye tuna by Japanese longline.

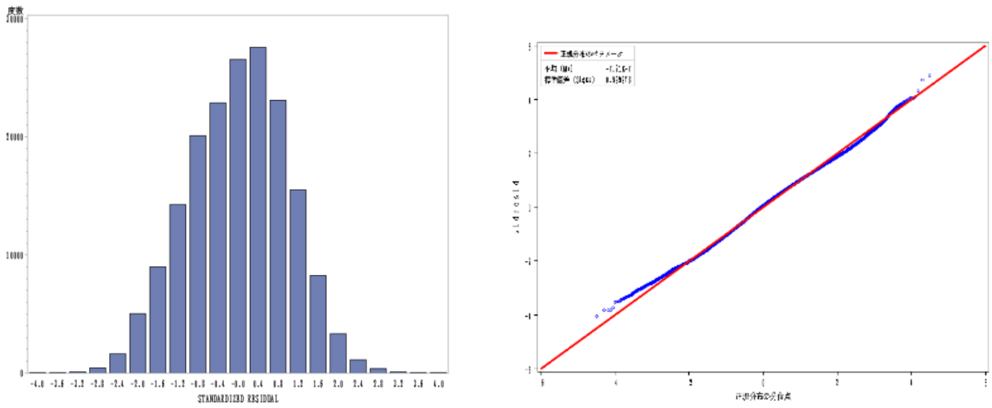
Quarter based Northwest(R1)



Quarter based Northeast(R2)



Quarter based Southwest(R3)



Quarter based Southeast(R4)

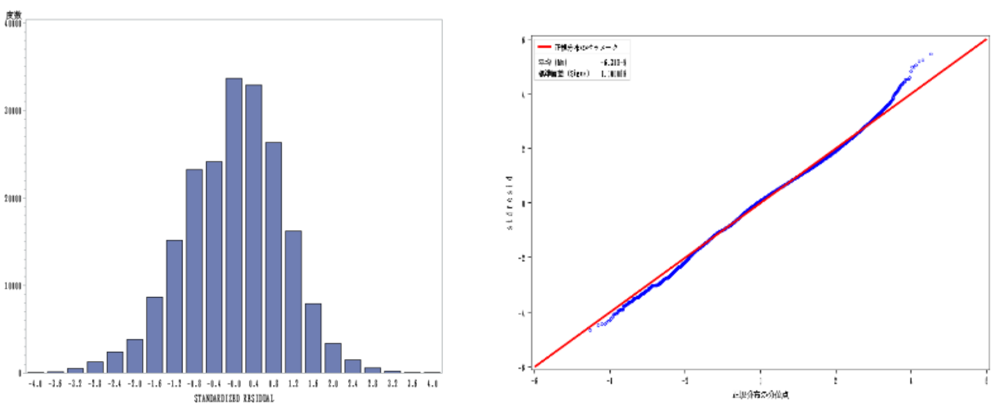


**Fig. 12**. Standardized residuals of area specific quarterly CPUE standardization.

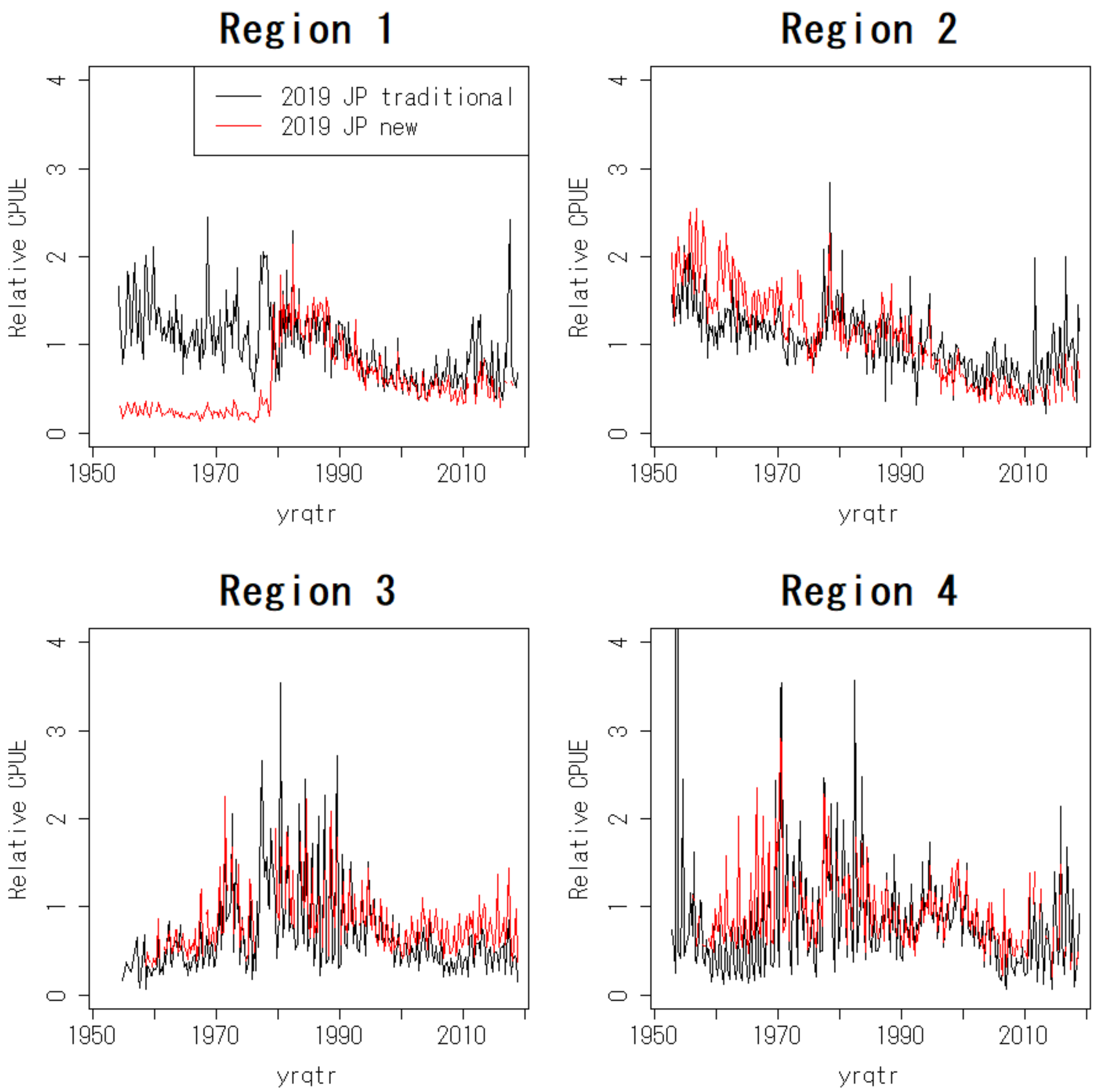



**Fig. 13**. Comparison of area specific CPUE series of bigeye tuna in this study with those by new method in the CPUE collaborative analysis (Matsumoto and Hoyle, 2019). “2019 JP traditional” and “2019 JP new LN” show the indices by traditional and new method (delta-lognormal model, with vessel effect) conducted this year, respectively.