Standardized CPUE of blue marlin (*Makaira mazara*) caught by Japanese longline fishery in the Indian Ocean: Analysis between 1979 and 2021

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Highlights

1. We addressed to standardize CPUE of blue marlin (*Makaira mazara*) caught by Japanese longline fishery in the Indian Ocean starting from 1979, which is the same as the indices used in the last stock assessment.
2. We used the three core areas (Northwest, Southwest and Central east) with high density of blue marlin catch for the analysis following the approach by Yokoi et al. (2016).
3. We applied the zero-inflated Poisson GLMM for the CPUE standardization (catch in number) of blue marlin.
4. Due to the shrinkage of Japanese longliner operation areas, we calculated different period for standardization by area (1979-2021 for Southwest and Central east, and 1979-2010 for the Northwest).
5. The standardized CPUEs usually showed decreasing trend.
6. In some areas, there was clear difference of standardized CPUEs among four quarters as well as between two gear depths.
7. In the model diagnostics, we checked Pearson residuals corresponding the explanatory variables. There were little clear trends against the explanatory variables, but Pearson residual showed some time-spatial patterns for all core areas.

Summary

We addressed to standardize CPUE of blue marlin (*Makaira mazara*) caught by Japanese longline fishery in the Indian Ocean. Start year is 1979 as with the indices in the last stock assessment. Three core areas (Northwest, Southwest and Central east) were used as with the previous studies. We applied the zero-inflated Poisson GLMM for the CPUE standardization (catch number). Terminal year for the Northwest CPUE was 2010 due to paucity of operations in recent years. The standardized CPUE usually showed decreasing trend. There was some difference of standardized CPUEs among quarters and between two gear depths. In the model diagnostics, we checked Pearson residuals corresponding to the explanatory variables. There are little clear trends against the explanatory variables, but Pearson residual

showed some time-spatial patterns for all core areas.

Introduction

Yokoi et al. (2016) updated the standardized CPUE (catch number) of blue marlin (*Makaira mazara*) caught by the Japanese tuna longline vessels in the Indian Ocean between 1971 and 2015 using log normal GLM, comparing to the past analyses (Uozumi 1998, Nishida et al. 2012, Nishida and Wang 2013). However, Japanese logbook format changed around 1994 and early period logbook data includes uncertainties such as species discrimination. In addition, a discrete probability distribution such as Poisson distribution should be applied for GLM standardization because log normal GLM CPUE loses the impact of fishing effort. Furthermore, zero-inflated models should be considered for by-catch species such as blue marlin with extra zero catches (Ijima 2018). To consider these issues, Ijima (2018) calculated standardized CPUE of Indian Ocean striped marlin using zero-inflated negative binomial GLMM (ZINB-GLMM). However, ZINB tends to cause underdispersion (e.g. Ijima 2017), thus we think zero-inflated Poisson GLMM (ZIP-GLMM) is more appropriate to use for the CPUE standardization. Therefore, Taki et al. (2019) explored the CPUE standardization (catch number) for blue marlin in the Indian Ocean using the Poisson GLM, the Poisson GLMM, and the zero-inflated Poisson GLMM during 1994-2018 for the three core areas (Northwest, Southwest and Central east) with high density of blue marlin catch Yokoi et al. (2016) defined. At 2019 IOTC WPB17 meeting, extending the period of CPUE back to 1979 was requested and so the indices starting from 1979 were created and were used for stock assessment. Also, as for northwest area, due to the paucity of operations in recent years, terminal year of CPUE was decided to be 2010. In this study, the method of standardization is the same as that in Taki et al. (2019), with start year 1979 and end year for northwest area 2010.

Material and Methods

Data sets

Japanese longline logbook operational data between 1979 and 2021 was used for the CPUE standardization of blue marlin in the Indian Ocean. The resolution of the logbook is 1x1 grid scale. Yokoi et al. (2016) defined three core areas with high density of blue marlin caught in the Indian Ocean, i.e. Northwest (between 11°S and 11°N and between 51°E and 69°E), Southwest (between 15°S and 40°S and between 20°E and 41°E), and Central east (between 14°S and 3°N and between 89°E and 119°E) (Fig. 1), and Taki et al. (2019) used the same areas. We followed their definition in this study. Japanese longliners have operated throughout the Indian Ocean up to 2000s, but after around 2010, because of the effect of piracy activities, the fishing ground has shrunk rapidly and there were few operations in the northwest area (Fig. 2). Therefore, terminal year for the Northwest CPUE was 2010 as with the previous analysis. Regarding the time-spatial changes in mean body weight of blue marlin, there were no clear trend (Fig. 3), thus size-dependent area definition for CPUE standardization (e.g. Ochi et al. 2016) was not considered.

Statistical models

We used the procedure for the CPUE standardization similar to that in Ijima (2018) and Taki et al. (2019). We applied zero-inflated Poisson GLMM (ZIP-GLMM) because of high blue marlin zero catch ratio (Fig. 4). The Zero-Inflated model is useful because this model can estimate "true" zero catch. The explanatory variables of fixed effect part are the year, quarter, gear and random effect part are area and fleet (vessel ID). The gear depth index, i.e. the number of hooks between float were categorized into 2 classes (shallow: <15 hooks and deep: >=15 hooks) from the changes in gear configuration showing generally two modes in all area (Fig. 5). All variables were treated as categorical variables. Considering the random effect is appropriate because there are a lot of variables for the vessel name and 5x5 area effect. The random effect model can also remove the pseudo-replication by vessel and operating area.

We used R software package glmmTMB for parameter estimation (Brooks et al. 2017). Several models with different variables and formula for zero-inflation were examined. We evaluated these models using Bayesian information criterion (BIC) and likelihood ratio test. We also checked the Pearson residuals for model diagnostics. Finally, we calculated the standardized blue marlin CPUE using the R software package lsmeans (Lenth 2016). The ZIP-GLMM is

$$Catch_i \sim ZIP(\pi_i, \mu_i),$$

$$E(Catch_i) = \mu_i(1 - \pi_i),$$

$$\mathrm{var}(Catch_i) = (1 - \pi_i)\ (\mu_i + \pi_i \mu_i^2),$$

$$\log(\mu_i) = \beta_0 + \mathbf{X}_i\boldsymbol{\beta} - \log(hooks_i) + a_i + b_i,$$

$$\mathrm{logit}(\pi_i) = \gamma_0 + \mathbf{Z}_i\boldsymbol{\gamma} + c_i + d_i,$$

$$a_i \sim N(0, \sigma_a^{\ 2}),\ b_i \sim N(0, \sigma_b^{\ 2}),\ c_i \sim N(0, \sigma_c^{\ 2}),\ \text{and}\ d_i \sim N(0, \sigma_d^{\ 2})$$

here π_i is the probability of zero catch of operation i. π_i is estimated by logit link function that the variable matrix is $\mathbf{Z}_i$ and the covariate vector is $\boldsymbol{\gamma}$ respectively. $Catch_i$ is the blue marlin catch number of operation i. μ_i is expected catch number of the operation i. The link function was used for log link function. β_0 and γ_0 are the intercepts, $\mathbf{X_i}$ is the matrix of variables, $\boldsymbol{\beta}$ is the covariates vectors, and hooks denote the hooks/1000 of the operation respectively. We applied the random effect for vessel name and 5x5 area (a_i and b_i) in catch model while zero model 5x5 area and fleet c_i and d_i. We did not use interaction for all models to avoid overfitting.

Result and Discussion

Northwest

We selected ZIP-GLMM for which BIC and AIC were the lowest among other candidate models (Table 1). Both nominal and standardized CPUEs showed decreasing trend during 1979-1989, increasing trend during 1990-1994, decreased again during 1997-2003, and was stable after that (Table 2, Fig. 6a). Pearson residuals are approximately scattered against predicted values (Fig. 6b). There is no definite residual trend for fixed effect variables (Fig. 6c-e). These validation results indicate the selected statistical model is well estimated. However, the time-spatial changes in Pearson residuals were not randomly plotted (there is the spatial correlation in this plot) (Fig. 7). There was no clear difference of standardized CPUE between four quarters, but shallow gear sets got higher CPUE (Fig. 8)

Southwest

We selected ZIP-GLMM for which BIC and AIC were the lowest among other candidate models (Table 3). The standardized CPUE showed decreasing trend with fluctuations, and it has large uncertainties before 2000. The trend of standardized CPUE was largely different from that of nominal CPUE (Table 4, Fig. 9a). Pearson residuals spiked around predicted zero catches (Fig. 9b). There was some residual trend for fixed effect variables (Fig. 9c-e). Also, the time-spatial changes in Pearson residuals were not randomly plotted (there is the spatial correlation in this plot) (Fig. 10). Standardized CPUE was higher in the first and fourth quarter (Fig. 10).

Central east

We selected ZIP-GLMM for which BIC and AIC were the lowest among other candidate models (Table 5). Both nominal and standardized CPUEs showed decreasing trend with fluctuations (Table 6, Fig. 12a). Pearson residuals are approximately scattered against predicted values (Fig. 12b). There was no definite residual trend for fixed effect variables (Fig. 12c-e). These validation results indicate the selected statistical model is well estimated. However, the time-spatial changes in Pearson residuals were not randomly plotted (there is the spatial correlation in this plot) (Fig. 13). There was some difference of standardized CPUE among quarter (second quarter was highest) and between two gear depths (shallow sets was higher) (Fig. 14).

Perspective

Pearson residual showed some time-spatial patterns for all core areas as mentioned above. Considering this result, it might need to address the geostatistical model to reduce the patterns in the future study. In addition, the core-areas needs to be revised considering more accurate distribution of high densities of blue marlin. Also, considering different format (data availability) and potential data quality, it may be worth considering splitting indices before and after 1994 in the future study.

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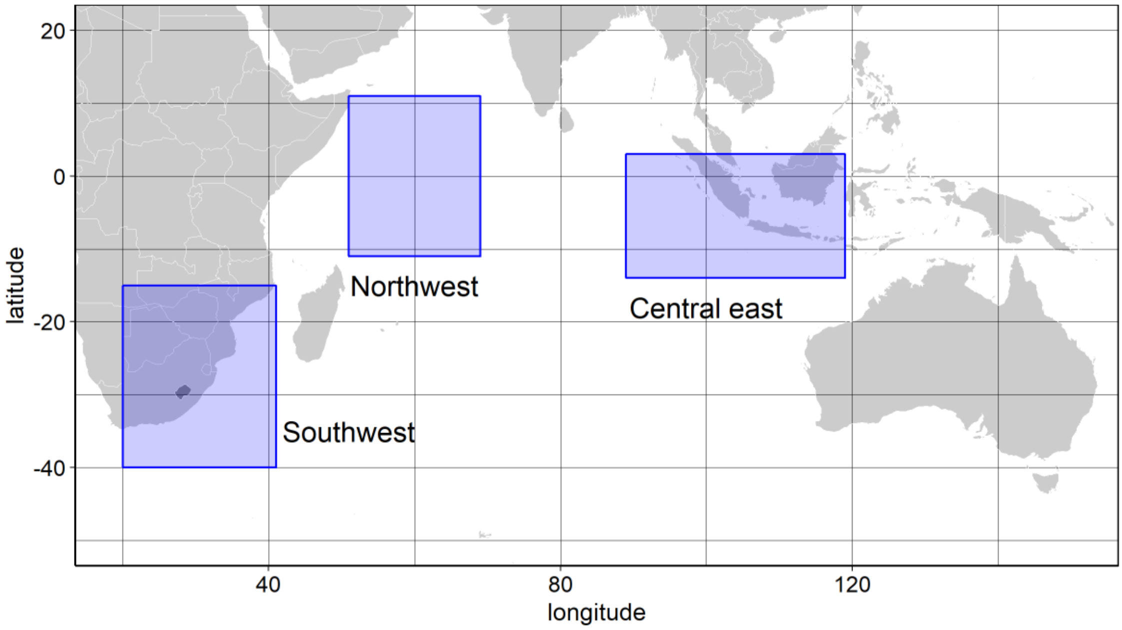

Fig. 1. Definition of areas for blue marlin CPUE by Japanese longline fishery in the Indian Ocean.

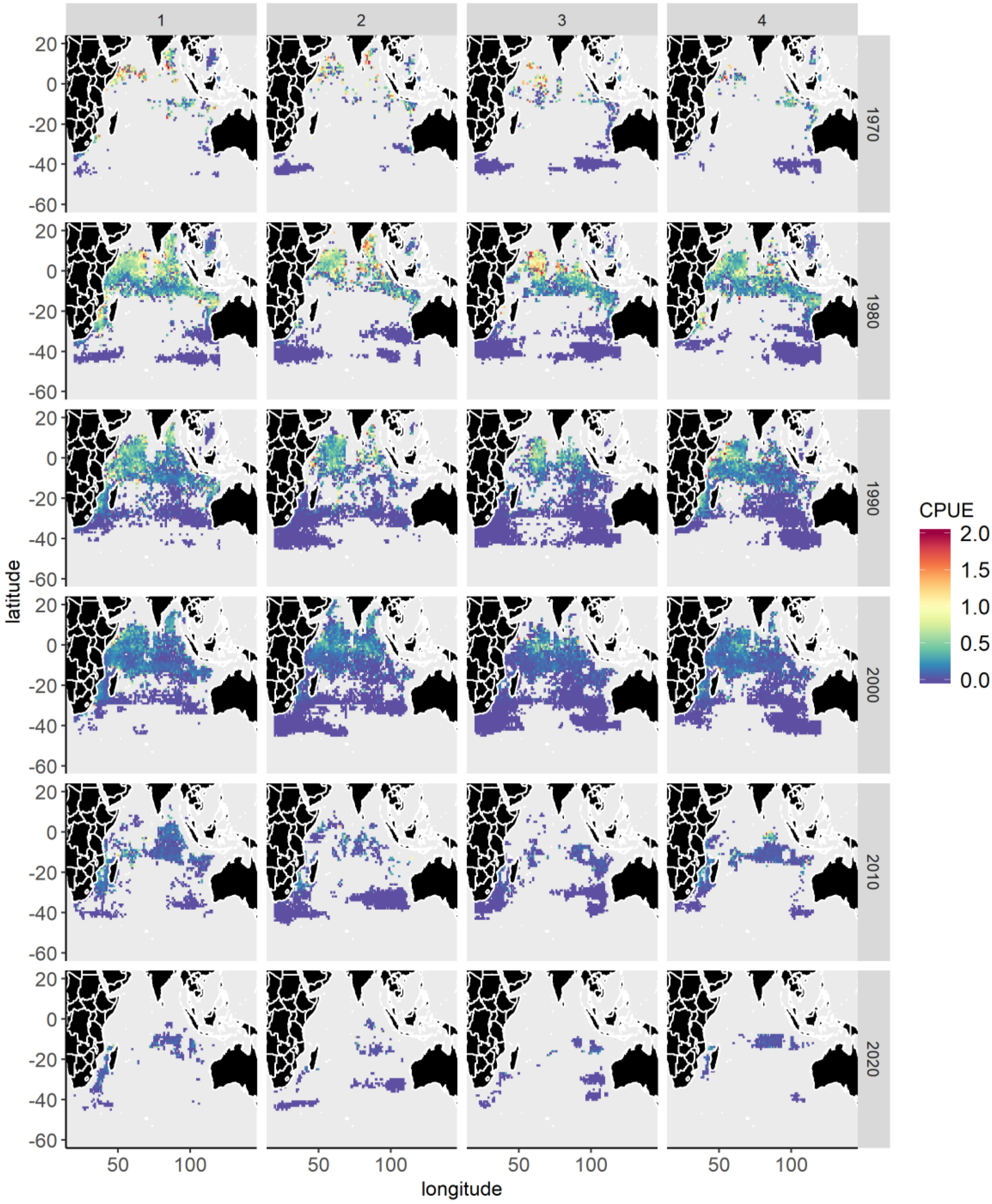

Fig. 2. Changes in time-spatial nominal CPUE (number of fish per 1,000 hooks) of blue marlin in the Indian Ocean for four quarters (1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) by decade in the data used for CPUE standardization.

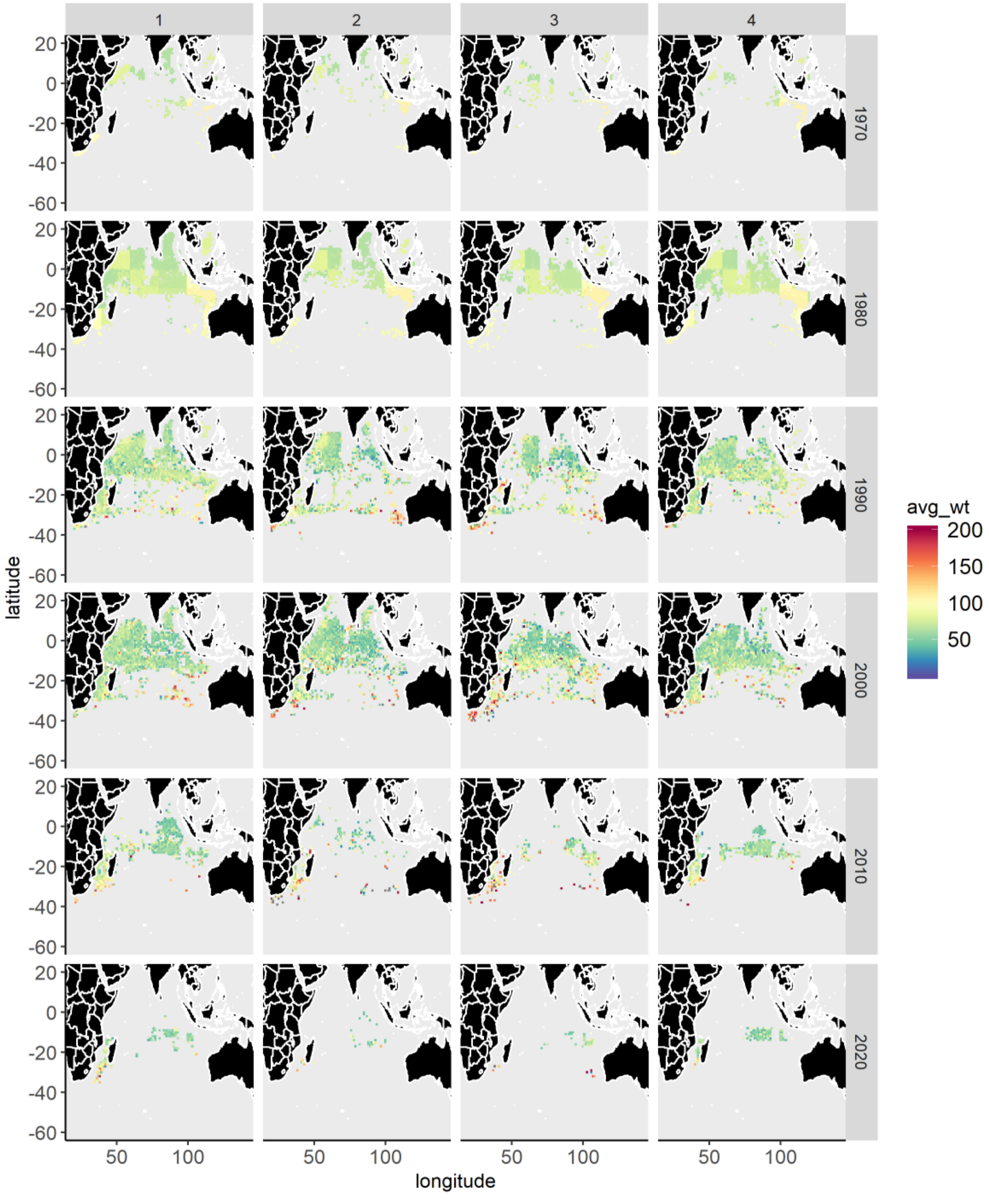

Fig. 3. Changes in time-spatial mean body weight (kg) of blue marlin caught by Japanese longline vessels in the Indian Ocean by quarter and decade.

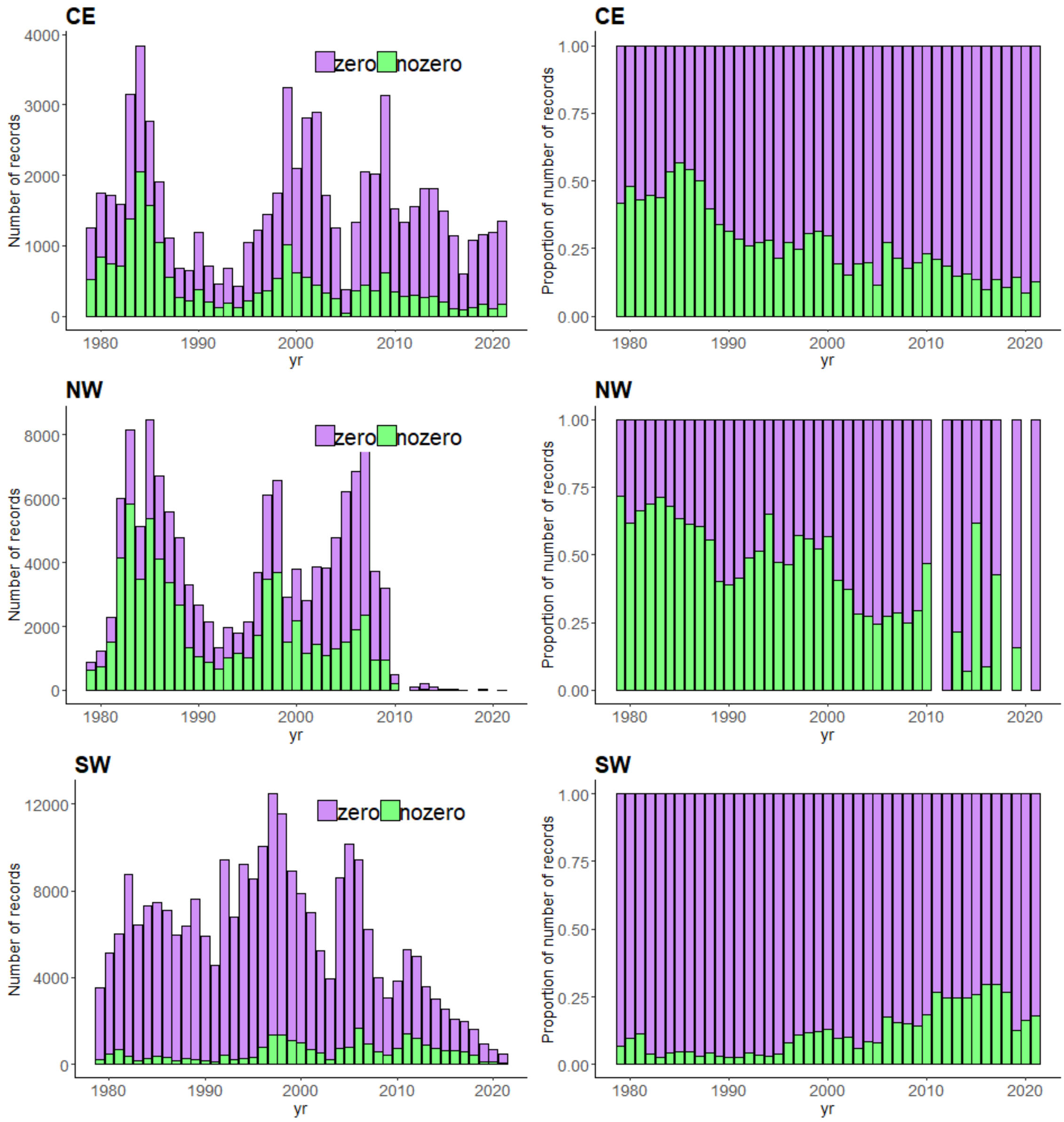

Fig. 4. Proportion of positive and zero catch of blue marlin caught by Japanese longline fishery for the three core areas in the Indian Ocean (Fig. 1) in the data used for CPUE standardization.

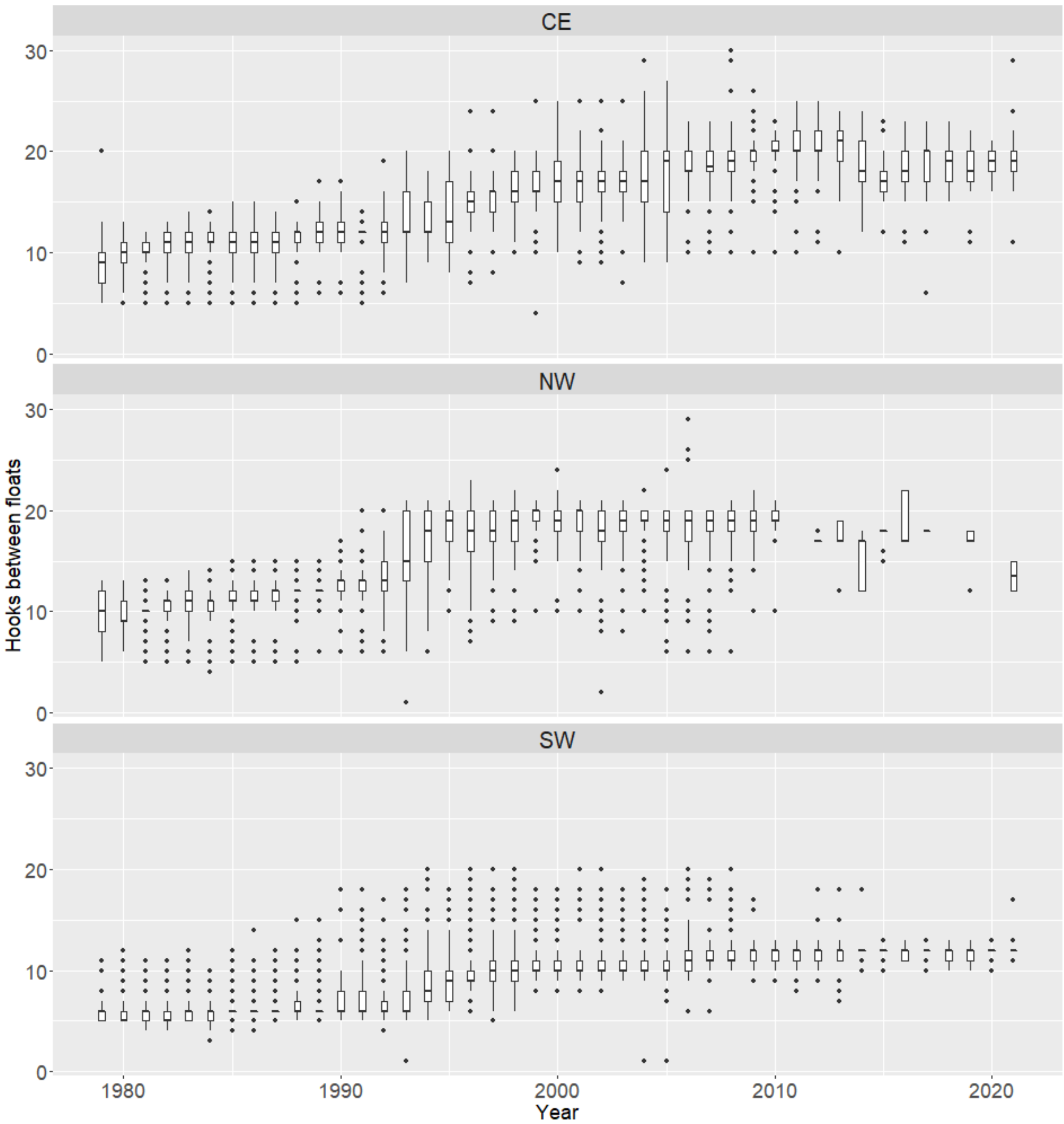

Fig. 5. Historical change in hooks between floats in each area shown in Fig. 1. We set two type gear configurations (deep or shallow sets) that boundary is fifteen hooks between floats in the three core areas. Top, bottom and middle of the box show 75 percentile, 25 percentile and median, respectively. Vertical bars show 75 percentile plus 1.5*IQR (Inter-Quartile Range) and 25 percentile minus 1.5*IQR, respectively. Dots show outliers.

Table 1. **Northwest.** Deviance table for blue marlin CPUE. The yellow-highlighted model was applied.

Models	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq
yr + offset(log(hooks/1000))	32	379047	379359	-189492	378983			
yr + qtr + offset(log(hooks/1000))	35	374899	375240	-187414	374829	4154.77	3	<2e-16
yr + qtr + gear2 + offset(log(hooks/1000)	36	374900	375251	-187414	374828	0.2518	1	0.6158
yr + qtr + gear2 + (1 ∣ area) + offset(log(hooks/1000))	37	368873	369233	-184399	368799	6029.727	1	<2e-16
yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet) + offset(log(hooks/1000))	38	353973	354343	-176948	353897	14902	1	<2e-16
yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet) + offset(log(hooks/1000)), zi=~yr	70	343430	344113	-171645	343290	10606.5	32	<2e-16
yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 ∣ area)	75	343056	343787	-171453	342906	384.0931	5	<2e-16
yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet)	76	341189	341930	-170519	341037	1868.935	1	<2e-16

Following models were not converged.

yr + qtr + gear2 + (1∣area) + (yr∣fleet) + offset(log(hooks/1000)

yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2

yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet) + offset(log(hooks/1000)), zi=~yr + qtr

yr + qtr + gear2 + (1 ∣ area) + (1 ∣ fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 ∣ fleet)

Table 2. **Northwest.** Standardized CPUE of blue marlin in the Northwest (1979-2010).

Year	Nominal CPUE	Stand. CPUE	Upper (95%)	Lower (95%)	Upper (80%)	Lower (80%)
1979	0.943	0.834	0.729	0.954	0.763	0.911
1980	0.633	0.822	0.715	0.944	0.751	0.899
1981	0.773	0.884	0.781	1.001	0.816	0.959
1982	0.773	0.831	0.738	0.934	0.769	0.897
1983	0.800	0.809	0.720	0.909	0.750	0.873
1984	0.719	0.762	0.677	0.858	0.706	0.823
1985	0.619	0.646	0.574	0.726	0.598	0.697
1986	0.563	0.595	0.529	0.670	0.551	0.643
1987	0.527	0.570	0.506	0.643	0.528	0.617
1988	0.446	0.561	0.497	0.633	0.518	0.607
1989	0.254	0.375	0.327	0.430	0.343	0.410
1990	0.244	0.346	0.299	0.401	0.315	0.381
1991	0.272	0.385	0.331	0.448	0.349	0.425
1992	0.323	0.473	0.401	0.557	0.425	0.526
1993	0.418	0.547	0.472	0.633	0.497	0.601
1994	0.575	1.026	0.903	1.165	0.944	1.115
1995	0.359	0.773	0.676	0.883	0.708	0.843
1996	0.298	0.441	0.387	0.503	0.405	0.481
1997	0.456	0.621	0.549	0.703	0.573	0.673
1998	0.406	0.544	0.480	0.617	0.502	0.591
1999	0.353	0.529	0.465	0.602	0.486	0.575
2000	0.376	0.505	0.445	0.574	0.465	0.549
2001	0.251	0.510	0.447	0.582	0.468	0.556
2002	0.214	0.403	0.352	0.463	0.369	0.441
2003	0.129	0.247	0.213	0.287	0.224	0.273
2004	0.131	0.244	0.209	0.285	0.221	0.270
2005	0.109	0.216	0.186	0.249	0.196	0.237
2006	0.134	0.236	0.205	0.271	0.215	0.258
2007	0.133	0.184	0.161	0.211	0.168	0.201
2008	0.128	0.202	0.174	0.235	0.184	0.223
2009	0.128	0.119	0.101	0.141	0.107	0.133
2010	0.225	0.244	0.197	0.303	0.212	0.281

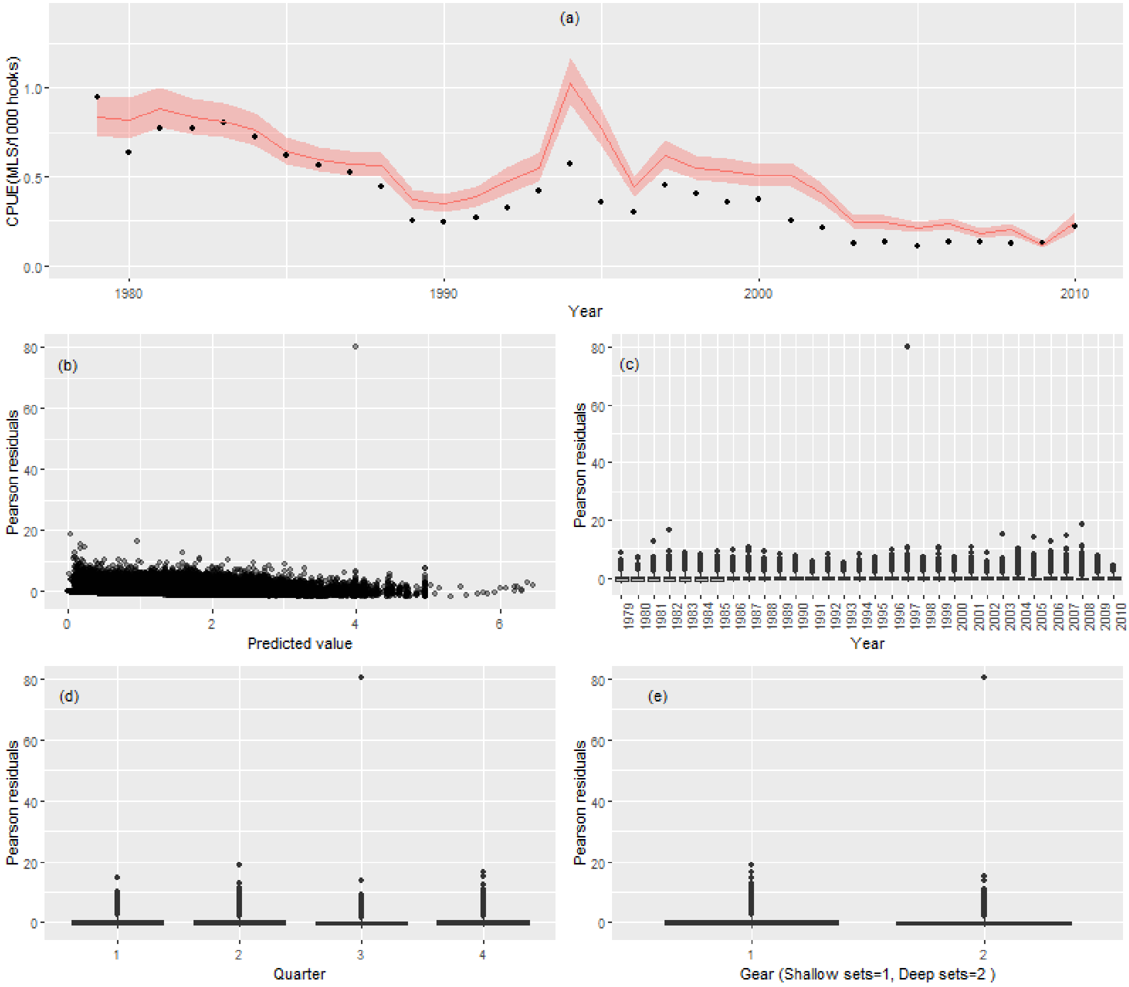

Fig. 6. **Northwest.** Results of CPUE standardization analysis of blue marlin caught. (a) Historical changes of CPUE. Red line is standardized CPUE and filled area is 95% confidence interval. Points denote nominal CPUE. (b)-(e): Trends of Pearson residuals.

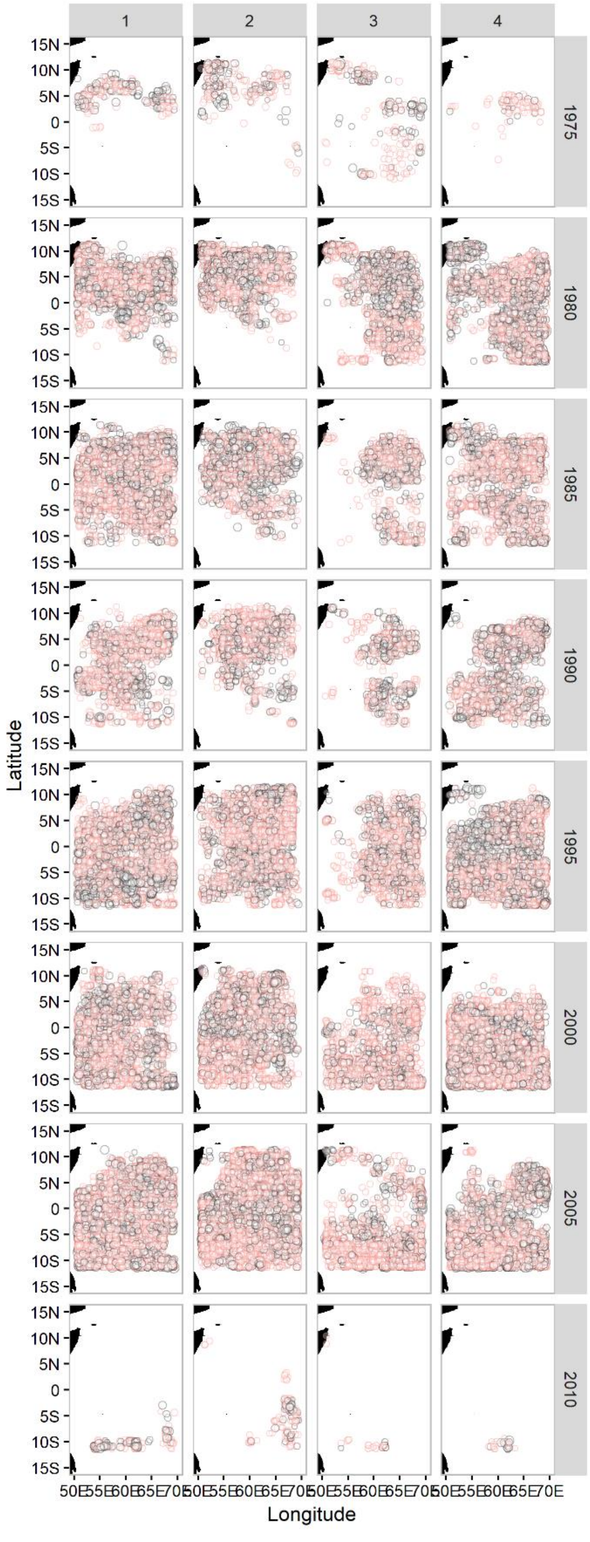

Fig. 7. **Northwest.** Time-spatial change of Pearson residuals. Red circles are positive residuals, and black circles are minus residuals. Size of circle correspond to magnitude of Pearson residuals.

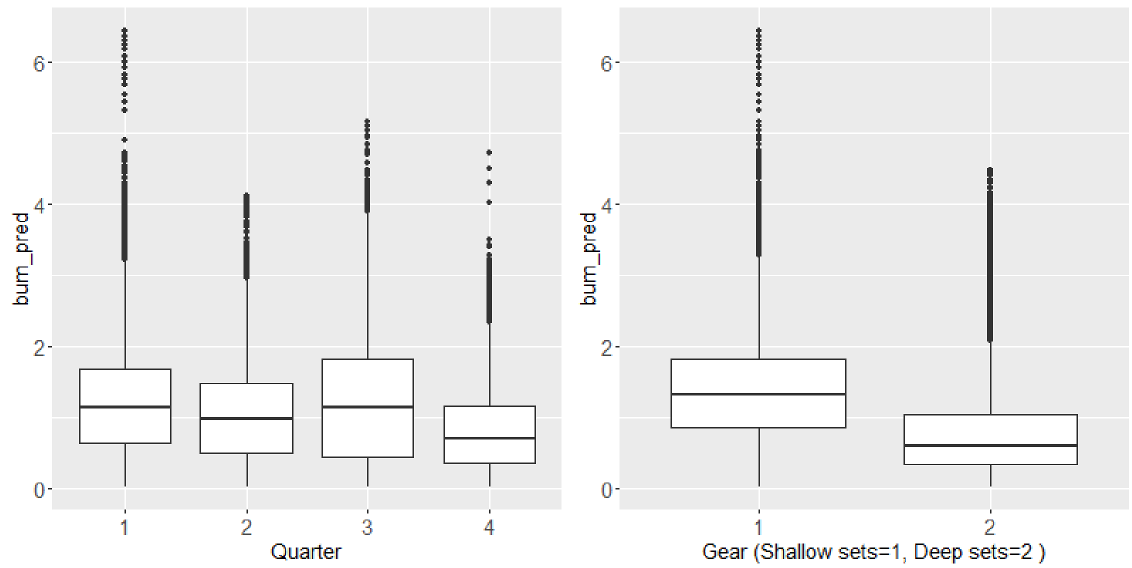

Fig. 8. **Northwest.** Results of CPUE standardization analysis among quarters (left; 1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) and gear depths (right; 1: Shallow, 2: Deep). Top, bottom and middle of the box show 75 percentile, 25 percentile and median, respectively. Vertical bars show 75 percentile plus 1.5*IQR (Inter-Quartile Range) and 25 percentile minus 1.5*IQR, respectively. Dots show outliers.

Table 3. **Southwest.** Deviance table for blue marlin CPUE. The yellow-highlighted model was applied.

<table>
<tr><th>Models</th><th>Df</th><th>AIC</th><th>BIC</th><th>logLik</th><th>deviance</th><th>Chisq</th><th>Chi Df</th><th>Pr(>Chisq</th></tr>
<tr><td>bum ~ yr + offset(log(hooks/1000)), zi=~0, disp=~1</td><td>43</td><td>253424</td><td>253873</td><td>-126669</td><td>253338</td><td></td><td></td><td></td></tr>
<tr><td>bum ~ yr + qtr + offset(log(hooks/1000)), zi=~0, disp=~1</td><td>46</td><td>200058</td><td>200538</td><td>-99983</td><td>199966</td><td>53372.57</td><td>3</td><td><2.2e-16</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + offset(log(hooks/1000)), zi=~0, disp=~1</td><td>47</td><td>200043</td><td>200534</td><td>-99974</td><td>199949</td><td>16.877</td><td>1</td><td>3.99E-05</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + (1 | area) + offset(log(hooks/1000)), zi=~0, disp=~1</td><td>48</td><td>175654</td><td>176155</td><td>-87779</td><td>175558</td><td>24390.96</td><td>1</td><td><2.2e-16</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~0, disp=~1</td><td>49</td><td>166290</td><td>166802</td><td>-83096</td><td>166192</td><td>9365.592</td><td>1</td><td><2.2e-16</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr, disp=~1</td><td>92</td><td>159607</td><td>160568</td><td>-79711</td><td>159423</td><td>1656.716</td><td>42</td><td><2.2e-16</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr, disp=~1</td><td>95</td><td>158158</td><td>159150</td><td>-78984</td><td>157968</td><td>1454.902</td><td>3</td><td><2.2e-16</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2, disp=~1</td><td>96</td><td>158147</td><td>159150</td><td>-78978</td><td>157955</td><td>12.787</td><td>1</td><td>0.000349</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | fleet), disp=~1</td><td>97</td><td>155788</td><td>156801</td><td>-77797</td><td>155594</td><td>2360.708</td><td>1</td><td><2.2e-16</td></tr>
<tr><td>bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | area) + (1 | fleet), disp=~1</td><td>98</td><td>154451</td><td>155474</td><td>-77127</td><td>154255</td><td>1339.468</td><td>1</td><td><2.2e-16</td></tr>
</table>

Following models were not converged.

bum ~ yr + qtr + gear2 + (1|area) + (yr|fleet) + offset(log(hooks/1000)), zi=~0, disp=~1

bum ~ yr + qtr + gear2 + (1|area) + (1|fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1|area), disp=~1

Table 4. **Southwest.** Standardized CPUE of blue marlin in the Northwest (1979-2021).

Year	Nominal CPUE	Stand. CPUE	Upper (95%)	Lower (95%)	Upper (80%)	Lower (80%)
1979	0.052	0.236	0.118	0.469	0.150	0.369
1980	0.111	0.245	0.126	0.475	0.159	0.378
1981	0.117	0.212	0.110	0.409	0.138	0.325
1982	0.030	0.140	0.072	0.273	0.091	0.217
1983	0.016	0.268	0.132	0.544	0.169	0.426
1984	0.025	0.191	0.097	0.374	0.123	0.296
1985	0.031	0.167	0.086	0.325	0.109	0.258
1986	0.040	0.147	0.076	0.284	0.095	0.226
1987	0.023	0.097	0.049	0.189	0.062	0.149
1988	0.028	0.090	0.046	0.177	0.058	0.140
1989	0.024	0.172	0.088	0.336	0.111	0.267
1990	0.019	0.161	0.081	0.319	0.103	0.251
1991	0.018	0.097	0.049	0.193	0.062	0.152
1992	0.030	0.142	0.073	0.278	0.092	0.220
1993	0.025	0.167	0.084	0.330	0.107	0.261
1994	0.025	0.197	0.101	0.385	0.127	0.305
1995	0.026	0.189	0.097	0.368	0.123	0.292
1996	0.066	0.239	0.124	0.461	0.156	0.367
1997	0.075	0.176	0.092	0.340	0.115	0.271
1998	0.079	0.165	0.085	0.317	0.107	0.252
1999	0.072	0.110	0.057	0.212	0.072	0.169
2000	0.076	0.112	0.058	0.217	0.073	0.173
2001	0.043	0.062	0.032	0.121	0.040	0.096
2002	0.057	0.081	0.042	0.158	0.053	0.126
2003	0.028	0.054	0.027	0.108	0.035	0.085
2004	0.047	0.089	0.046	0.173	0.058	0.138
2005	0.039	0.062	0.032	0.121	0.040	0.096
2006	0.084	0.056	0.029	0.108	0.037	0.086
2007	0.068	0.047	0.024	0.090	0.030	0.072
2008	0.067	0.058	0.030	0.112	0.037	0.089
2009	0.065	0.048	0.025	0.092	0.031	0.073
2010	0.085	0.077	0.040	0.149	0.050	0.118
2011	0.133	0.082	0.042	0.157	0.053	0.125
2012	0.118	0.070	0.036	0.135	0.046	0.108
2013	0.114	0.067	0.034	0.128	0.043	0.102
2014	0.109	0.058	0.030	0.113	0.038	0.090
2015	0.108	0.050	0.026	0.098	0.033	0.078
2016	0.119	0.041	0.021	0.080	0.027	0.064
2017	0.144	0.074	0.038	0.144	0.048	0.114
2018	0.125	0.072	0.037	0.140	0.047	0.111
2019	0.047	0.040	0.020	0.081	0.025	0.064
2020	0.060	0.036	0.017	0.074	0.022	0.057
2021	0.066	0.039	0.019	0.081	0.024	0.063

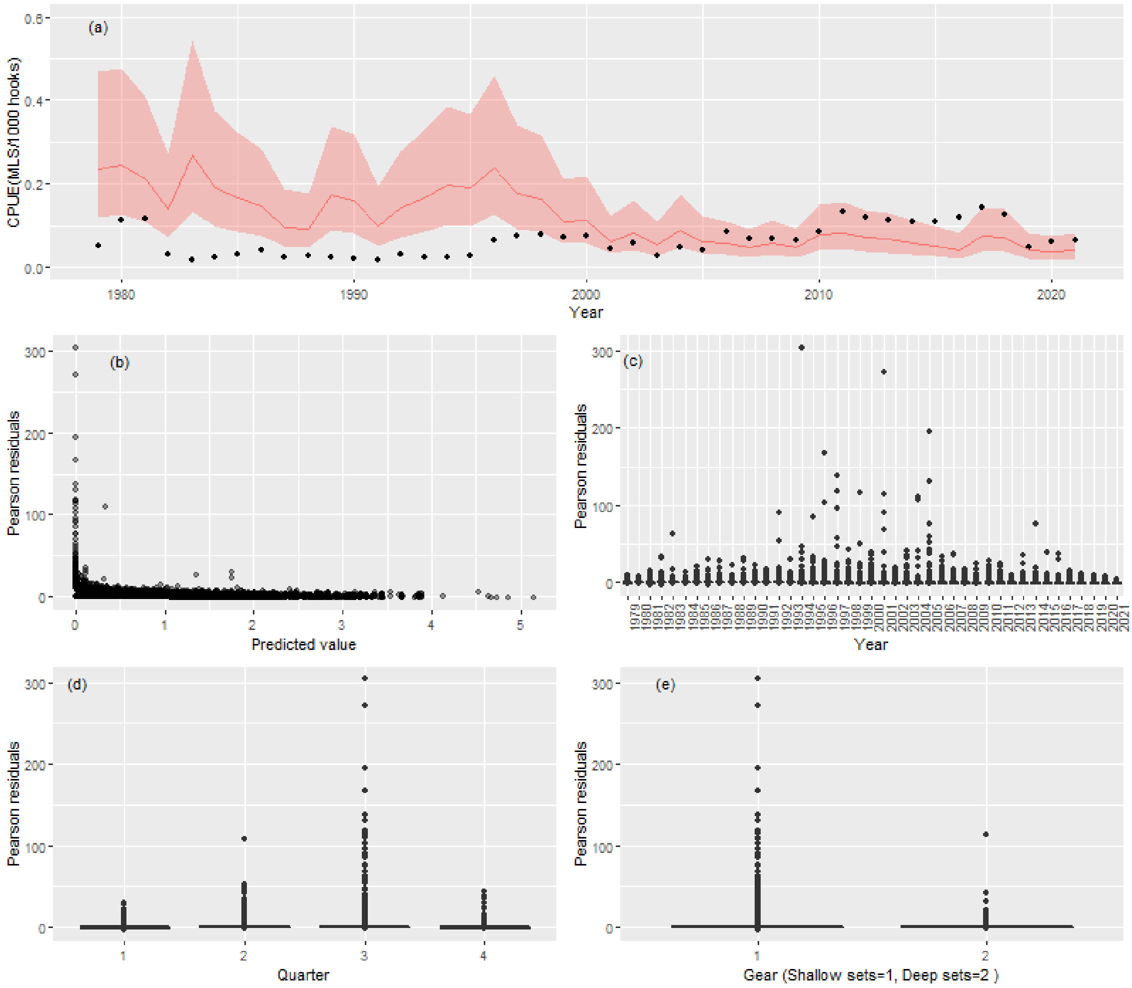

Fig. 9. **Southwest.** Results of CPUE standardization analysis of blue marlin caught. (a) Historical changes of CPUE. Red line is standardized CPUE and filled area is 95% confidence interval. Points denote nominal CPUE. (b)-(e): Trends of Pearson residuals.

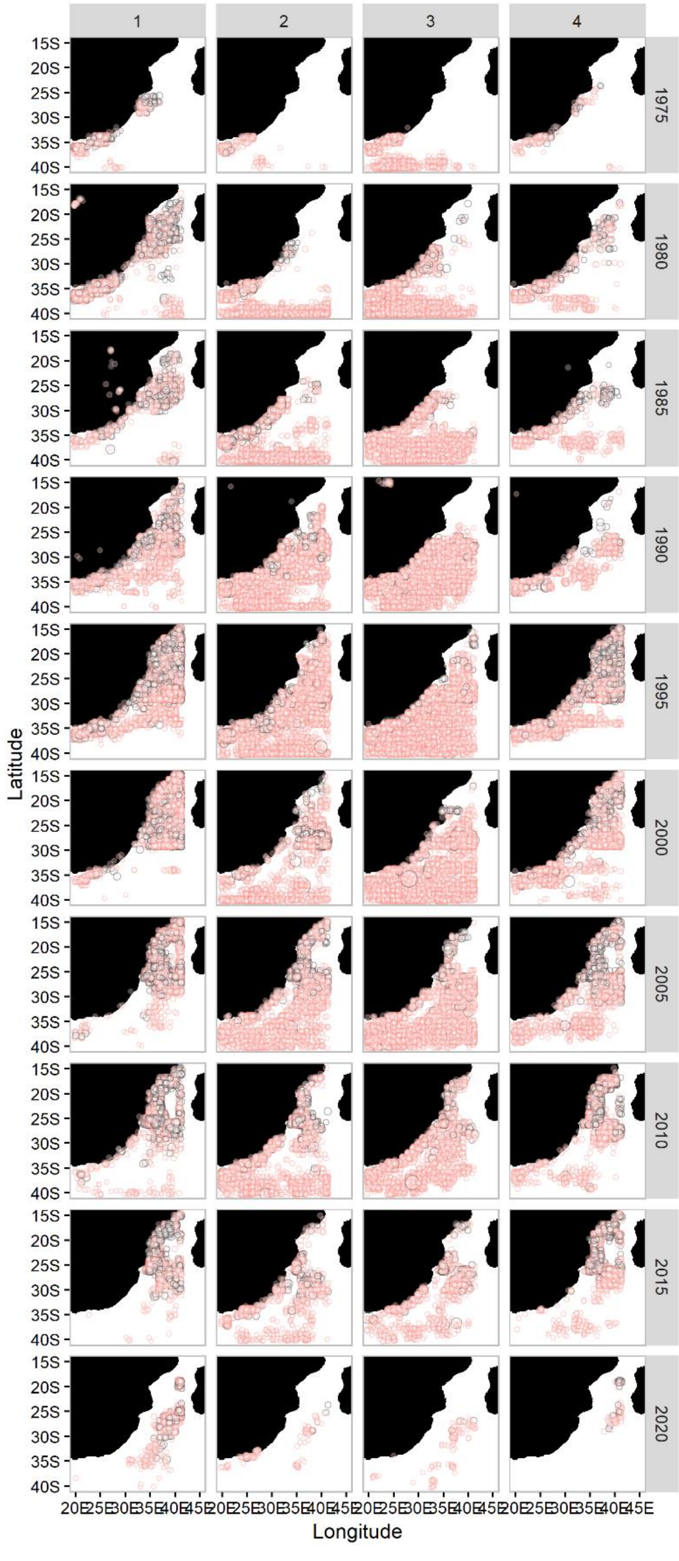

Fig. 10. **Southwest.** Time-spatial change of Pearson residuals for five year period. Red circles are positive residuals, and black circles are minus residuals. Size of circle correspond to magnitude of Pearson residuals.

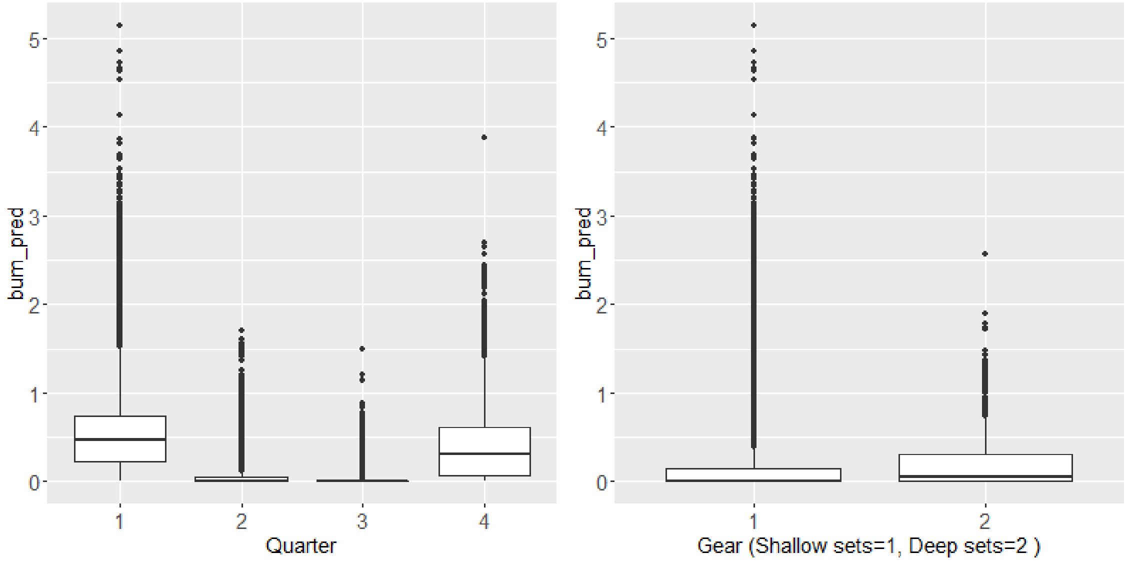

Fig. 11. **Southwest.** Results of CPUE standardization analysis among quarters (left; 1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) and gear depths (right; 1: Shallow, 2: Deep). Top, bottom and middle of the box show 75 percentile, 25 percentile and median, respectively. Vertical bars show 75 percentile plus 1.5*IQR (Inter-Quartile Range) and 25 percentile minus 1.5*IQR, respectively. Dots show outliers.

Table 5. **Central east.** Deviance table for blue marlin CPUE. The yellow-highlighted model is applied.

Models	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq
bum ~ yr + offset(log(hooks/1000)), zi=~0, disp=~1	43	720182	720642	-360048	720096			
bum ~ yr + qtr + offset(log(hooks/1000)), zi=~0, disp=~1	46	711338	711830	-355623	711246	8850.257	3	<2e-16
bum ~ yr + qtr + gear2 + offset(log(hooks/1000)), zi=~0, disp=~1	47	711335	711838	-355621	711241	4.6387	1	0.03126
bum ~ yr + qtr + gear2 + (1 | area) + offset(log(hooks/1000)), zi=~0, disp=~1	48	699556	700070	-349730	699460	11780.79	1	<2e-16
bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~0, disp=~1	49	684874	685398	-342388	684776	14684.43	1	<2e-16
bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2, disp=~1	96	671356	672383	-335582	671164	13612.39	47	<2e-16

Following models were not converged.
bum ~ yr + qtr + gear2 + (1|area) + (yr|fleet) + offset(log(hooks/1000)), zi=~0, disp=~1
bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr, disp=~1
bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr, disp=~1
bum ~ yr + qtr + gear2 + (1|area) + (1|fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1|area), disp=~1
bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | fleet), disp=~1
bum ~ yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | area) + (1 | fleet), disp=~1

Table 6. **Central east.** Standardized CPUE of blue marlin in the Northwest (1979-2021).

Year	Nominal CPUE	Stand. CPUE	Upper (95%)	Lower (95%)	Upper (80%)	Lower (80%)
1979	0.231	0.280	0.240	0.327	0.253	0.310
1980	0.244	0.307	0.263	0.358	0.278	0.339
1981	0.229	0.294	0.252	0.343	0.266	0.325
1982	0.337	0.427	0.367	0.497	0.386	0.471
1983	0.357	0.476	0.409	0.554	0.431	0.525
1984	0.321	0.419	0.360	0.488	0.379	0.463
1985	0.265	0.329	0.282	0.384	0.298	0.364
1986	0.234	0.329	0.282	0.383	0.297	0.363
1987	0.300	0.349	0.300	0.406	0.316	0.385
1988	0.217	0.295	0.253	0.344	0.267	0.326
1989	0.186	0.240	0.206	0.280	0.217	0.266
1990	0.220	0.294	0.252	0.343	0.266	0.325
1991	0.212	0.255	0.219	0.297	0.231	0.282
1992	0.345	0.353	0.304	0.411	0.320	0.390
1993	0.274	0.315	0.270	0.367	0.285	0.348
1994	0.149	0.274	0.186	0.406	0.213	0.354
1995	0.111	0.237	0.183	0.308	0.200	0.281
1996	0.148	0.290	0.229	0.368	0.248	0.338
1997	0.124	0.284	0.222	0.364	0.242	0.334
1998	0.177	0.240	0.196	0.295	0.210	0.275
1999	0.155	0.340	0.282	0.408	0.301	0.383
2000	0.147	0.270	0.221	0.330	0.237	0.308
2001	0.095	0.301	0.246	0.367	0.264	0.342
2002	0.063	0.175	0.135	0.228	0.148	0.208
2003	0.082	0.143	0.104	0.196	0.116	0.175
2004	0.087	0.183	0.136	0.246	0.151	0.222
2005	0.046	0.139	0.068	0.282	0.087	0.220
2006	0.122	0.324	0.257	0.408	0.278	0.377
2007	0.086	0.200	0.157	0.254	0.171	0.234
2008	0.065	0.142	0.104	0.194	0.116	0.174
2009	0.075	0.170	0.134	0.214	0.146	0.198
2010	0.087	0.172	0.130	0.228	0.143	0.207
2011	0.085	0.326	0.251	0.424	0.275	0.387
2012	0.068	0.175	0.128	0.239	0.143	0.215
2013	0.055	0.225	0.164	0.307	0.183	0.276
2014	0.059	0.142	0.101	0.198	0.114	0.176
2015	0.052	0.173	0.119	0.253	0.135	0.222
2016	0.036	0.153	0.090	0.262	0.108	0.218
2017	0.055	0.241	0.134	0.436	0.164	0.355
2018	0.040	0.153	0.089	0.265	0.107	0.219
2019	0.054	0.232	0.159	0.339	0.181	0.297
2020	0.031	0.098	0.049	0.195	0.063	0.154
2021	0.049	0.180	0.123	0.262	0.140	0.230

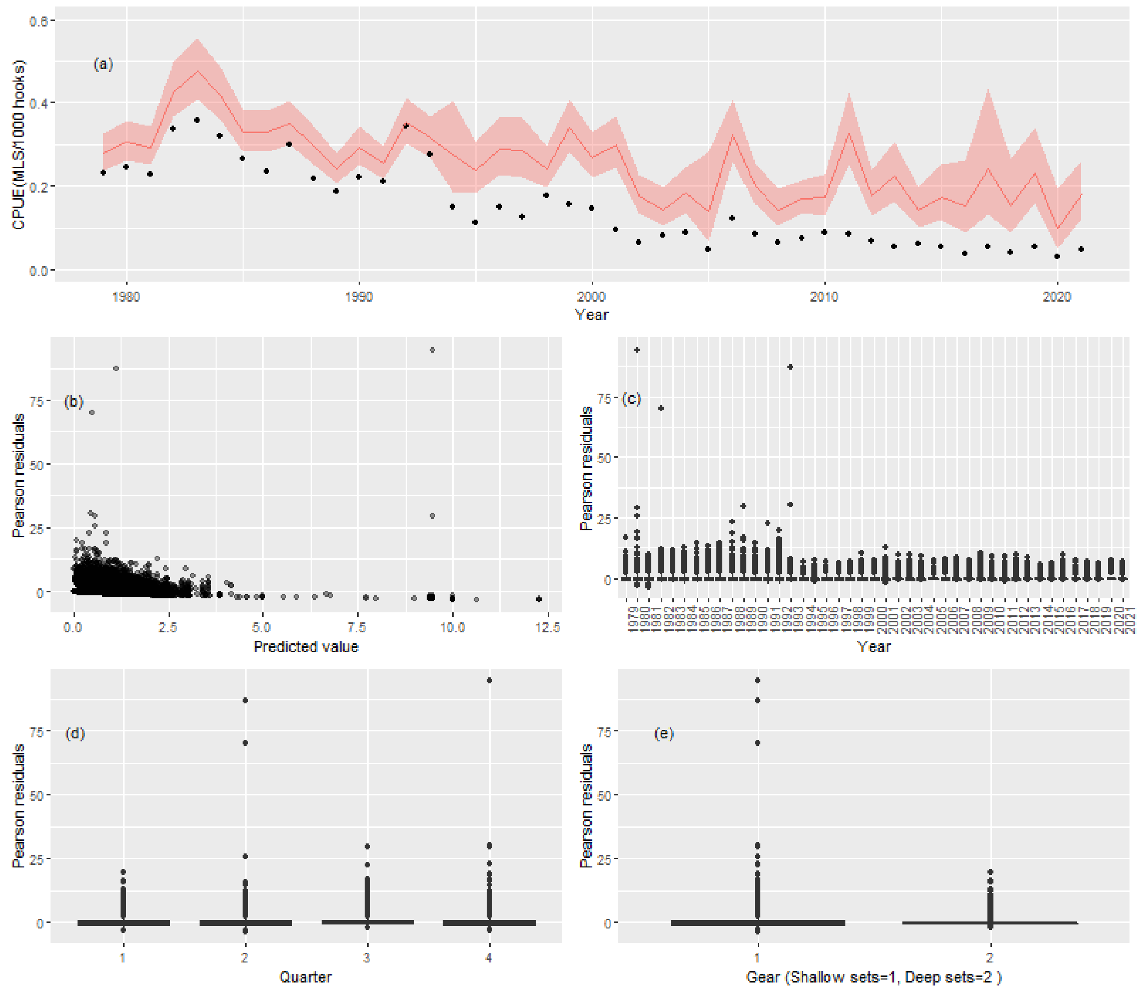

Fig. 12. **Central east.** Results of CPUE standardization analysis of blue marlin caught. (a) Historical changes of CPUE. Red line is standardized CPUE and filled area is 95% confidence interval. Points denote nominal CPUE. (b)-(e): Trends of Pearson residuals.

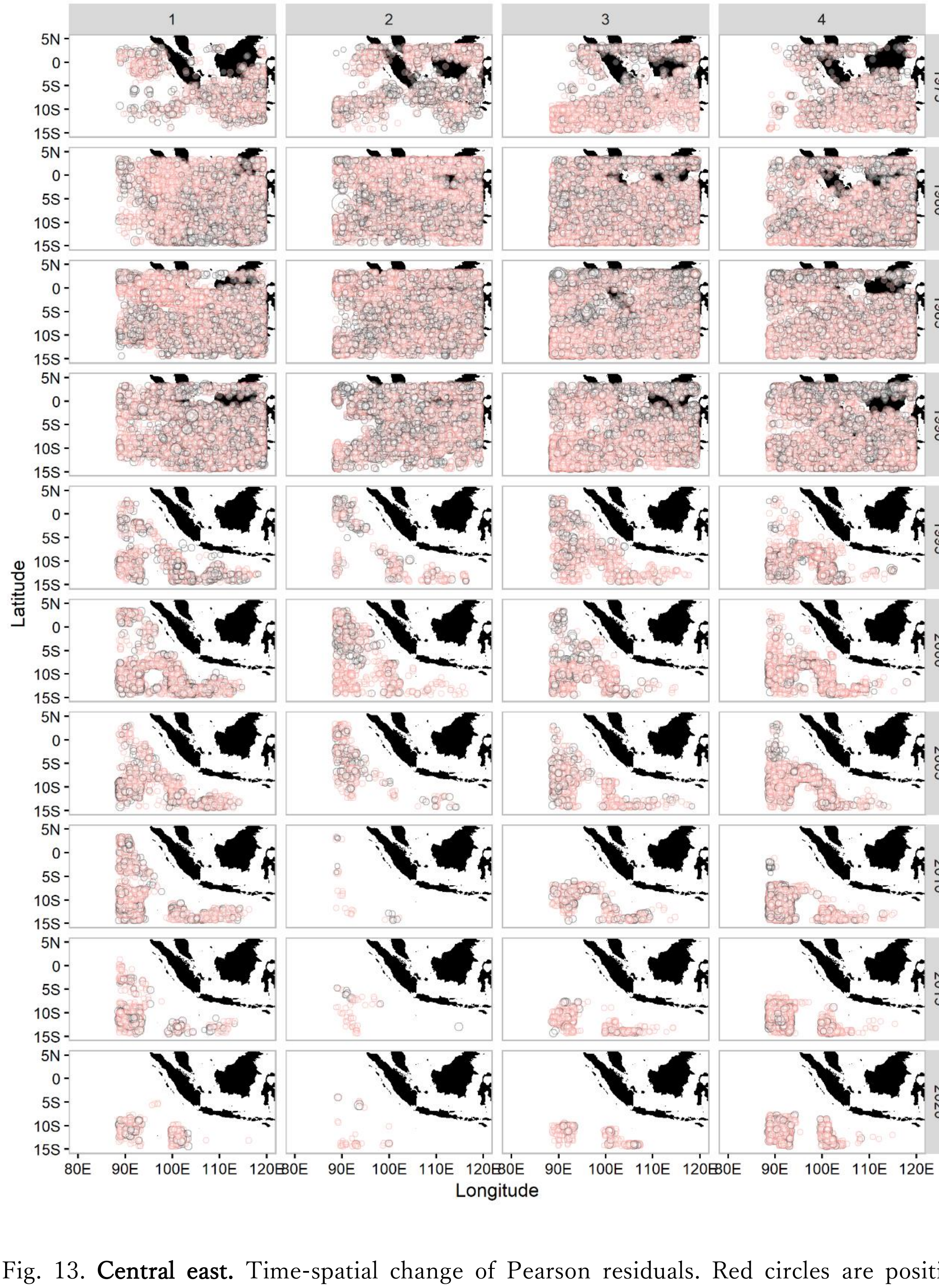

Fig. 13. **Central east.** Time-spatial change of Pearson residuals. Red circles are positive residuals, and black circles are minus residuals. Size of circle correspond to magnitude of Pearson residuals.

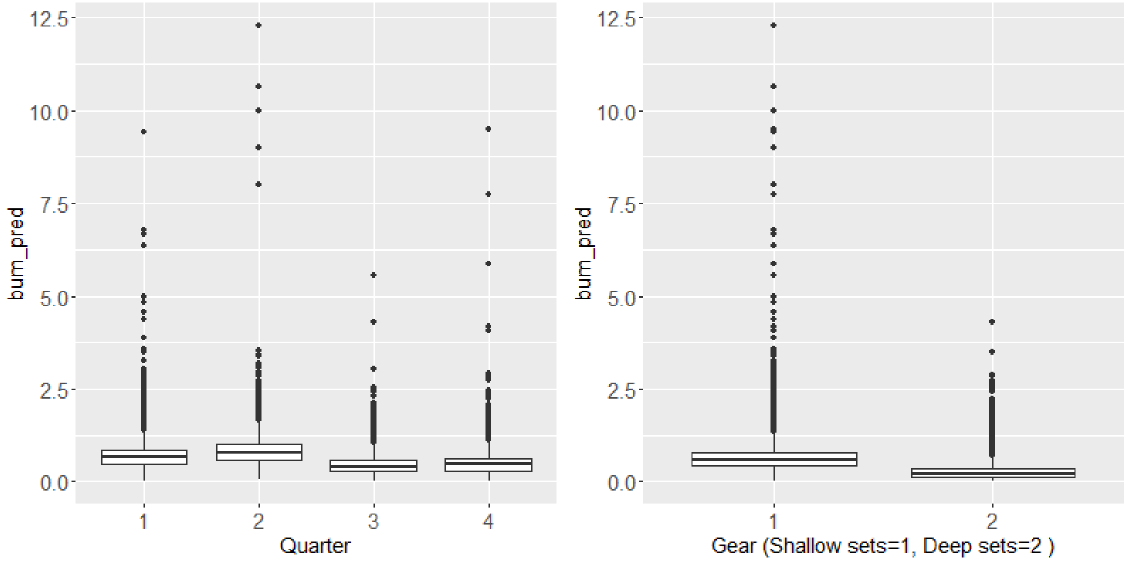

Fig. 14. **Central east.** Results of CPUE standardization analysis among quarters (left; 1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) and gear depths (right; 1: Shallow, 2: Deep). Top, bottom and middle of the box show 75 percentile, 25 percentile and median, respectively. Vertical bars show 75 percentile plus 1.5*IQR (Inter-Quartile Range) and 25 percentile minus 1.5*IQR, respectively. Dots show outliers.