Standardized CPUE of blue marlin (*Makaira mazara*) caught by Japanese longline fishery in the Indian Ocean: Analysis between 1994 and 2018

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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. The time-period of this study limits between 1994 and 2018 due to large uncertainties such as species discrimination in billfish in the earlier period logbook data.
2. We used the three core areas (Northwest, Southwest and Central east) with high density of blue marlin caught for the analysis following the approach by Yokoi et al. (2016).
3. We applied the zero-inflated Poisson GLMM for the CPUE standardization (catch number) of blue marlin.
4. To evaluate the shrink of Japanese longliner operations, we calculated different period standardized CPUE (1994-2010 and 1994-2018 (1994-2014 for the Northwest)). There was no substantial difference between the two CPUEs for all core areas.
5. The standardized CPUE typically decreased from mid-1990s to mid-2000s for all core areas, although the trend was different from that of nominal CPUE in the Southwest.
6. There was little significant difference of standardized CPUEs between four quarters as well as between two gear depths for each core area, but the zero-catch rate during April-September (second and third quarters) always rose close to 100% in the Southwest.
7. In the model diagnosis, we checked Pearson residuals corresponding the explanatory variables. There are little clear trends against the explanatory variables, but Pearson residual showed some time-spatial patterns for all core areas. Considering this result, it might need to address the geostatistical model in the future study.

Abstract

We addressed to standardize CPUE of blue marlin (*Makaira mazara*) caught by Japanese longline fishery in the Indian Ocean. The time-period of this study limits between 1994 and 2018 due to large uncertainties such as species discrimination in the earlier period logbook data. We used the three core areas (Northwest, Southwest and Central east) with high density of blue marlin caught for the analysis following the approach by Yokoi et al. (2016). We applied the zero-inflated Poisson GLMM for the CPUE standardization (catch number) of blue marlin. To evaluate the shrink of Japanese longliner operations, we calculated different period standardized CPUE (1994-2010 and 1994-2018 (1994-2014 for the Northwest)). There was no substantial difference between the two CPUEs for all core areas. The standardized CPUE typically decreased from mid-1990s to mid-2000s for all core areas, although the trend was different from that of nominal CPUE in the Southwest. There was little significant difference of standardized CPUE between four quarters as well as between two gear depths for each core area, but the zero-catch rate during April-September always rose close to 100% in the Southwest. In the model diagnosis, we checked Pearson residuals corresponding the explanatory variables. There are little clear trends against the explanatory variables, but Pearson residual showed some time-spatial patterns for all core areas. Considering this result, it might need to address the geostatistical model in the future study.

Introduction

Yokoi et al. (2016) updated the standardized CPUE (catch number) of blue marlin (*Makaira mazara*) caught by the Japanese tuna longline vessels 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 large 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 lose 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. Here, we 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 caught Yokoi et al. (2016) defined.

Material and Methods

Data sets

Japanese longline logbook data was used for the CPUE standardization of blue marlin in the Indian Ocean. The resolution of the logbook is 1x1 grid scale. The format of the logbook was changed around 1994. Thus, we used the logbook data between 1994 and 2018 for updating. 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) (Figure 1). We followed their definition in this study. Japanese longliners have operated throughout the Indian Ocean from the 1990s to the 2000s, but after 2010, because of the influence of pirates, the fishing ground has shrunk rapidly (Figure 1). To evaluate the shrink of Japanese longliner operations, we calculated different period standardized CPUE (1994-2010 and 1994-2018). For Northwest, the number of longlines was too small (<10) since 2015, thus we used the data between 1994 and 2014 for the analysis. Regarding the time-spatial changes in mean body weight of blue marlin, there were no clear trend, thus size-dependent area definition for CPUE standardization (e.g. Ochi et al. 2016) was not considered (Figure 2).

Statistical models

We used the similar procedure for the CPUE standardization with Ijima (2018). We applied zero-inflated Poisson GLMM (ZIP-GLMM) because almost blue marlin catch was zero (Figure 3). 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. 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 (Figure 4). All variables were treated as the 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). To select an appropriate statistical model, we also considered the simpler model such as GLM and GLMM. We evaluated these models using Bayesian information criterion (BIC) and likelihood ratio test. We also check the Pearson residuals for model diagnosis. 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 the interaction for all models to avoid overfitting.

Result and Discussion

Northwest

We selected ZIP-GLMM that BIC and AIC were the lowest between other candidate models (Table 1). The trends for both nominal and standardized CPUEs showed decreasing continuously during 1994-2014 (Table 2, Figure 5a). There is no difference between the two different period CPUE, but the large uncertainties occurred since 2010 (Figure 5 a). Pearson residuals are approximately scattered against predicted values (Figure 5 b). There is no definite residual trend for fixed effect variables (Figure 5 c-e). These validation results indicate the selected statistical model is well estimated. However, the time-spatial changes in Pearson residuals was not randomly plotted (there is the spatial correlation in this plot) (Figure 6). There was no significant difference of standardized CPUE between four quarters as well as between two gear depths (Fig. 7)

Southwest

We selected ZIP-GLMM that BIC and AIC were the lowest between other candidate models (Table 3). The standardized CPUE decreased from mid-1990s to mid-2000s, however had large uncertainties and the trend was rather different from that of nominal CPUE (Table 4, Figure 8 a). Pearson residuals spiked around predicted zero catches (Figure 8 b). There is no definite residual trend for fixed effect variables (Figure 8 c-e). However, the time-spatial changes in Pearson residuals was not randomly plotted (there is the spatial correlation in this plot) (Figure 9). There was no significant difference of standardized CPUE between four quarters as well as between two gear depths (Fig. 10), although the zero-catch rate during second and third quarters (April-September) always rose close to 100% (Figure 3) and the nominal CPUE in these quarters showed remarkably lower (Fig. 10).

Central east

We selected ZIP-GLMM that BIC and AIC were the lowest between other candidate models (Table 5). The trends for both nominal and standardized CPUEs decreased from mid-1990s to mid-2000s but jumped in 2016 then decreased until 2018 (Table 6, Figure 11 a). There was no difference between the two different period CPUE. Pearson residuals are approximately scattered against predicted values (Figure 11 b). There was no definite residual trend for fixed effect variables (Figure 11 c-e). These validation results indicate the selected statistical model is well estimated. However, the time-spatial changes in Pearson residuals was not randomly plotted (there is the spatial correlation in this plot) (Figure 12). There was a significant difference of standardized CPUE between quarter 1 (Jan-Mar) and 3 (Jul-Sep) but no significant difference between other combinations as well as between two gear depths (Figure 13).

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.

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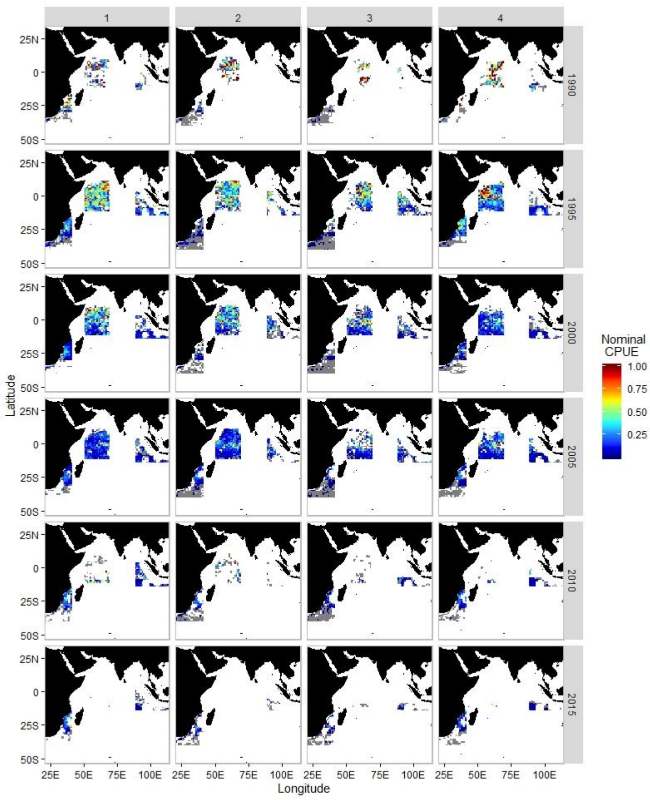

Figure 1. Changes in time-spatial CPUE of blue marlin in the Indian Ocean for four quarters (1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) during 1990s – 2015s.

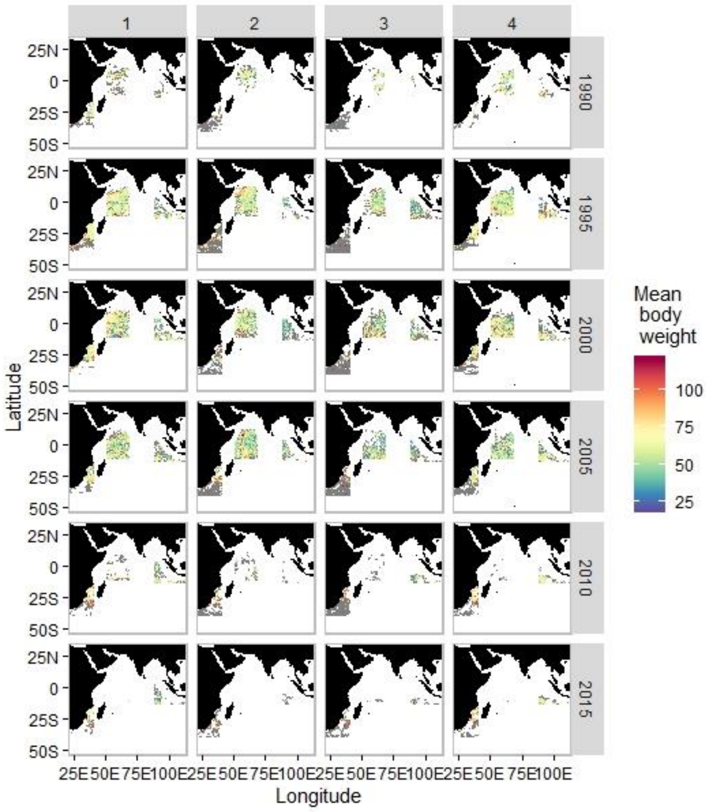

Figure 2. Changes in time-spatial mean body weight of blue marlin caught by Japanese longline vessels in the Indian Ocean.

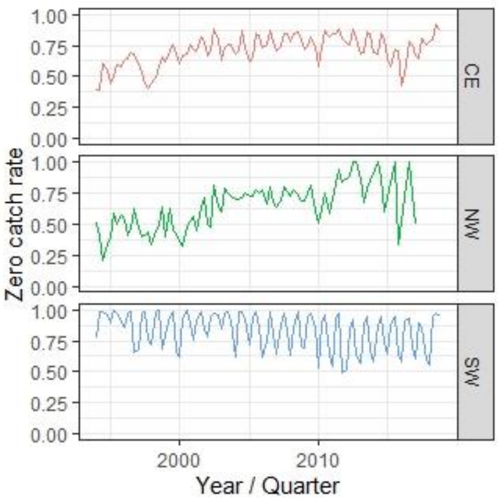

Figure 3. Zero catch rate of blue marlin caught by Japanese longline fishery for the three core areas in the Indian Ocean.

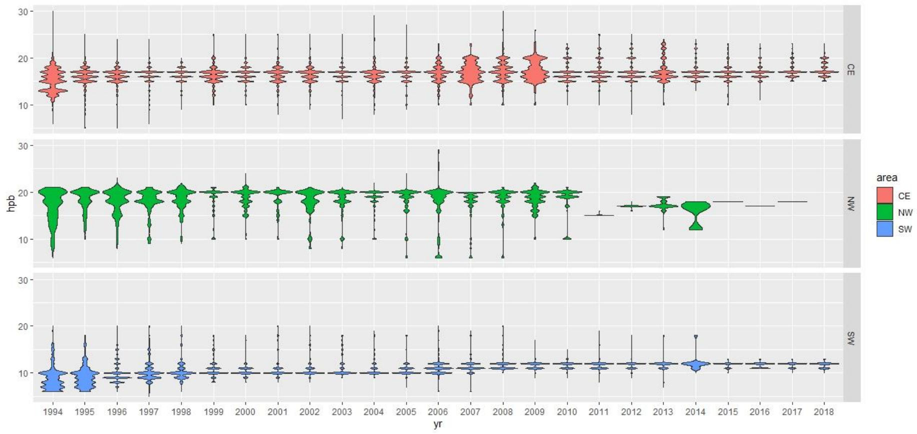

Figure 4. Historical change of hooks between floats. We set two type gear configurations (deep or shallow sets) that boundary is fifteen hooks between floats in the three core areas.

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

Models	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
yr + offset(log(hooks/1000))	21	168677	168868	168635		
yr + qtr + offset(log(hooks/1000))	24	168072	168291	168024	611.1	<0.001
yr + qtr + gear2 + offset(log(hooks/1000)	25	168021	168249	167971	52.78	<0.001
yr + qtr + gear2 + (1 | area) + offset(log(hooks/1000))	26	164193	164431	164141	3830	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000))	27	156872	157119	156818	7323	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~1	28	152678	152934	152622	4196	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr	48	152374	152812	152278	344.6	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr	51	152352	152817	152250	27.81	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2	52	152265	152740	152161	88.72	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | area)	53	152070	152554	151964	197.4	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | fleet)	53	150911	151395	150805	1159	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | area) + (1 | fleet)	54	150765	151258	150657	148.1	<0.001

Following models were not converged.
yr + qtr + gear2 + (1|area) + (yr|fleet) + offset(log(hooks/1000)

Table 2. **Northwest.** Standardized CPUE of blue marlin in the Northwest (1994-2014).

Year	Nominal CPUE	Stand. CPUE	Upper (95%)	Lower (95%)	Upper (80%)	Lower (80%)
1994	0.575	1.010	1.152	0.886	1.101	0.927
1995	0.359	0.742	0.851	0.647	0.811	0.678
1996	0.298	0.426	0.487	0.372	0.465	0.390
1997	0.456	0.590	0.671	0.519	0.642	0.543
1998	0.406	0.517	0.588	0.454	0.562	0.475
1999	0.353	0.484	0.553	0.424	0.528	0.444
2000	0.376	0.465	0.531	0.408	0.507	0.427
2001	0.251	0.481	0.551	0.420	0.525	0.440
2002	0.214	0.365	0.421	0.316	0.400	0.332
2003	0.129	0.221	0.258	0.190	0.245	0.200
2004	0.131	0.224	0.262	0.191	0.248	0.202
2005	0.109	0.193	0.224	0.166	0.212	0.175
2006	0.134	0.205	0.237	0.178	0.225	0.187
2007	0.133	0.168	0.193	0.146	0.184	0.153
2008	0.128	0.185	0.216	0.159	0.205	0.167
2009	0.128	0.110	0.130	0.093	0.122	0.099
2010	0.225	0.211	0.262	0.170	0.243	0.183
2011	0.076	0.192	0.929	0.040	0.538	0.068
2012	0.018	0.174	0.725	0.042	0.442	0.069
2013	0.093	0.128	0.278	0.059	0.212	0.077
2014	0.024	0.115	0.574	0.023	0.328	0.040

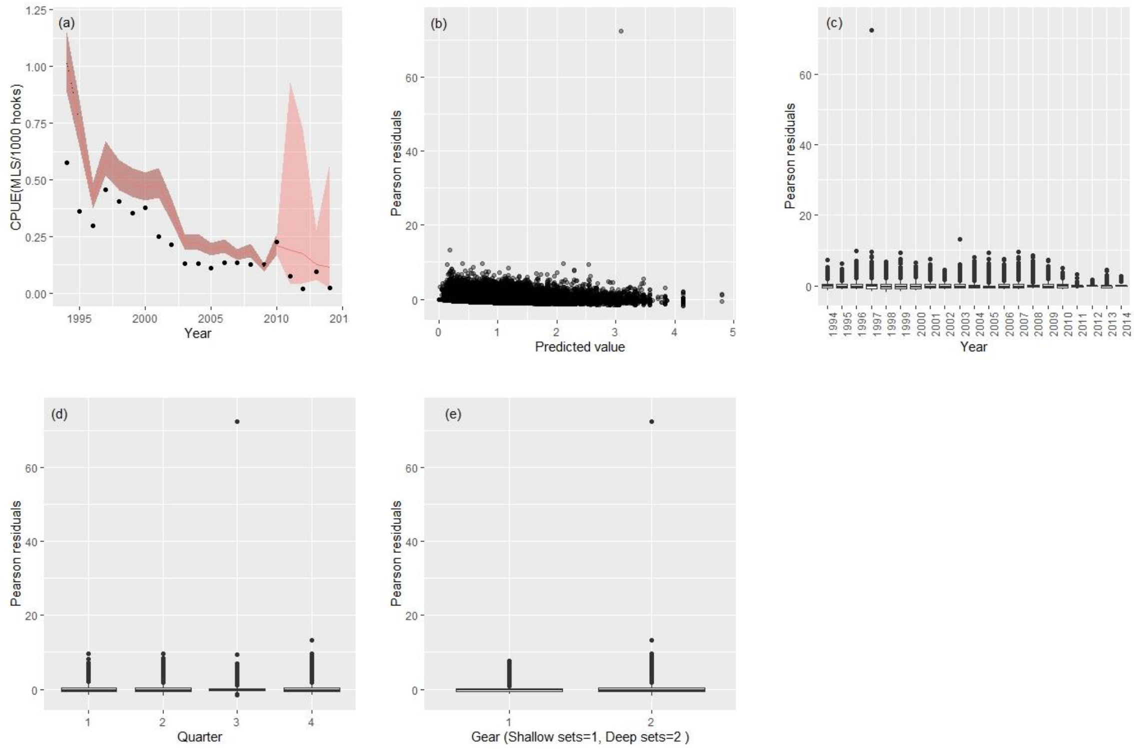

Figure 5. **Northwest.** Results of CPUE standardization analysis of blue marlin caught. (a) Historical changes of CPUE. Red line is standardized CPUE and filled area is 95% confidence interval. Points denote nominal CPUE. Black line and filled area show the results using different period data (1994-2010). (b)-(e): Trends of Pearson residuals.

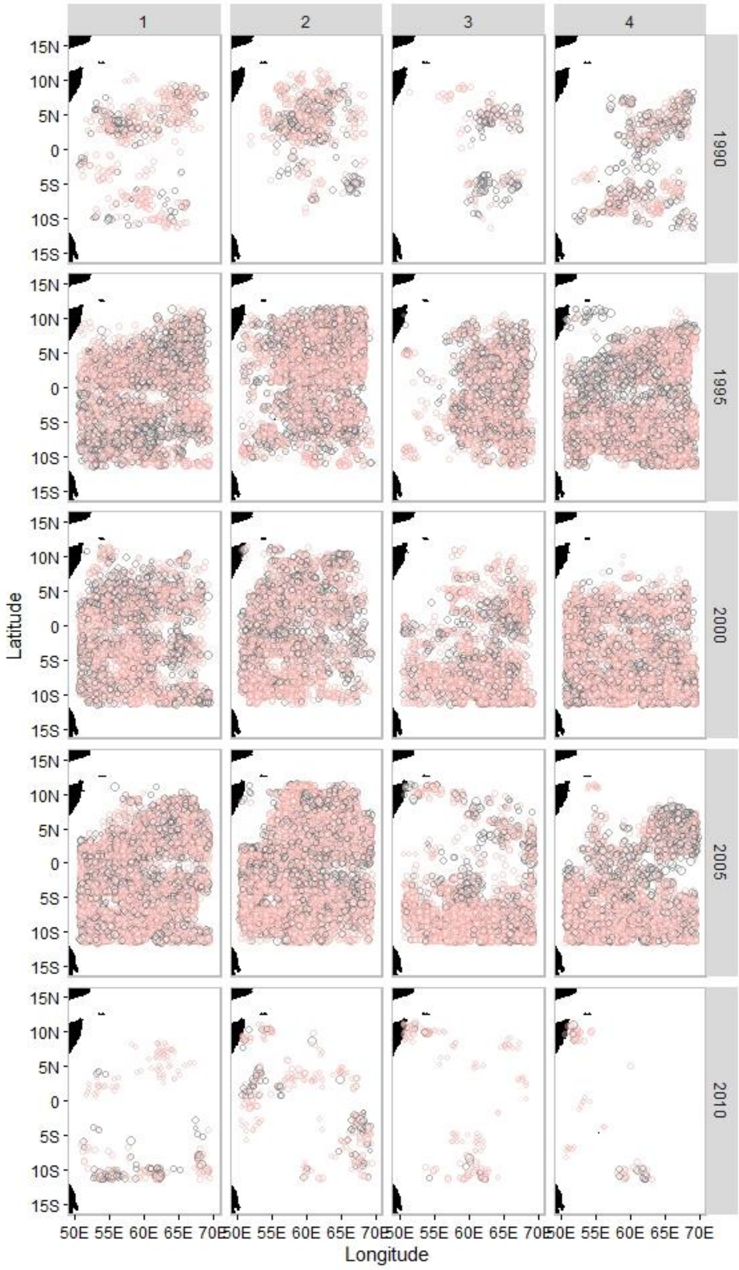

Figure 6. **Northwest.** Time-spatial change of Pearson residuals. Red circles are positive residuals, and black circles are minus residuals. Size of circle correspond to magnitude of Pearson residuals.

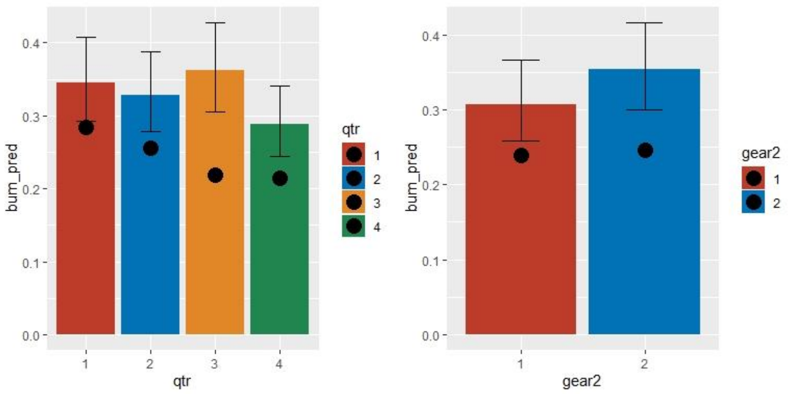

Fig. 7. **Northwest.** Results of CPUE standardization analysis between quarters (left; 1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) and gear depths (right; 1: Shallow, 2: Deep). Vertical bars denote 95% confidence interval of standardized CPUE. Solid points are nominal CPUEs

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

Models	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
yr + offset(log(hooks/1000))	25	190222	190470	190172		
yr + qtr + offset(log(hooks/1000))	28	161966	162244	161910	28262	<0.001
yr + qtr + gear2 + offset(log(hooks/1000)	29	161963	162251	161905	5.054	<0.05
yr + qtr + gear2 + (1 | area) + offset(log(hooks/1000))	30	149664	149961	149604	12302	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000))	31	142516	142823	142454	7150	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr	56	135490	136044	135378	7076	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr	59	133766	134351	133648	1729	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2	60	133765	134359	133645	3.27	<0.1
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | area)	61	132845	133449	132723	922	<0.001
yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | area) + (1 | fleet)	62	130920	131534	130796	1927	<0.001

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

Table 4. **Southwest.** Standardized CPUE of blue marlin in the Northwest (1994-2018).

Year	Nominal CPUE	Stand. CPUE	Upper (95%)	Lower (95%)	Upper (80%)	Lower (80%)
1994	0.045	0.247	0.567	0.107	0.425	0.143
1995	0.029	0.170	0.393	0.074	0.294	0.098
1996	0.072	0.224	0.515	0.098	0.386	0.130
1997	0.082	0.161	0.368	0.070	0.276	0.093
1998	0.087	0.151	0.347	0.066	0.260	0.088
1999	0.079	0.105	0.242	0.046	0.181	0.061
2000	0.080	0.096	0.221	0.042	0.166	0.056
2001	0.056	0.061	0.140	0.026	0.105	0.035
2002	0.060	0.075	0.174	0.033	0.130	0.044
2003	0.031	0.044	0.103	0.019	0.076	0.025
2004	0.056	0.079	0.182	0.034	0.136	0.046
2005	0.043	0.059	0.137	0.026	0.102	0.034
2006	0.085	0.050	0.114	0.022	0.086	0.029
2007	0.070	0.041	0.093	0.018	0.070	0.024
2008	0.097	0.050	0.115	0.022	0.086	0.029
2009	0.066	0.041	0.094	0.018	0.071	0.024
2010	0.092	0.066	0.151	0.029	0.113	0.038
2011	0.133	0.078	0.179	0.034	0.134	0.045
2012	0.122	0.062	0.142	0.027	0.107	0.036
2013	0.116	0.059	0.136	0.026	0.102	0.034
2014	0.110	0.054	0.124	0.023	0.093	0.031
2015	0.112	0.050	0.115	0.022	0.086	0.029
2016	0.120	0.043	0.100	0.019	0.075	0.025
2017	0.152	0.073	0.167	0.032	0.125	0.042
2018	0.129	0.068	0.156	0.029	0.117	0.039

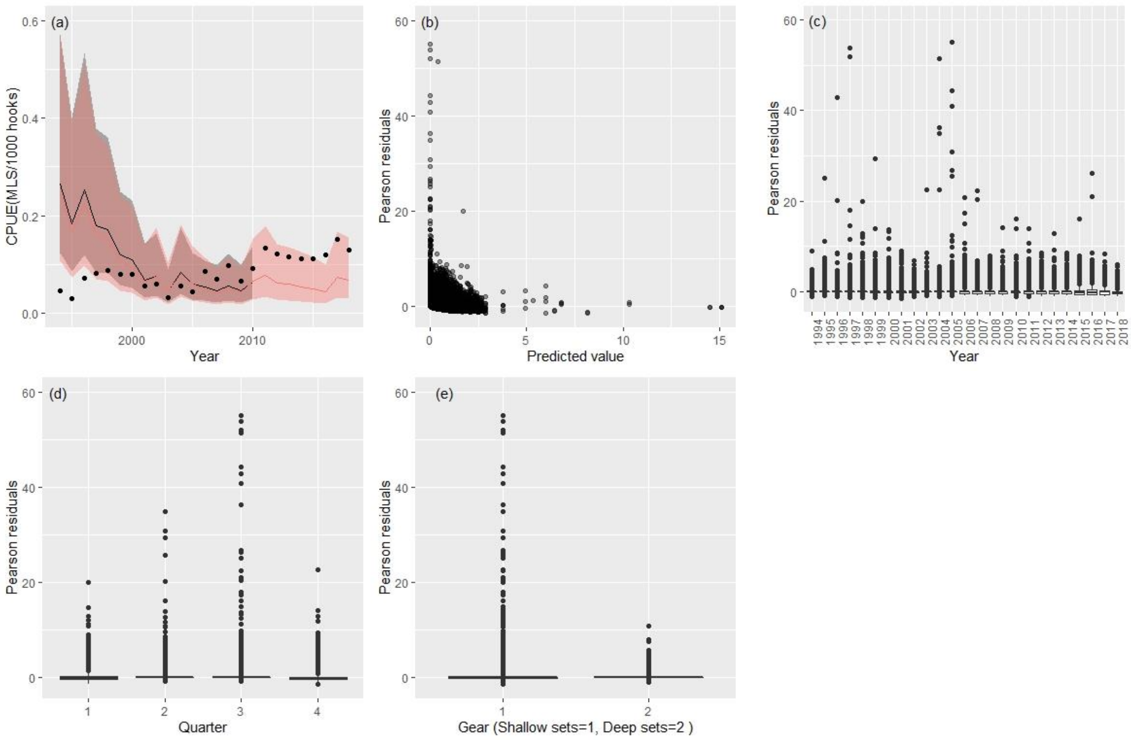

Figure 8. **Southwest.** Results of CPUE standardization analysis of blue marlin caught. (a) Historical changes of CPUE. Red line is standardized CPUE and filled area is 95% confidence interval. Points denote nominal CPUE. Black line and filled area show the results using different period data (1994-2010). (b)-(e): Trends of Pearson residuals.

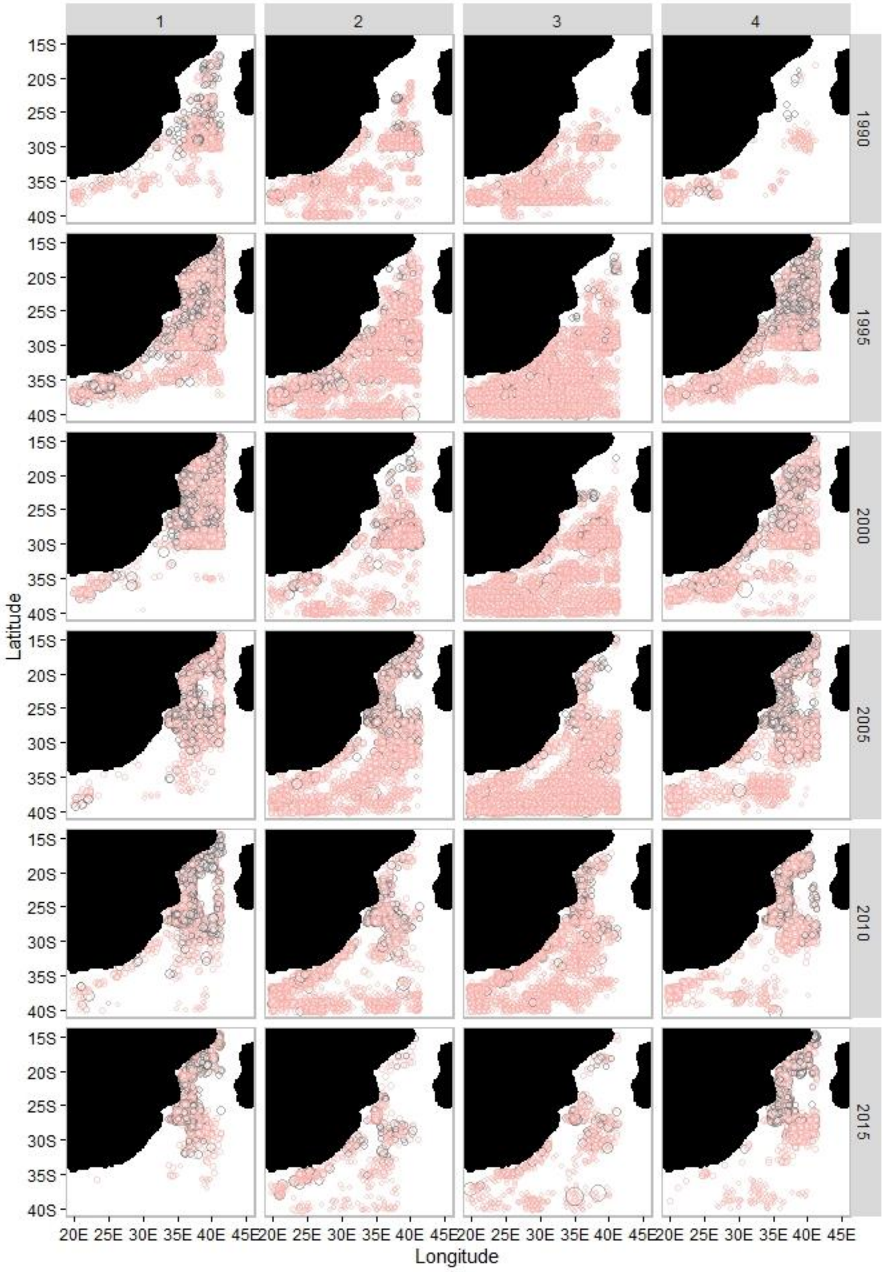

Figure 9. Southwest. Time-spatial change of Pearson residuals. Red circles are positive residuals, and black circles are minus residuals. Size of circle correspond to magnitude of Pearson residuals.

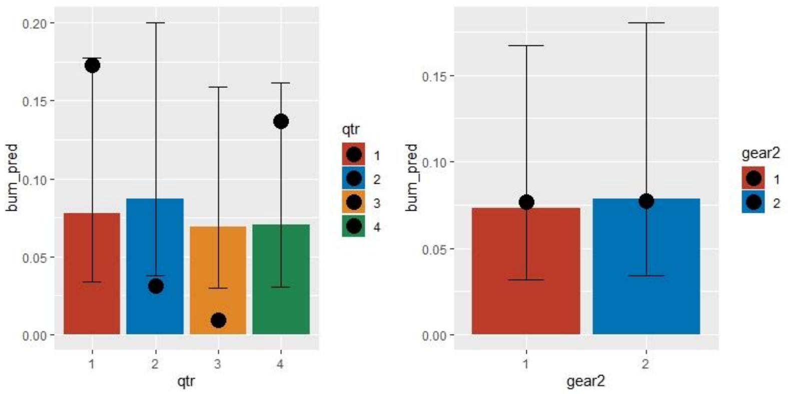

Fig. 10. **Southwest.** Results of CPUE standardization analysis between quarters (left; 1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) and gear depths (right; 1: Shallow, 2: Deep). Vertical bars denote 95% confidence interval of standardized CPUE. Solid points are nominal CPUEs

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

<table>
<tr><th>Models</th><th>Df</th><th>AIC</th><th>BIC</th><th>deviance</th><th>Chisq</th><th>Pr(>Chisq)</th></tr>
<tr><td>yr + offset(log(hooks/1000))</td><td>25</td><td>495818</td><td>496078</td><td>495768</td><td></td><td></td></tr>
<tr><td>yr + qtr + offset(log(hooks/1000))</td><td>28</td><td>491340</td><td>491632</td><td>491284</td><td>4484</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + offset(log(hooks/1000)</td><td>29</td><td>490558</td><td>490860</td><td>490500</td><td>784.5</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + (1 | area) + offset(log(hooks/1000))</td><td>30</td><td>475239</td><td>475551</td><td>475179</td><td>15321</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000))</td><td>31</td><td>462906</td><td>463228</td><td>462844</td><td>12335</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~1</td><td>32</td><td>455416</td><td>455749</td><td>455352</td><td>7492</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr</td><td>56</td><td>455202</td><td>455785</td><td>455090</td><td>261.9</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr</td><td>59</td><td>455012</td><td>455626</td><td>454894</td><td>195.6</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2</td><td>60</td><td>454998</td><td>455623</td><td>454878</td><td>15.75</td><td><0.001</td></tr>
<tr><td>yr + qtr + gear2 + (1 | area) + (1 | fleet) + offset(log(hooks/1000)), zi=~yr + qtr + gear2 + (1 | area) + (1 | fleet)</td><td>62</td><td>451694</td><td>452339</td><td>451570</td><td>3309</td><td><0.001</td></tr>
</table>

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 + (1 | area)

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

Table 6. **Central east.** Standardized CPUE of blue marlin in the Northwest (1994-2018).

Year	Nominal CPUE	Stand. CPUE	Upper (95%)	Lower (95%)	Upper (80%)	Lower (80%)
1994	0.440	0.533	0.607	0.468	0.580	0.489
1995	0.400	0.504	0.574	0.442	0.549	0.462
1996	0.203	0.282	0.323	0.247	0.308	0.259
1997	0.452	0.395	0.450	0.346	0.430	0.362
1998	0.367	0.440	0.502	0.386	0.480	0.404
1999	0.189	0.292	0.335	0.255	0.319	0.267
2000	0.158	0.204	0.234	0.177	0.223	0.186
2001	0.119	0.195	0.224	0.170	0.214	0.178
2002	0.112	0.164	0.190	0.143	0.180	0.150
2003	0.161	0.218	0.250	0.190	0.238	0.199
2004	0.144	0.192	0.221	0.167	0.210	0.175
2005	0.153	0.194	0.226	0.167	0.214	0.176
2006	0.104	0.143	0.170	0.120	0.160	0.127
2007	0.109	0.190	0.221	0.163	0.210	0.172
2008	0.083	0.101	0.118	0.087	0.112	0.091
2009	0.117	0.165	0.192	0.143	0.182	0.150
2010	0.139	0.238	0.276	0.206	0.262	0.217
2011	0.069	0.073	0.085	0.062	0.081	0.066
2012	0.097	0.139	0.163	0.118	0.154	0.125
2013	0.117	0.193	0.225	0.166	0.213	0.175
2014	0.129	0.173	0.201	0.149	0.191	0.157
2015	0.179	0.206	0.238	0.179	0.226	0.188
2016	0.243	0.388	0.446	0.337	0.425	0.354
2017	0.143	0.184	0.214	0.158	0.203	0.167
2018	0.068	0.080	0.097	0.066	0.091	0.070

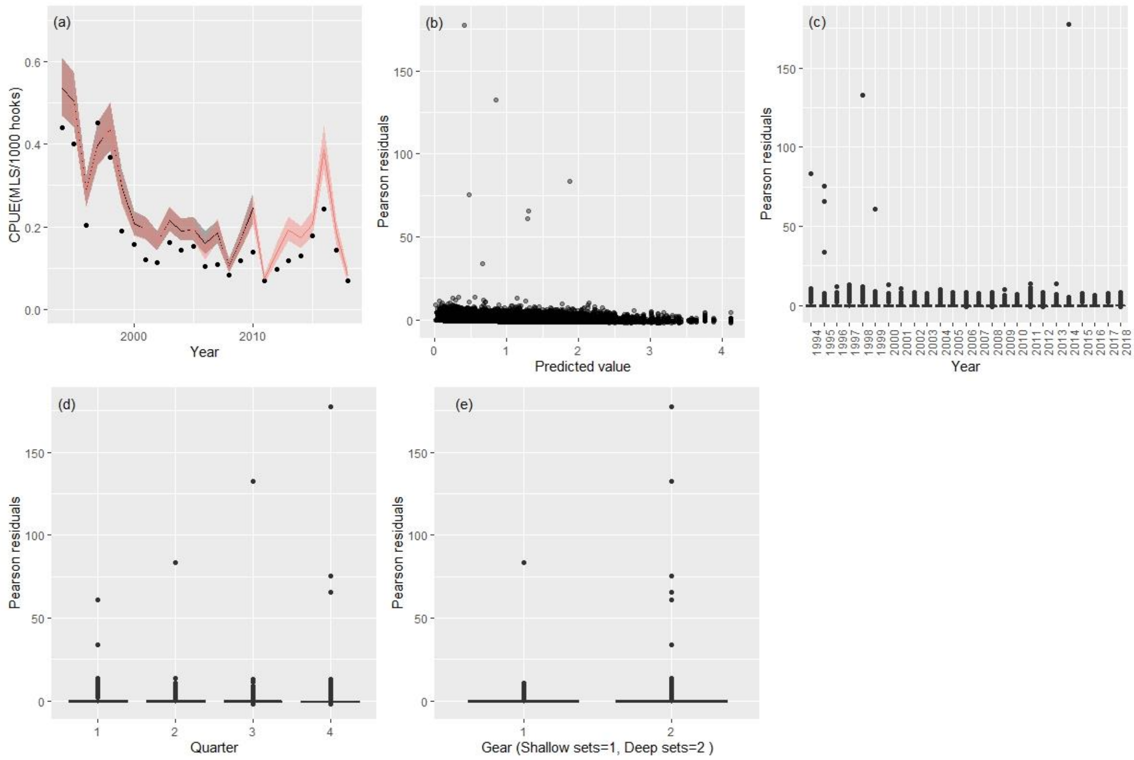

Figure 11. **Central east.** Results of CPUE standardization analysis of blue marlin caught. (a) Historical changes of CPUE. Red line is standardized CPUE and filled area is 95% confidence interval. Points denote nominal CPUE. Black line and filled area show the results using different period data (1994-2010). (b)-(e): Trends of Pearson residuals.

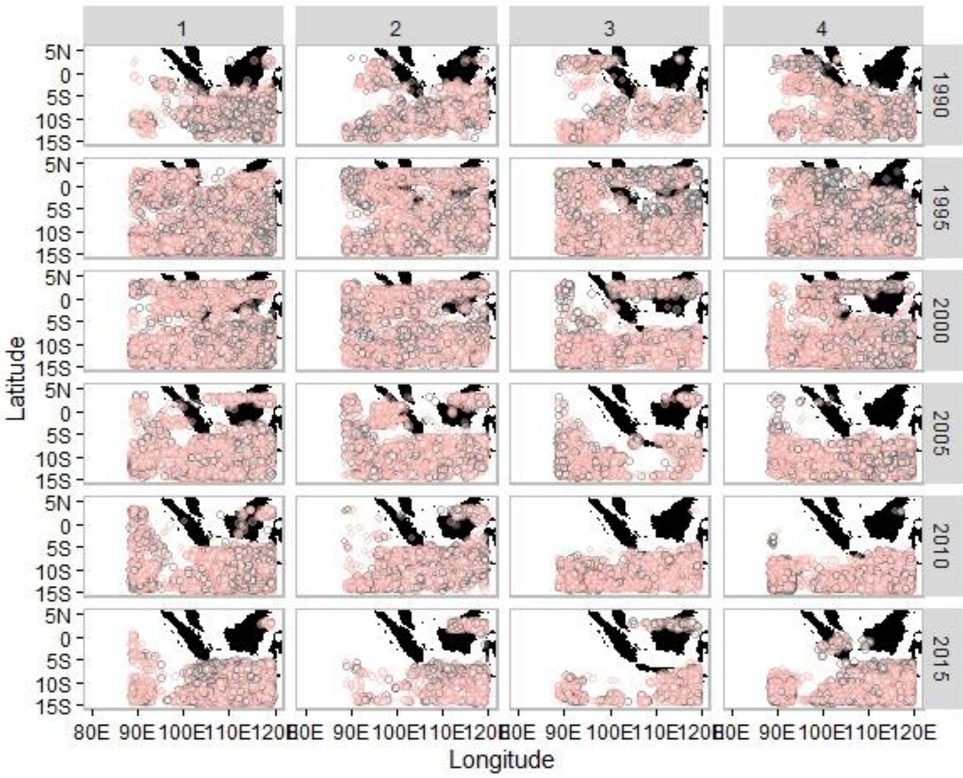

Figure 12. **Central east.** Time-spatial change of Pearson residuals. Red circles are positive residuals, and black circles are minus residuals. Size of circle correspond to magnitude of Pearson residuals.

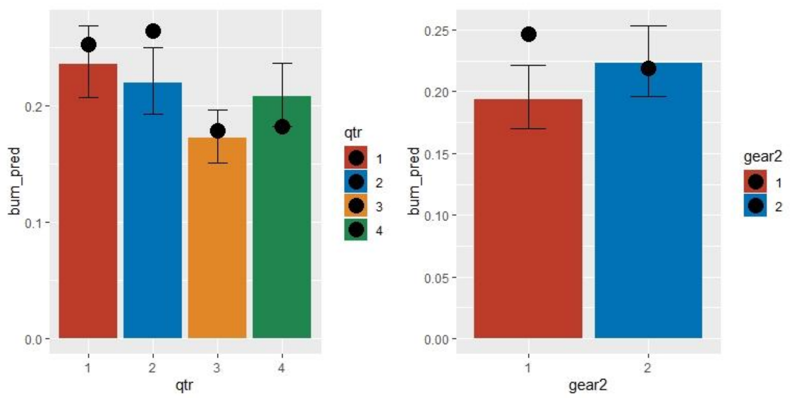

Fig. 13. **Central east.** Results of CPUE standardization analysis between quarters (left; 1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, 4: Oct-Dec) and gear depths (right; 1: Shallow, 2: Deep). Vertical bars denote 95% confidence interval of standardized CPUE. Solid points are nominal CPUEs