Standardized CPUE of the Indian Ocean striped marlin (*Tetrapturus audax*) caught by Japanese longline fishery: Update analysis between 1994 and 2017

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Highlights

1. I updated standardized CPUE of the Indian Ocean striped marlin (*Tetrapturus audax*) caught by Japanese longline fishery. The time-period of this study is between 1994 and 2017.

2. In this analysis, I followed the methodology of the previous study (IOTC-2017-WPB15-31). As a result, the similar model (Zero-inflated negative binomial GLMM) was selected for all areas.

3. To evaluate the shrink of Japanese longliners operation, I calculated different period standardized CPUE (1994-2010 and 1994-2017). There is no substantial difference between two CPUEs in North West and North East area, but CPUE after 2010 still includes large uncertainties.

4. In the model diagnosis, I checked Pearson residuals corresponding the explanatory variables. There are no clear trends against the explanatory variables. However, although I applied Zero-inflated negative binomial model, there are still large zero trends in South East and South West area. Furthermore, Pearson residual showed time-spatial patterns for all areas. Considering this result, it might need to address the geostatistical model in the future study

5. I compared time-spatial changes in mean body weight (fish size) of MLS caught by Japanese longliners. In quarter 1 and 4 in North Indian Ocean, Japanese longliners have caught small MLS (<20kg) that is age 0 fish, while over 40kg fish (3-4 years old fish) have been caught in quarter 2 and 3. Usually, catch and effort data of juvenile fish is a noisy recruitment index rather than adult information. To reflect this result for the stock assessment, WPB needs to reconsider area definition or to use seasonal CPUE (quarter 2 and 3) to Surplus Production Model. However, this result din not consistent with size frequency data (Japanese size frequency shows larger size than the Taiwanese fleet.). Thus, at this point, CPUE of North West (1994-2010) is the best available index for Billfish working party.

Abstract

Using previous study procedures, I updated standardized CPUE of the Indian Ocean striped marlin (*Tetrapturus audax*) caught by Japanese longline fishery. The time-period of this study is between 1994 and 2017, and the selected models were Zero-inflated negative binomial GLMM. For additional research, I checked time-spatial changes of mean body weight (fish size) and Pearson residuals. The trends of mean body weight indicated Japanese longliners had caught zero age fish that is noise for CPUE standardization, but this result was different to size frequency data. Pearson residuals showed a

time-spatial correlation. To evaluate the shrink of Japanese longliners coverage, I also calculated the standardized CPUE that period is 1994-2010. There is no substantial difference between two time-period CPUEs, but CPUE after 2010 still includes large uncertainties.

Introduction

In 2017, the Indian Ocean Tuna Commission (IOTC) of Working Party on Billfish (WPB) carried out the stock assessment of striped marlin (MLS) in the Indian Ocean (IOTC 2017). In this stock assessment, WPB members used four different models, stock reduction analysis (SRA), two production models (ASPIC and SSBSP) and Stock Synthesis 3 (SS3). Excluding a data-limited catch only method as SRA, Japanese longline CPUE was used for stock assessment model (Wang 2017, Yokoi and Nishida 2017, Andrade 2017). WPB will conduct the stock assessment of MLS again in 2018. The object of this document is 1) to supply updating the Japanese longline standardized CPUE of MLS in the Indian Ocean, and 2) summarize time-spatial changes of mean body weight of fish caught by Japanese longliners to discuss area definition of the stock assessment. In this analysis, I used the same procedure of CPUE standardization as the previous study (Ijima 2017).

Material and Methods

Data sets

Japanese longline logbook data was used for the CPUE standardization of MLS in the Indian Ocean. The resolution of the logbook is 1x1 grid scale. The format of the logbook was changed around 1994. Thus, I used the logbook data between 1994 and 2017 for updating. WPB defined four area in the Indian Ocean (Figure 1). I followed the definition of WPB 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 2). There is large zero catch area in the Southeast Indian Ocean because Japanese longliners have been vigorously targeting Southern Bluefin tuna in the Southern Indian Ocean (Figure 2). Regarding the time-spatial changes in mean body weight (fish size) of MLS, Japanese longliners have caught small MLS (<20kg) that is age 0 fish in first quarter and 4th quarter in North Indian Ocean, while over 40kg fish (3-4 years old fish) have been caught in quarter 2 and 3 (Figure 3). This result was not consistent with Japanese size composition data of MLS (Ijima 2017).

Statistical models

I used the same procedure of the previous study for the CPUE standardization (Ijima 2017). I applied zero-inflated negative binominal GLMM (ZINB-GLMM) because almost MLS catch is zero (Figure 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. The changes in gear configuration show two modes in all area. Thus, I defined two gear type as shallow or deep sets (Figure 5). 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 pseudoreplication by vessel and operating area.

I used R software package glmmTMB for parameter estimation (Brooks et al., 2017). To select an appropriate statistical model, I also considered the simpler model such as GLM and GLMM. I evaluated these models using Bayesian information criterion (BIC) and likelihood ratio test. I also check the Pearson residuals for model diagnosis. Finally, I calculated the standardized MLS CPUE using the R software package lsmeans (Lenth 2016). The ZINB-GLMM is

$$Catch_i \sim ZINB(\pi_i, \mu_i, k),$$

$$E(Catch_i) = \mu_i(1 - \pi_i),$$
$$\mathrm{var}(Catch_i) = (1 - \pi_i)\mu_i(1 + \pi_i\mu_i + \mu_i/k),$$
$$\log(\mu_i) = \beta_0 + \mathbf{X}_i\boldsymbol{\beta} - \log(hooks_i) + a_i + b_i,$$
$$\mathrm{logit}(\pi_i) = \gamma_0 + \mathbf{Z}_i\boldsymbol{\gamma} + c_i + d_i,$$
$$a_i \sim N(0, \sigma_a^2),\ b_i \sim N(0, \sigma_b^2),\ c_i \sim N(0, \sigma_c^2), \text{ and } d_i \sim N(0, \sigma_d^2)$$

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 MLS catch number of operation i. μ_i is expected catch number of the operation i. k is the dispersion parameter of the negative binomial distribution The link function was used for log link function. β_0 is the intercept, $\mathbf{X_i}$ is the matrix of variables, $\boldsymbol{\beta}$ is the covariates vectors, and hooks denote the hooks/1000 of the operation respectively. I 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. I did not use the interaction for all models to avoid overfitting.

Result and Discussion

North East area

The selected model was the same as the previous study (Table 1). The trends in MLS CPUE shows decreasing continuously (Table 2, Figure 6). There is no difference between the two different period CPUE (Figure 7a). Pearson residuals are approximately scattered against predicted values (Figure 7 b). There is no definite residual trend for fixed effect variables (Figure 7 c-e). These validation results indicate the selected statistical model is well estimated. However, this model still has issues. For example, time-spatial changes in Pearson residuals was not randomly plotted (there is the spatial correlation in this plot) (Figure 8). The geostatistical model may be one solution for these issues. The dataset of the North East area may include the juvenile fish catch (Figure 3). In the future work, it needs to remove juvenile information because strong year class spiked in the CPUE index. After 2010 CPUE may still include substantial uncertainty because of lack of area coverage.

North West area

The selected model was ZINB-GLMM, but the fixed variable is different from the previous study (Table 3). The MLS CPUE decreased till 2009 and jumped from 2010 to 2012 (Table 4, Figure 6). There is no difference between the two different period CPUE (Figure 9 a). Pearson residuals approximately scattered against predicted values (Figure 9 b). There is no definite residual trend for fixed effect variables (Figure 9 c-e). These diagnosis results suggested that the selected model was well estimated. However, time-spatial changes in Pearson residuals showed the spatial correlation (Figure 10). The juvenile fish may appear in the North West area (Figure 3). The reason of CPUE Jump of 2009-2012 might be the effect of strong year class but include large uncertainty because of lack of area coverage.

South East area

The selected model is the same as the previous study (Table 5). The MLS CPUE gradually increased till 2007 and decreased from 2009 to 2017 (Table 6, Figure 6). When I removed the after 2011 data, the estimated least square means changed (Figure 11 a). Pearson residuals spiked around predicted zero catches (Figure 11 b). There is no definite residual trend for fixed effect variables (Figure 11 c-e). The time-spatial changes in Pearson residuals showed the spatial correlation (Figure 12). Japanese longliner vigorously targeting Southern Bluefin tuna in the South Indian Ocean and most of catches of MLS in

South East area is zero (Figure 4). These validations indicated that the CPUE of MLS in South East area is not well estimated.

South West area

The selected model is the same as the previous study (Table 7). The standardized CPUE was close to zero catch between 1994 and 2008 and increased rapidly from 2009 to 2012 (Table 8, Figure 6). When I removed the current dataset, the estimated least square means changed (Figure 13 a). Pearson residuals spiked around predicted zero catches (Figure 13 b). There is no definite residual trend for fixed effect variables (Figure 11 c-e). However, the time-spatial changes in Pearson residuals showed the spatial correlation (Figure 14). Japanese longliner vigorously targeting Southern Bluefin tuna in the South Indian Ocean and most of MLS catch in South East area is zero till 2008 (Figure 4). These validations indicated that the CPUE of MLS in South East area is not well estimated.

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Table 1. Deviance table for black marlin CPUE in the North East Indian Ocean by Japanese longline fishery (1994-2017). Bold is the best model selected by BIC.

Models:	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
yr+offset(log(hooks/1000))	25	66339	66572	66289	-	-
yr+qtr+offset(log(hooks/1000))	28	65908	66169	65852	437.167	<0.0001
yr+qtr+gear+offset(log(hooks/1000))	29	65119	65389	65061	791.042	<0.0001
yr+qtr+gear+(1|area)+offset(log(hooks/1000))	30	60188	60467	60128	4932.744	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000))	31	59035	59323	58973	1155.271	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr	55	58782	59294	58672	300.614	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr	58	58738	59278	58622	49.713	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr+gear	59	58722	59271	58604	18.348	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr+gear+(1|area)+(1|fleet)	61	58064	58632	57942	662.169	<0.0001

*Selected model is same as previous study (IOTC-2017-WPB15-31).

Table 2. Standardized CPUE of Striped marlin caught by Japanese longline in the North East Indian Ocean (1994-2017). Standardized CPUE was calculated by the least square means.

Year	Nominal CPUE	Standardized CPUE	Lower	Upper
1994	0.832	0.865	0.655	1.142
1995	0.718	0.624	0.477	0.816
1996	1.066	1.058	0.807	1.388
1997	0.772	0.794	0.615	1.026
1998	0.295	0.387	0.295	0.508
1999	0.188	0.409	0.311	0.538
2000	0.142	0.249	0.189	0.328
2001	0.130	0.267	0.201	0.356
2002	0.103	0.478	0.346	0.660
2003	0.075	0.353	0.241	0.518
2004	0.089	0.203	0.140	0.294
2005	0.076	0.221	0.143	0.342
2006	0.098	0.237	0.175	0.321
2007	0.069	0.112	0.082	0.152
2008	0.152	0.344	0.254	0.467
2009	0.042	0.106	0.077	0.147
2010	0.081	0.173	0.120	0.248
2011	0.049	0.144	0.084	0.246
2012	0.047	0.092	0.061	0.141
2013	0.070	0.245	0.164	0.368
2014	0.066	0.200	0.132	0.305
2015	0.028	0.104	0.053	0.205
2016	0.057	0.109	0.071	0.167
2017	0.038	0.102	0.045	0.233

Table 3. Deviance table for black marlin CPUE in the North West Indian Ocean by Japanese longline fishery (1994-2017). Bold is the best model selected by BIC.

Models:	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
yr+offset(log(hooks/1000))	24	116782	117012	116734	-	-
yr+qtr+offset(log(hooks/1000))	27	115633	115892	115579	1155.3494	<0.0001
yr+qtr+gear+offset(log(hooks/1000))	28	115632	115900	115576	2.8495	0.0914
yr+qtr+gear+(1|area)+offset(log(hooks/1000))	29	112427	112705	112369	3207.3101	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000))	30	109714	110001	109654	2714.9985	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr	53	109417	109925	109311	342.374	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr+gear+(1|area)	**58**	**108810**	**109366**	**108694**	**617.2484**	**<0.0001**

*The selected model is similar as previous study (IOTC-2017-WPB15-31).
Previous model:
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000))
yr+qtr+gear.

Table 4. Standardized CPUE of Striped marlin caught by Japanese longline in the North West Indian Ocean (1994-2017). Standardized CPUE was calculated by the least square means.

Year	Nominal CPUE	Standardized CPUE	Lower	Upper
1994	0.812	0.987	0.764	1.277
1995	0.806	0.939	0.723	1.219
1996	0.561	0.843	0.651	1.092
1997	0.480	0.543	0.423	0.699
1998	0.318	0.395	0.306	0.510
1999	0.456	0.394	0.305	0.509
2000	0.617	0.512	0.395	0.663
2001	0.176	0.332	0.251	0.438
2002	0.200	0.362	0.275	0.477
2003	0.106	0.174	0.131	0.232
2004	0.130	0.202	0.153	0.267
2005	0.066	0.079	0.060	0.106
2006	0.098	0.105	0.080	0.137
2007	0.066	0.059	0.045	0.077
2008	0.200	0.205	0.157	0.269
2009	0.054	0.050	0.038	0.067
2010	0.288	0.313	0.228	0.430
2011*	-	-	-	-
2012	2.015	0.946	0.633	1.415
2013	1.523	1.050	0.706	1.563
2014	0.209	0.206	0.113	0.373
2015	0.104	0.145	0.082	0.257
2016	0.618	0.447	0.291	0.687
2017	0.287	0.191	0.123	0.296

*Because of the pirates, Japanese longliners did not operate North West area in 2011

Table 5. Deviance table for black marlin CPUE in the South East Indian Ocean by Japanese longline fishery (1994-2017). Bold is the best model selected by BIC.

Models:	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
yr+offset(log(hooks/1000))	25	42202	42446	42152	-	-
yr+qtr+offset(log(hooks/1000))	28	41473	41746	41417	735.07	<0.0001
yr+qtr+gear+offset(log(hooks/1000))	29	40965	41248	40907	509.83	<0.0001
yr+qtr+gear+(1|area)+offset(log(hooks/1000))	30	38142	38435	38082	2825.4	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000))	31	36618	36921	36556	1525.76	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr+gear	59	35845	36421	35727	829.14	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr+gear+(1|area)	**60**	**35418**	**36004**	**35298**	**428.82**	**<0.0001**

*Selected model is same as previous study (IOTC-2017-WPB15-31).

Table 6. Standardized CPUE of Striped marlin caught by Japanese longline in the South East Indian Ocean (1994-2017). Standardized CPUE was calculated by the least square means.

Year	Nominal CPUE	Standardized CPUE	Lower	Upper
1994	0.027	0.074	0.049	0.113
1995	0.031	0.079	0.054	0.116
1996	0.030	0.025	0.017	0.038
1997	0.029	0.025	0.016	0.039
1998	0.027	0.040	0.025	0.065
1999	0.040	0.055	0.036	0.084
2000	0.068	0.062	0.042	0.090
2001	0.066	0.074	0.051	0.107
2002	0.077	0.267	0.183	0.388
2003	0.027	0.056	0.036	0.088
2004	0.043	0.111	0.073	0.171
2005	0.054	0.157	0.104	0.238
2006	0.105	0.181	0.122	0.268
2007	0.027	0.113	0.064	0.198
2008	0.068	0.182	0.118	0.278
2009	0.075	0.087	0.057	0.135
2010	0.077	0.107	0.068	0.167
2011	0.161	0.107	0.067	0.171
2012	0.061	0.045	0.025	0.080
2013	0.021	0.063	0.033	0.121
2014	0.019	0.093	0.054	0.161
2015	0.018	0.042	0.024	0.074
2016	0.017	0.077	0.043	0.137
2017	0.042	0.024	0.013	0.042

Table 7. Deviance table for black marlin CPUE in the South West Indian Ocean by Japanese longline fishery (1994-2017). Bold is the best model selected by BIC.

Models:	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
yr+offset(log(hooks/1000))	25	119290	119541	119240	-	-
yr+qtr+offset(log(hooks/1000))	28	113908	114190	113852	5387.809	<0.0001
yr+qtr+gear+offset(log(hooks/1000))	29	113835	114127	113777	75.039	<0.0001
yr+qtr+gear+(1|area)+offset(log(hooks/1000))	30	109653	109955	109593	4184.259	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000))	31	106199	106511	106137	3456.073	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr	55	105717	106271	105607	529.346	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr+gear	59	104273	104867	104155	1452.329	<0.0001
yr+qtr+gear+(1|area)+(1|fleet)+offset(log(hooks/1000)) yr+qtr+gear+(1|area)	**60**	**103143**	**103746**	**103023**	**1132.474**	**<0.0001**

*Selected model is same as previous study (IOTC-2017-WPB15-31).

Table 8. Standardized CPUE of Striped marlin caught by Japanese longline in the South West Indian Ocean (1994-2017). Standardized CPUE was calculated by the least square means.

Year	Nominal CPUE	Standardized CPUE	Lower	Upper
1994	0.067	0.124	0.090	0.170
1995	0.122	0.186	0.137	0.254
1996	0.097	0.155	0.115	0.210
1997	0.080	0.110	0.081	0.148
1998	0.077	0.102	0.075	0.137
1999	0.141	0.135	0.100	0.182
2000	0.091	0.103	0.076	0.140
2001	0.064	0.074	0.054	0.101
2002	0.029	0.032	0.023	0.045
2003	0.016	0.020	0.014	0.030
2004	0.022	0.021	0.015	0.031
2005	0.013	0.012	0.008	0.017
2006	0.035	0.024	0.017	0.032
2007	0.024	0.017	0.012	0.024
2008	0.053	0.034	0.025	0.047
2009	0.069	0.058	0.042	0.081
2010	1.001	0.743	0.552	1.000
2011	1.236	0.970	0.720	1.307
2012	0.487	0.427	0.316	0.576
2013	0.346	0.275	0.203	0.372
2014	0.251	0.173	0.127	0.235
2015	0.111	0.066	0.048	0.091
2016	0.878	0.445	0.329	0.603
2017	0.435	0.282	0.207	0.383

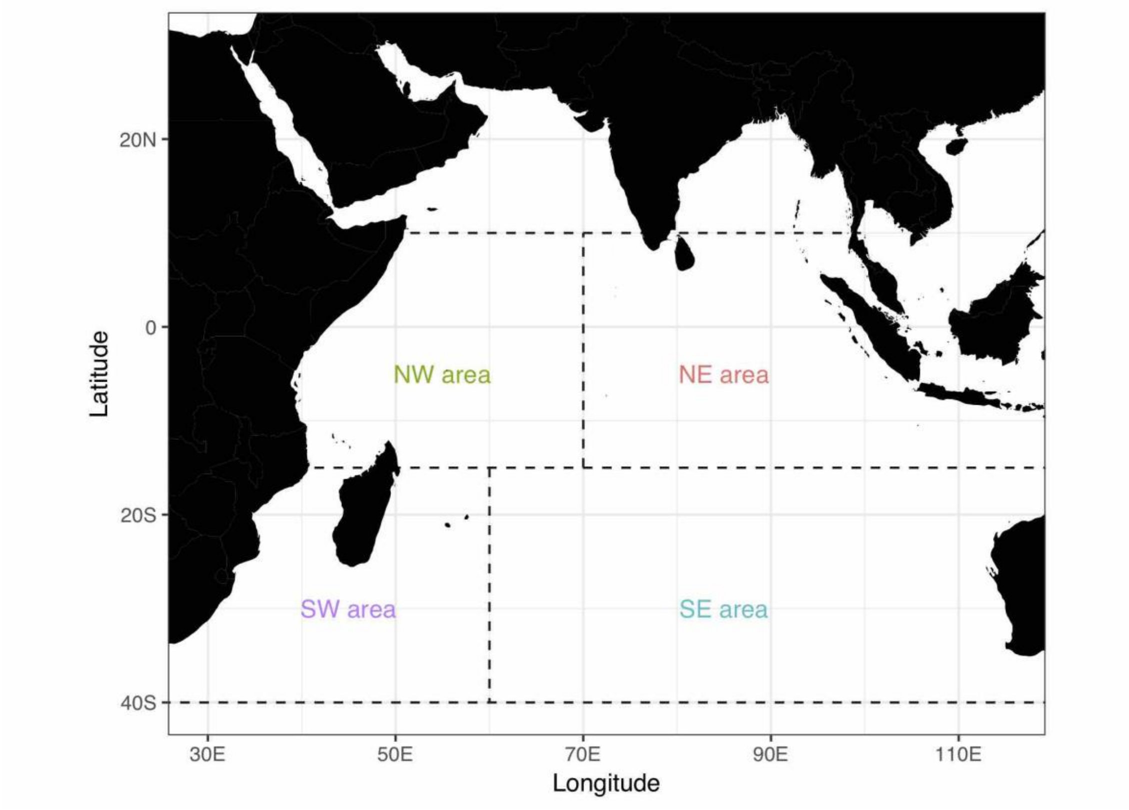

Figure 1. Analysis area for the striped marlin CPUE standardization given by Japanese longline fishery in the Indian Ocean.

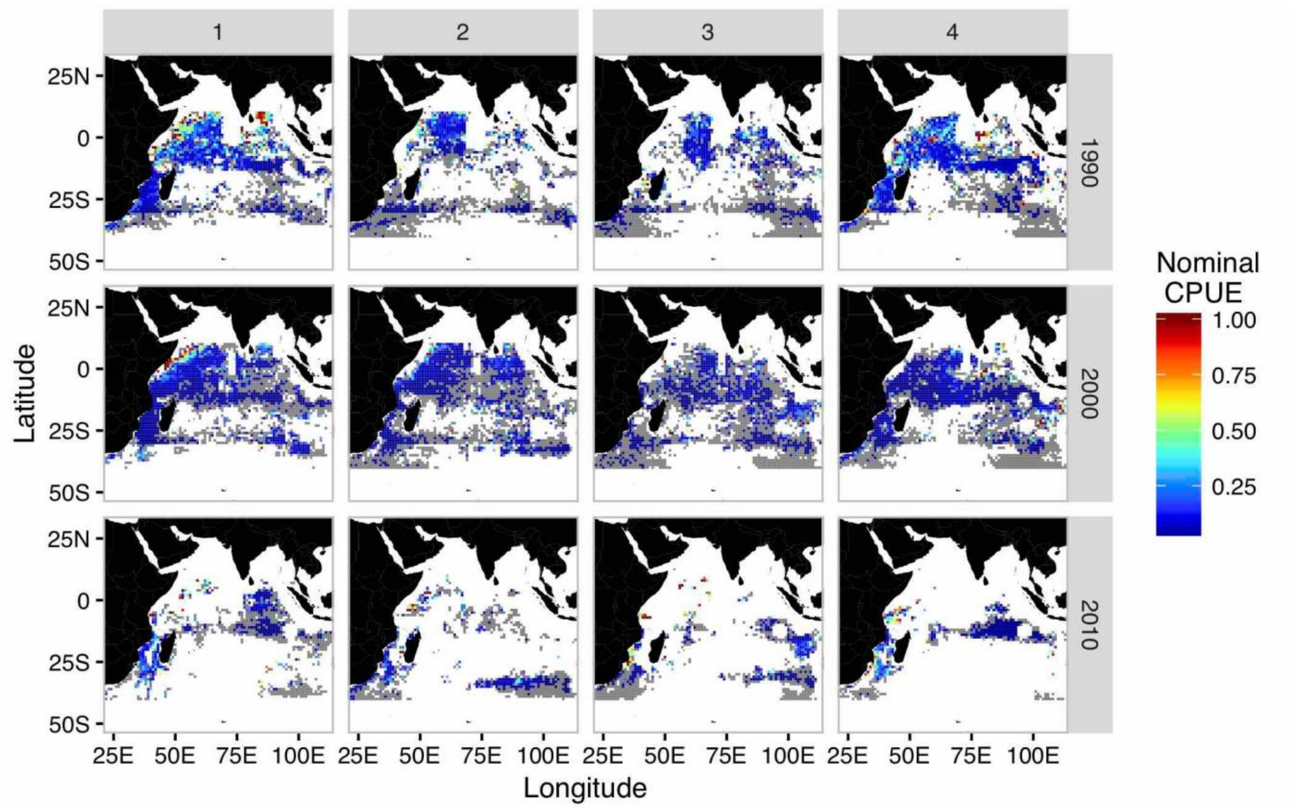

Figure 2. Time spatial change of the nominal striped marlin CPUE by Japanese longline in Indian Ocean.

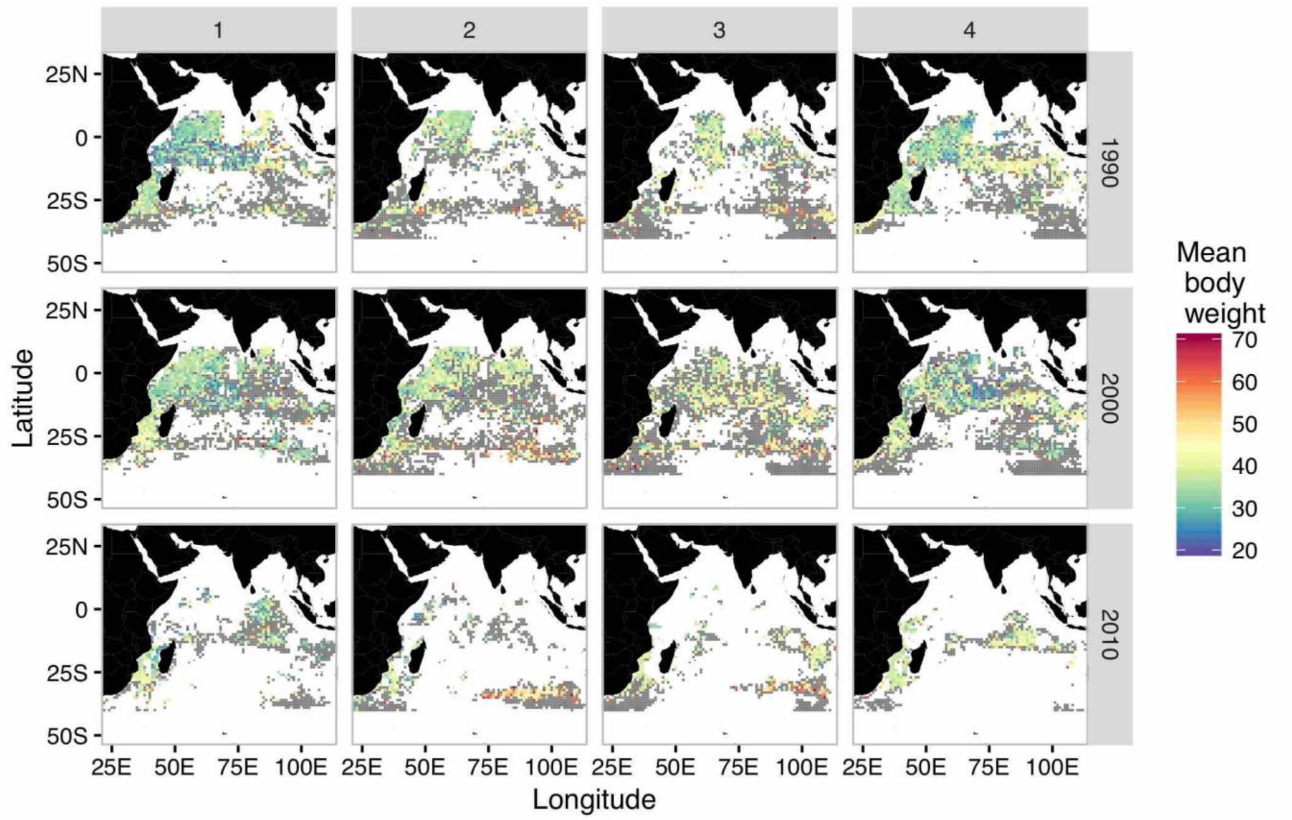

Figure 3. Time spatial change of the mean weight striped marlin caught by Japanese longline in Indian Ocean.

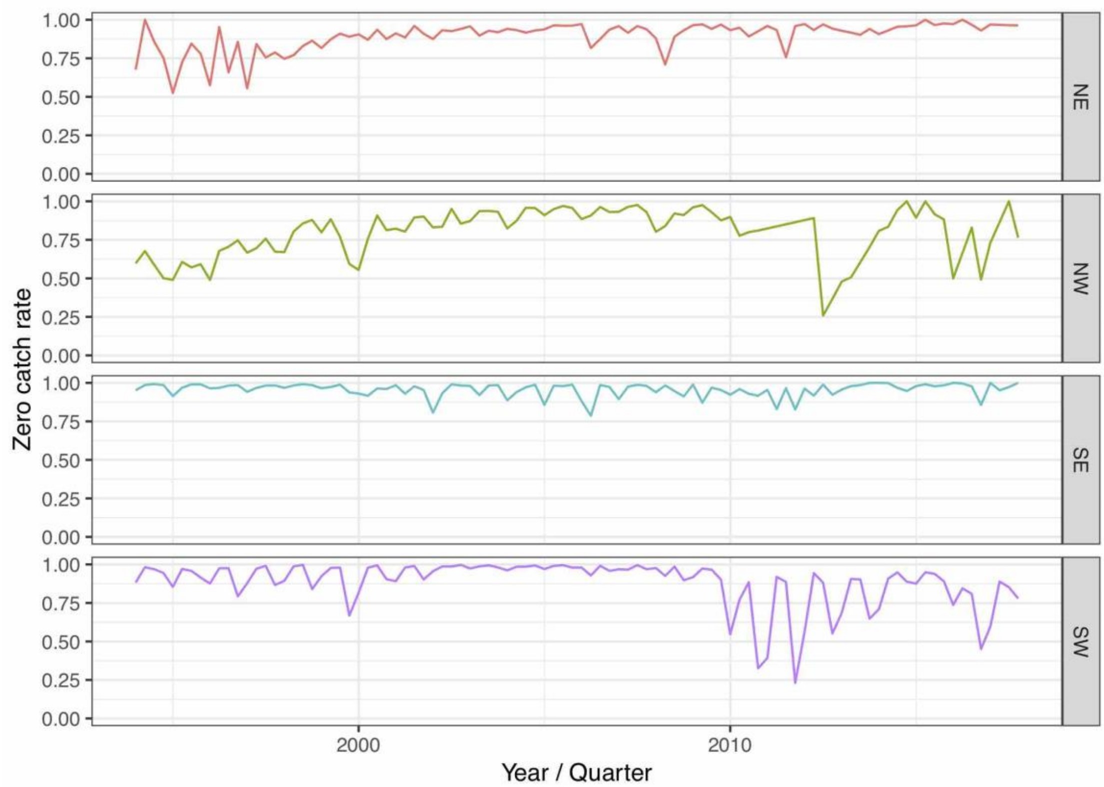

Figure 4. Zero catch rate of striped marlin caught by Japanese long line fishery.

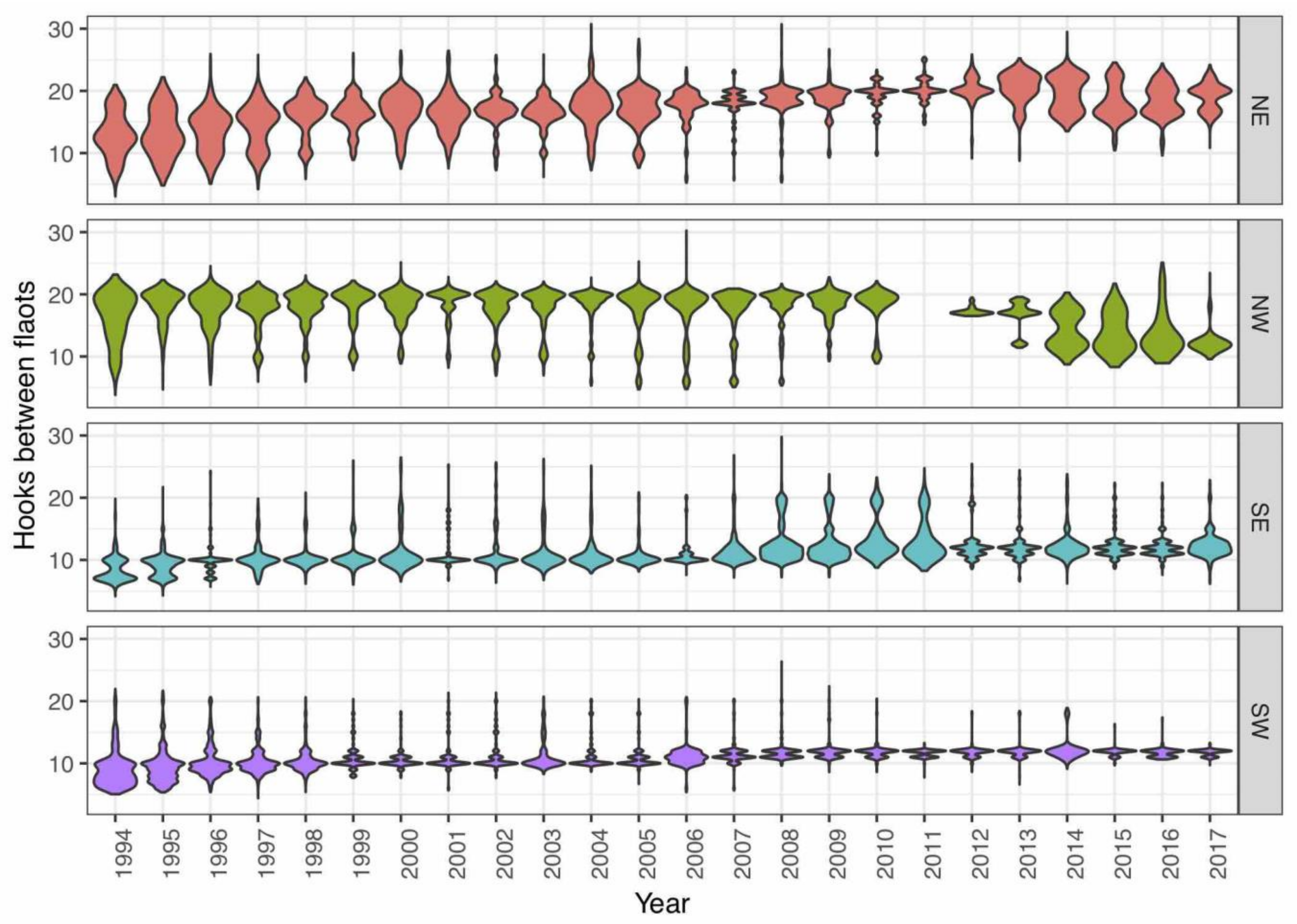

Figure 5. Historical change of the gear setting (hooks between floats) in Indian Ocean. Gear configuration is different between North and South Indian Ocean because Japanese longliners are targeting Southern Bluefin tuna in the South Indian Ocean.

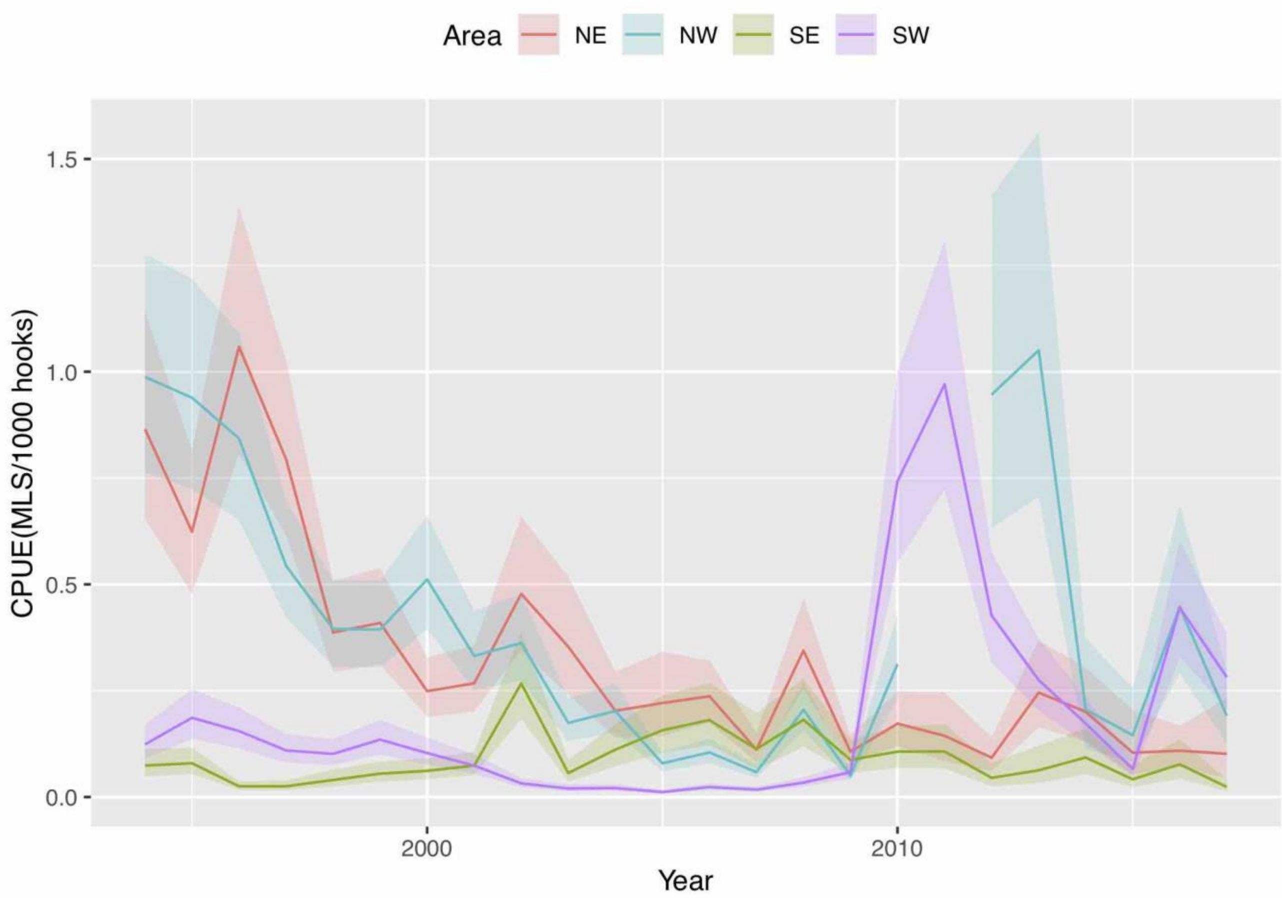

Figure 6. Standardized CPUE of the Indian Ocean striped marlin caught by Japanese longline fishery. The best models were selected by BIC and standardized CPUE was calculated by least squares mean. Filled areas denote 95% confidence interval of standardized CPUE.

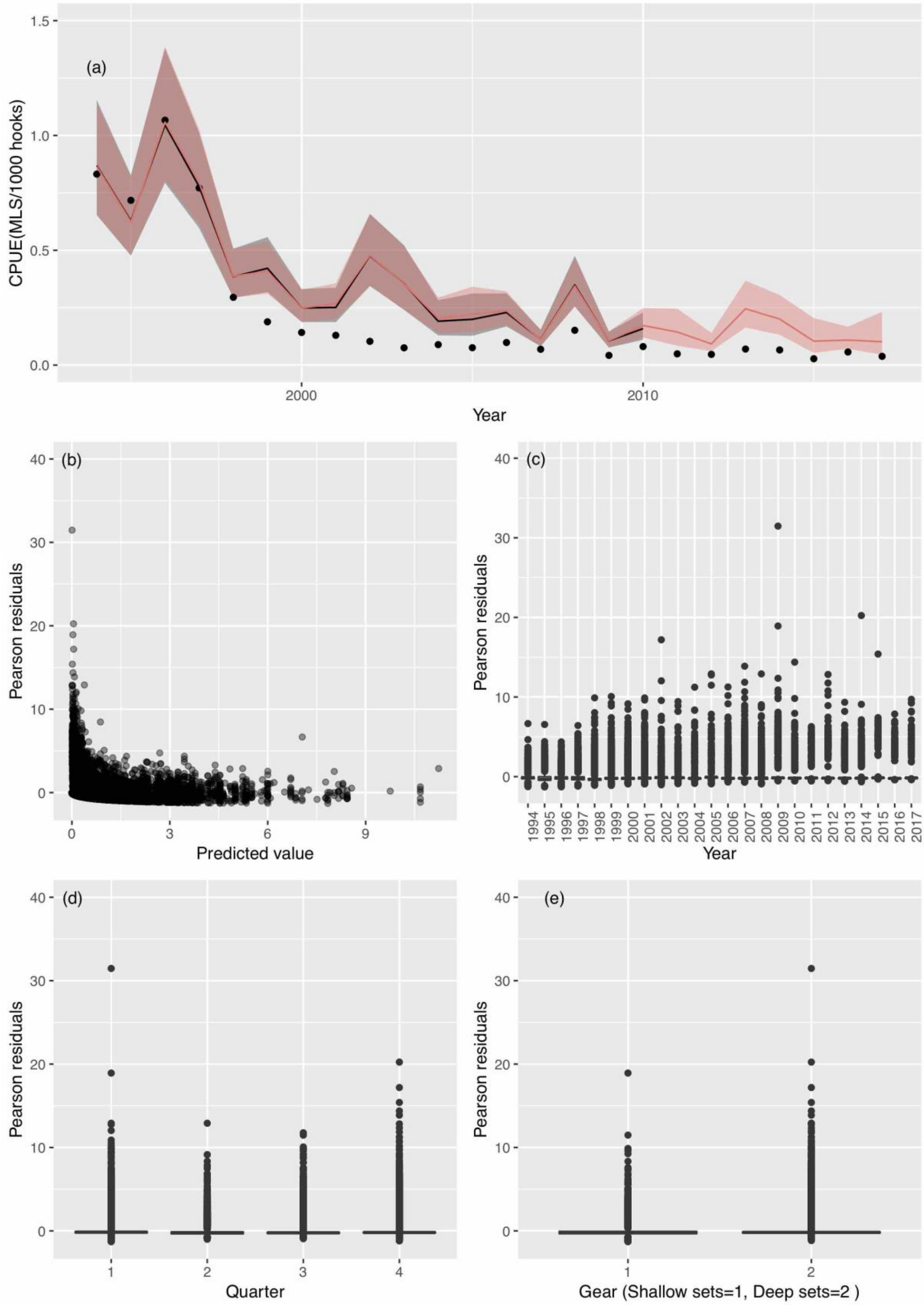

Figure 7. The result of CPUE standardization analysis of North East Indian Ocean striped marlin caught by Japanese longline fishery. (a) The historical changes of CPUE. Red lines is standardized CPUE, Points denote nominal CPUE and filled areas is 95% confidence interval. Black line and filled area show the result using different period data (1994-2010). (b)-(e) The trends of Pearson residuals for by variables.

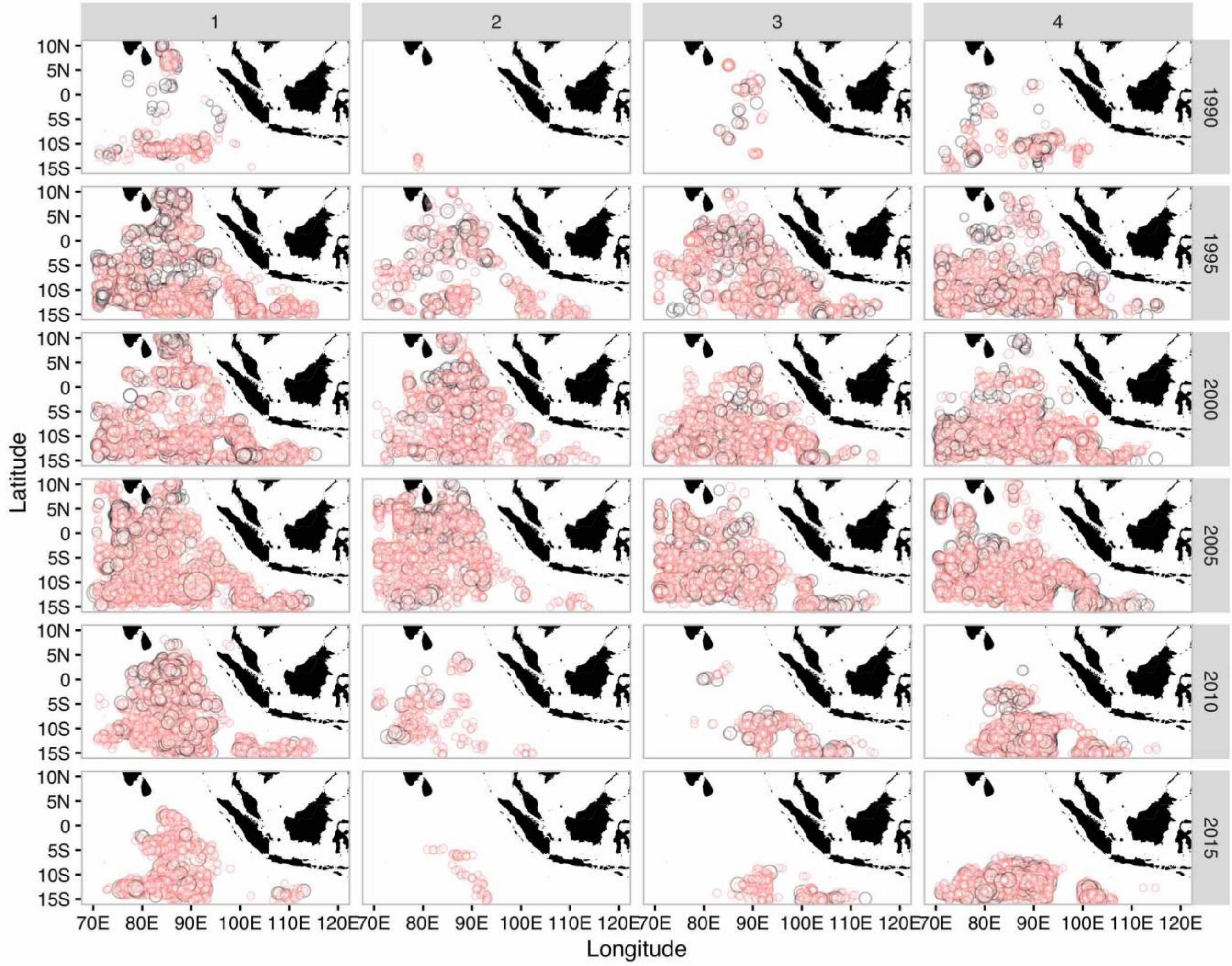

Figure 8. Time spatial change of Pearson residuals in the North East area. Red circles are positive residuals, and black circles are minus residuals. Size of circle means magnitude of Pearson residuals.

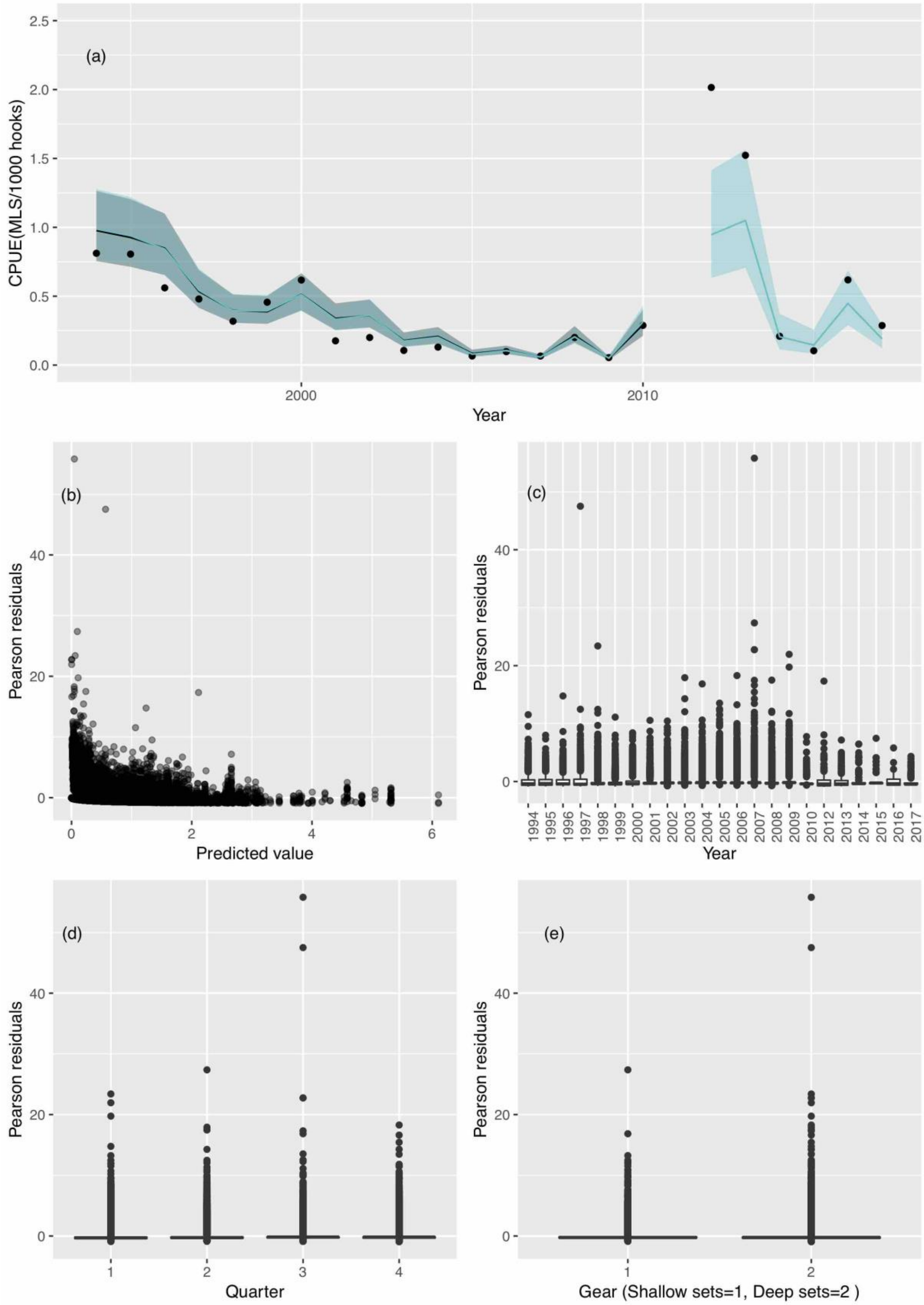

Figure 9. The result of CPUE standardization analysis of North West Indian Ocean striped marlin caught by Japanese longline fishery. (a) The historical changes of CPUE. Red lines is standardized CPUE, Points denote nominal CPUE and filled areas is 95% confidence interval. Black line and filled area show the result using different period data (1994-2010). (b)-(e) The trends of Pearson residuals for by variables.

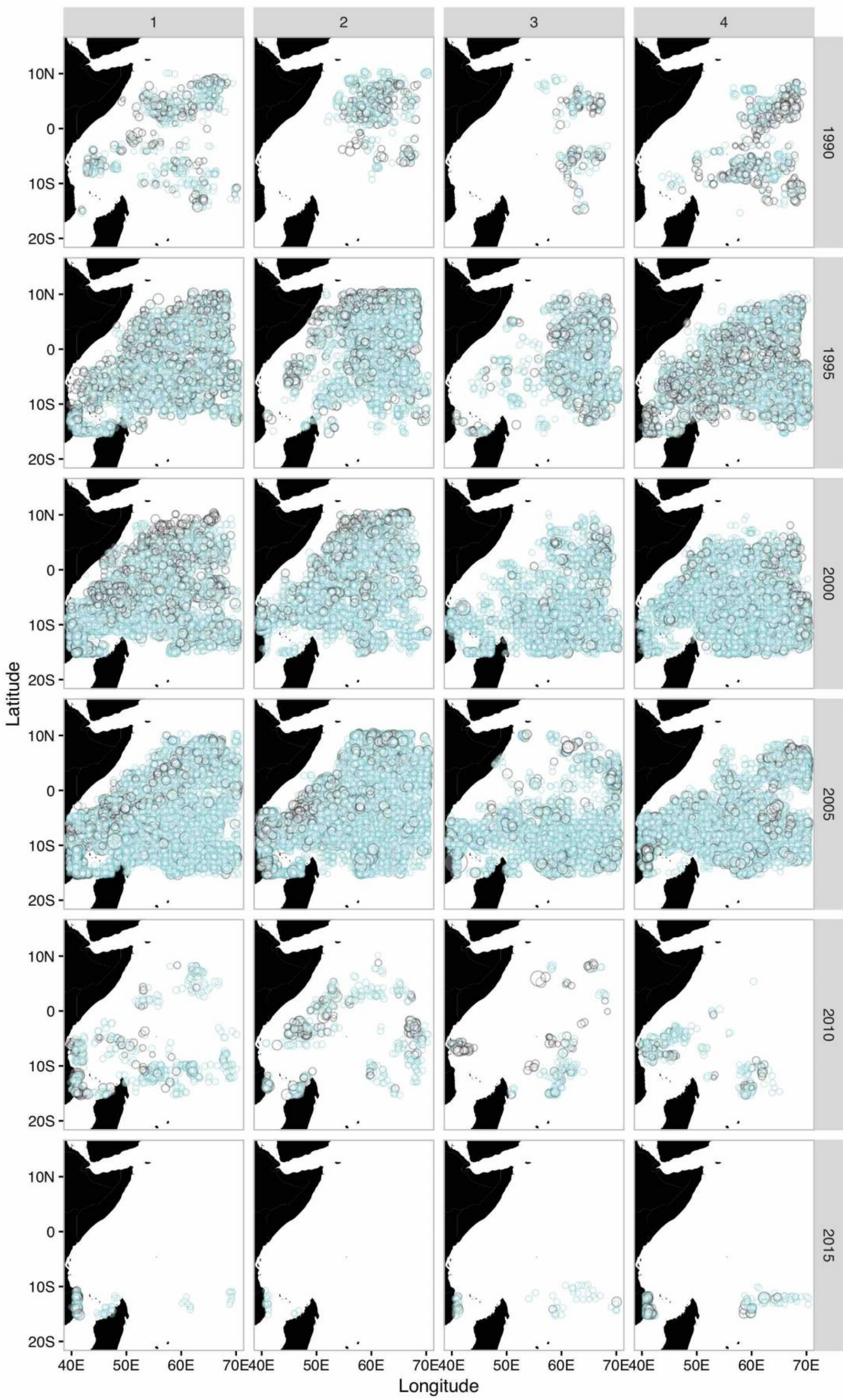

Figure 10. Time spatial change of Pearson residuals in the North West area. Red circles are positive residuals, and black circles are minus residuals. Size of circle means magnitude of Pearson residuals.

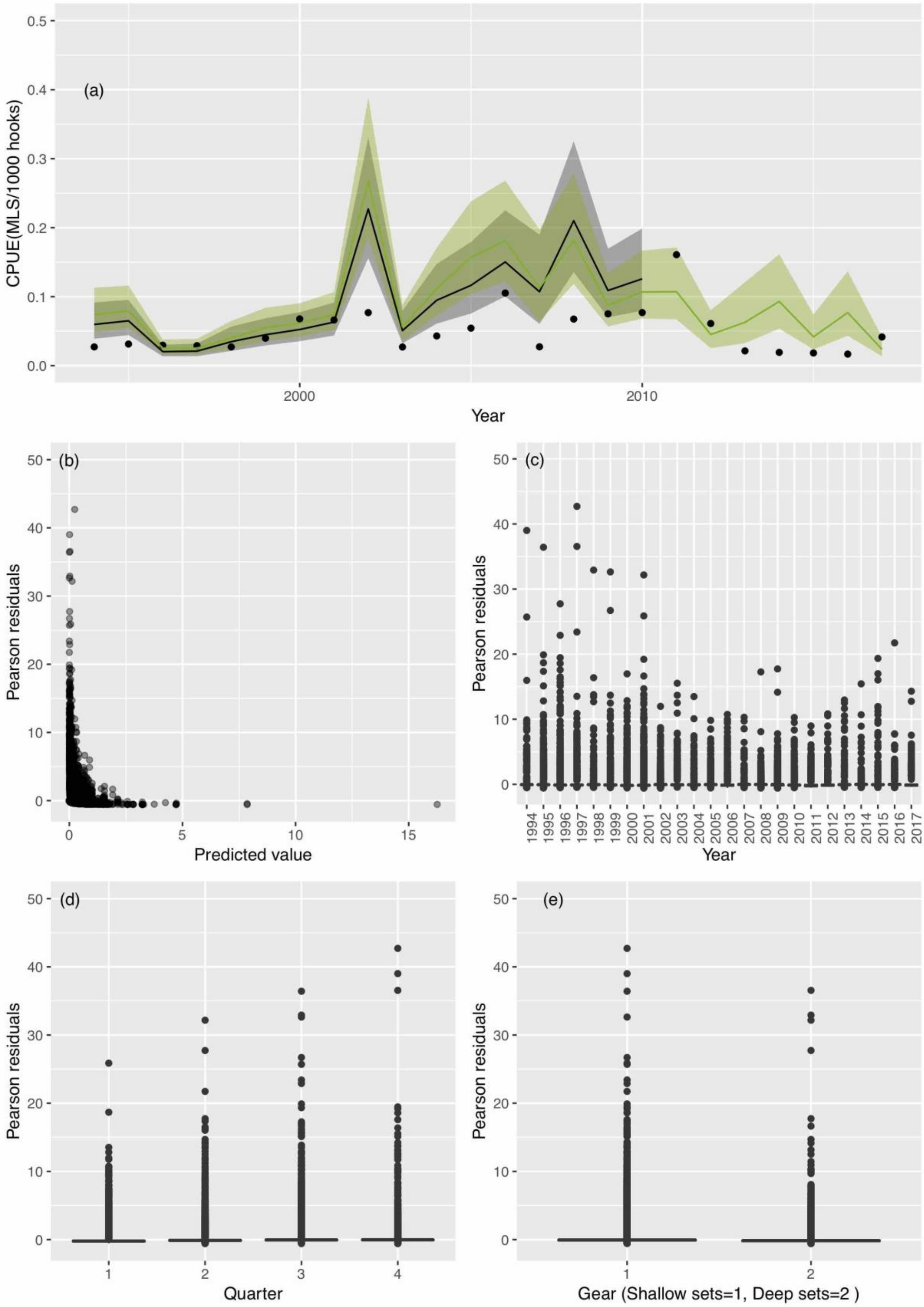

Figure 11. The result of CPUE standardization analysis of South East Indian Ocean striped marlin caught by Japanese longline fishery. (a) The historical changes of CPUE. Red lines is standardized CPUE, Points denote nominal CPUE and filled areas is 95% confidence interval. Black line and filled area show the result using different period data (1994-2010). (b)-(e) The trends of Pearson residuals for by variables.

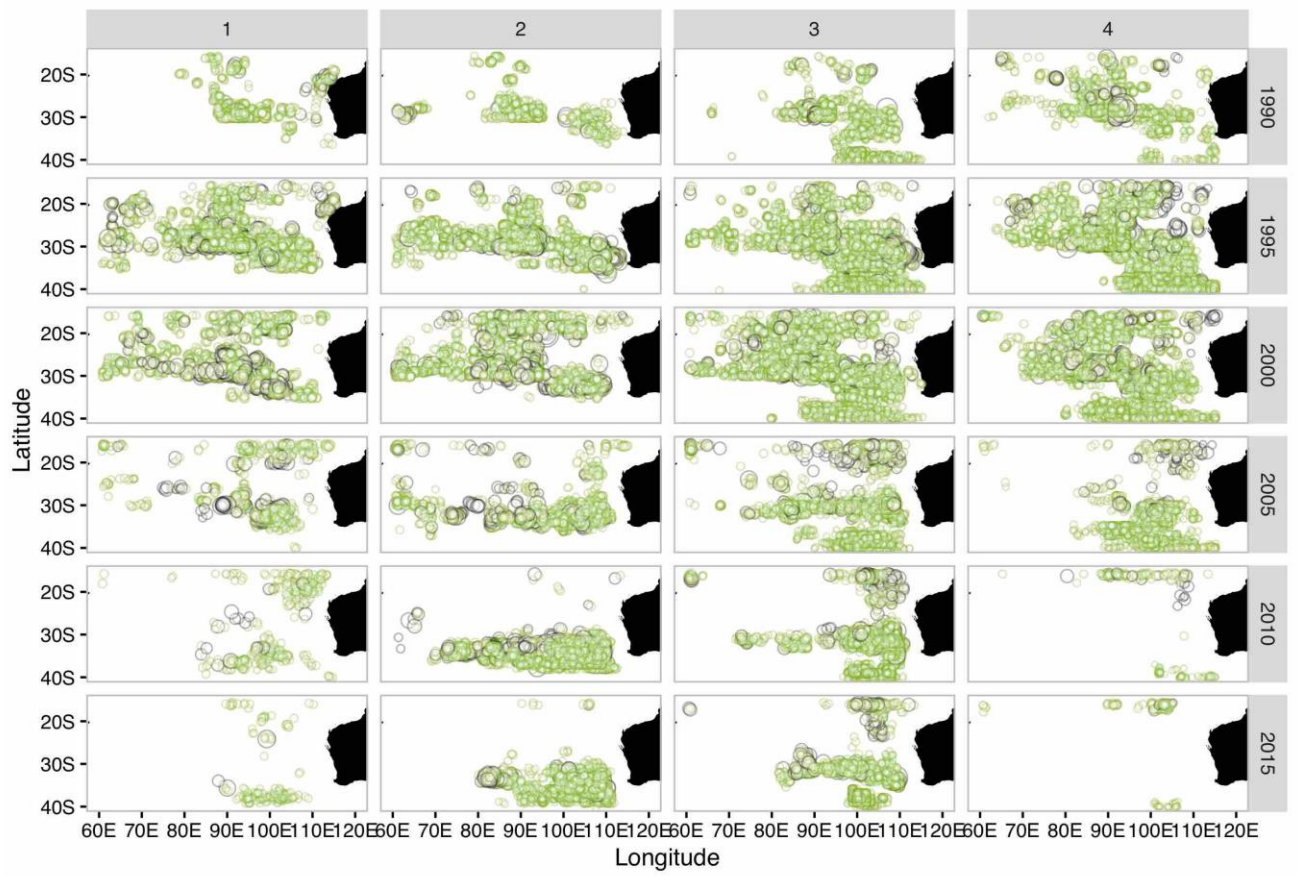

Figure 12. Time spatial change of Pearson residuals in the South East area. Red circles are positive residuals, and black circles are minus residuals. Size of circle means magnitude of Pearson residuals.

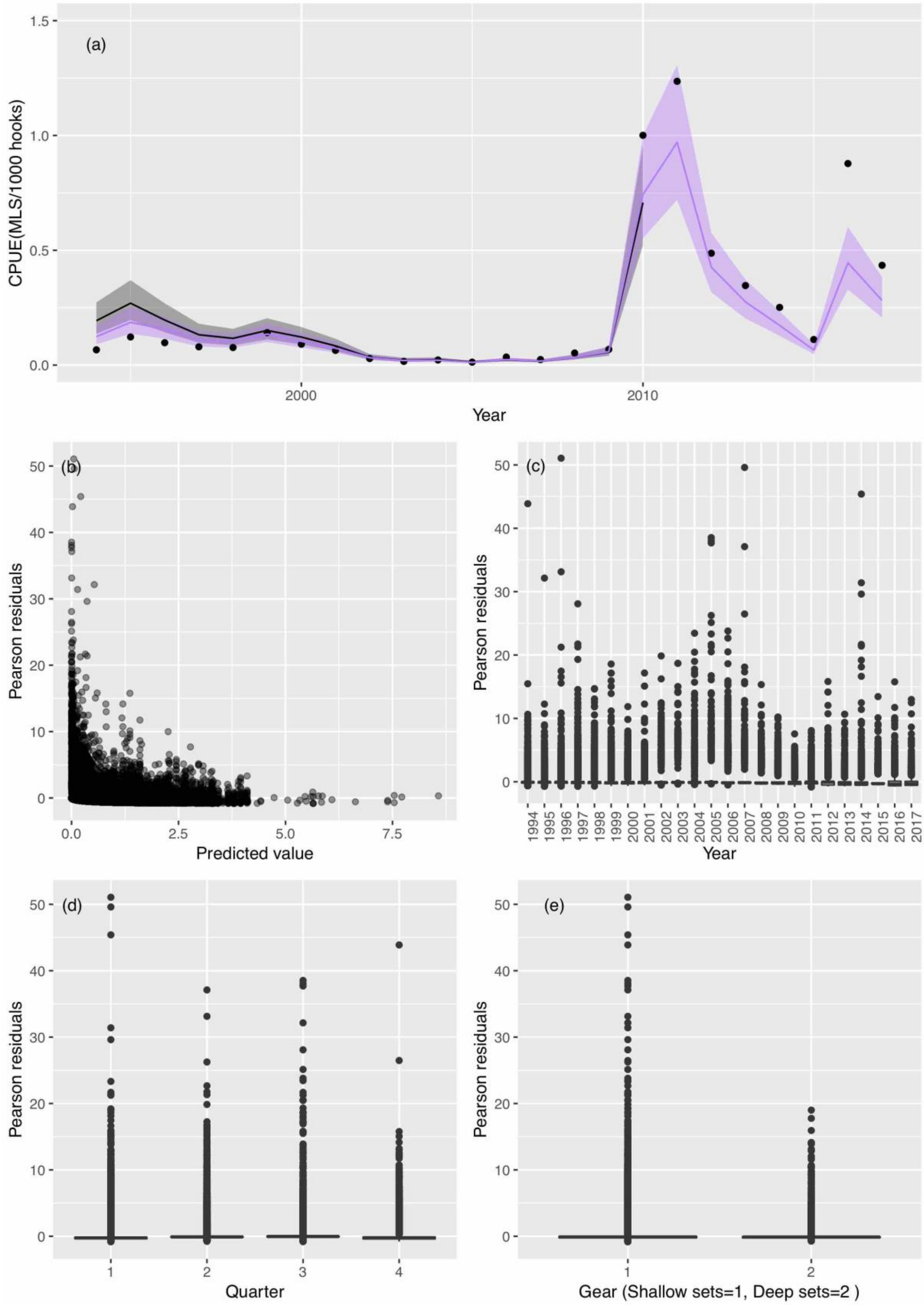

Figure 13. The result of CPUE standardization analysis of South West Indian Ocean striped marlin caught by Japanese longline fishery. (a) The historical changes of CPUE. Red lines is standardized CPUE, Points denote nominal CPUE and filled areas is 95% confidence interval. Black line and filled area show the result using different period data (1994-2010). (b)-(e) The trends of Pearson residuals for by variables.

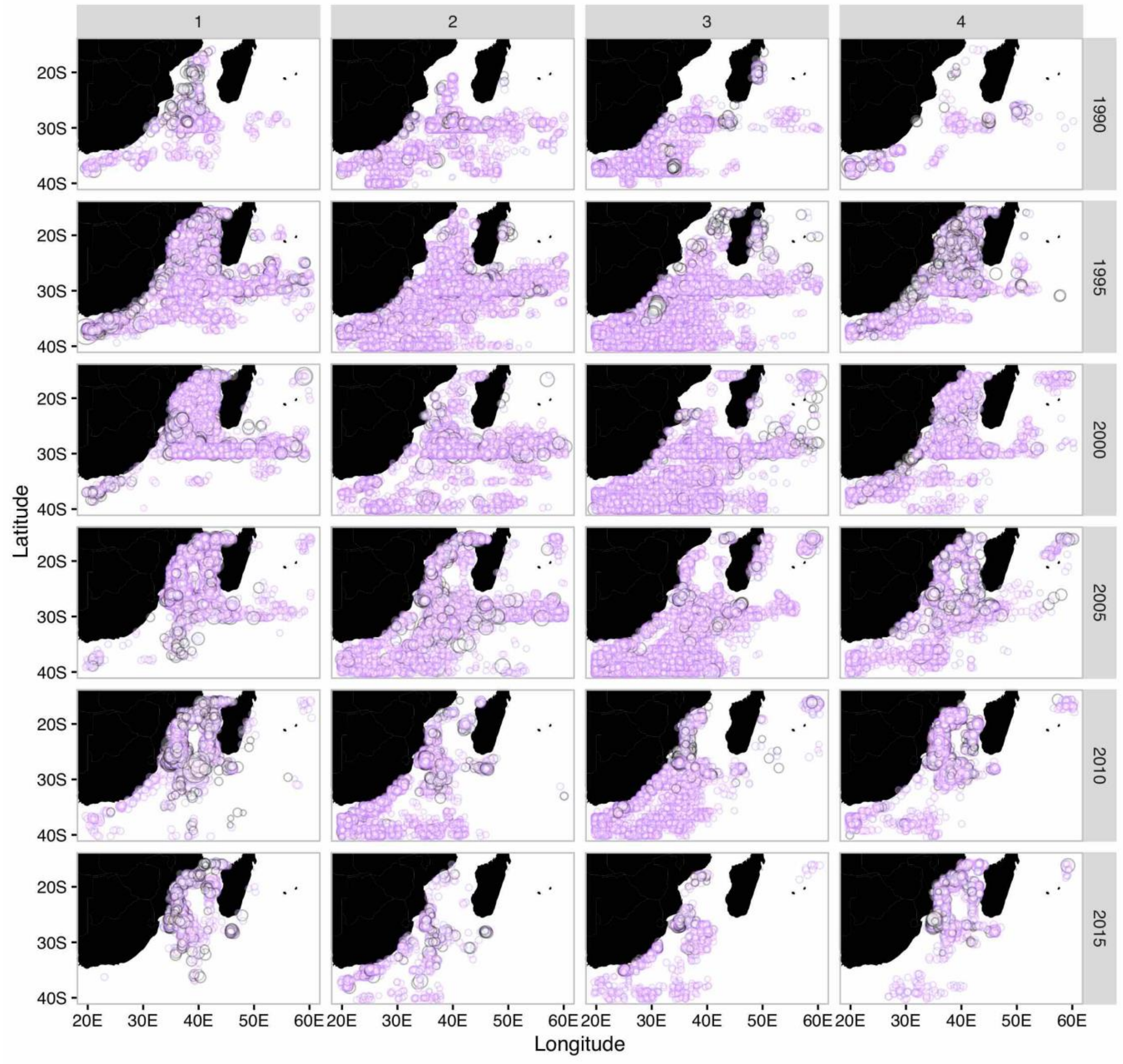

Figure 14. Time spatial change of Pearson residuals in the South West area. Red circles are positive residuals, and black circles are minus residuals. Size of circle means magnitude of Pearson residuals.