CPUE standardization of the Indian Ocean striped marlin (*Tetrapturus audax*) by Japanese longline fisheries: Using negative binomial GLMM and zero inflated negative binomial GLMM to consider vessel effect.

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Highlights

1. Using R software package glmmTMB, I applied the negative binomial GLM, the negative binomial GLMM (NB-GLMM) and the zero-inflated negative binomial GLMM for the CPUE standardization of the Indian Ocean striped marlin. I used the random effects for the vessel name and the 5 x 5 grid area.

2. I set two time-series 1976-1993 and 1994-2015. Because 1) the Japanese logbook format modified in 1994, 2) The shallow sets changed to the deep sets during the mid of the 1990s, 3) Number of operated vessels were decreased until mid of the 1990s then these vessels came back to the Indian Ocean.

3. Japanese logbook is a big data thus I used BIC for the model selection. Using the selected model and R software package lsmeans, I calculated standardized CPUE for each area.

4. I used the Pearson residuals for the model validation. The selected models of North East and North West area showed approximately good fitting. However, the Pearson residuals on zero catch estimation showed large values in South East and South West area and that zero catch rate was near 100%. These results indicated that the standardized CPUE might not be well estimated in South East and South West area.

5. The CPUE for the whole Indian Ocean might be misunderstood to realize trends of adult biomass, because length frequency varies by areas. Thus, it is better to use CPUE of North West area where the data is substantial to the production models such as ASPIC and BSPM.

6. Since 2010, the number of operating vessels drastically decreases, and area coverage also reduces, hence the standardized CPUE after 2010 might be unreliable. Also, there is a possibility that data after 2010 will have an impact on past estimates quality. Therefore, it is necessary to standardize before 2010 or to use geostatistical models to fill time-spatial defects. In this analysis, I did not use the interaction to avoid overfitting for the GLMMs. In actual, there may be a correlation between year and area. Such relationship can also be handled with the geostatistical models.

Abstract

The IOTC has conducted the stock assessment of striped marlin by dividing the Indian Ocean into four areas. For the benchmark stock assessment in 2017, I standardized the Japanese longline CPUE of striped marlin for each of these regions. In this analysis, I applied the negative binomial GLM, the negative binomial GLMM, and the zero-inflated negative binomial GLMM to properly handle information that was included by vessel names such as differences in targeting and equipment, and zero inflated catch data. I used the BIC for the model selection, and the R software package lsmeans to calculate the standardized CPUE.

Introduction

The Indian Ocean Tuna Commission (IOTC) has conducted the stock assessment for using production models such as ASPIC and BSPM (IOTC 2014). Ijima et al., (2015) calculated the standardized CPUE caught by Japanese longline fishery for this stock assessment. They addressed simple GLM analysis that was assumed the lognormal distribution for the residuals (Ijima et al., 2015). However, they did not consider critical information such as targeting, vessel equipment and operational technique of crew. This information has a significant influence on the catchability which is the essential issue to standardize CPUE caught by Japanese longline fishery. It is thought that this information is including in the "vessel name" of the Japanese logbook data. It is better to use random effect rather than the fixed effect to consider the vessel effect because a lot of Japanese vessels operated in the Indian Ocean. In detail, if over hundred covariates are used for GLM analysis, the standardized CPUE tend to be over fit to nominal CPUE. Striped Marilyn is the bycatch species for Japanese longliners in the Indian Ocean, and the number of catch in one operation tends to be zero. To treat zero-catch in count data is also a major problem for standardization of bycatch species. Improving these problems, I used the GLM with a negative binomial distribution (NB-GLM), the GLMM with a negative binomial distribution (NB-GLMM), and the GLMM with a zero-inflated negative binomial distribution (ZINB-GLMM) in the standardization of the CPUE of Indian Ocean striped marlin.

Material and Method

Data sets

I used a Japanese longline logbook data to standardize the CPUE of the Indian Ocean striped marlin. Japanese logbook data has been reported the detail of operation the longline fishery. The number of vessels operated in the Indian Ocean has been historically changed (Figure 2). The number of operating vessels increased to the middle 1980s and then declined over the next the 1990s (Figure 2). From the mid of the 1990s to the 2000s, the number of operated vessels increased again (Figure 2). However, the number of vessels dropped sharply in the 2010s (Figure 2). It is thought that in this historical change was occurred by the vessel moving to another Oceans. In the 1970s, Japanese tuna longliners operated near the equator, and the southern bluefin tuna fishery operated near the 50 degrees south (Figure 3). After that, the fishing ground of Japanese longline spread throughout the Indian Ocean from the 1990s to the 2000s (Figure 3). Since 2010, the fishing ground has shrunk rapidly (Figure 3). The high CPUE in the wide area throughout is North West area (Figure 4). However, due to the influence of pirates, there is no operation in 2011.

Area definition

I calculated CPUE for the four IOTC areas (Figure 1). It is relatively reasonable because the operational style greatly differs between North area and South area due to targeting species (Figure 5) and historical trend of zero catch rate varies by area (Figure 6). Although there is no clear difference of length frequency data by area (Figure 7), it is thought that standardized CPUE by area could be fit to the area based fishery defined by SS3. NW area is the most appropriate for CPUE standardization to fit the production models such as ASPIC and BSPM, because the data is substantial and that CPUE is relatively higher than another area.

Time periods

The analysis period was set between 1976 and 2015 because the vessel names for each operation was compiled accurately since 1976. I also set two time periods as 1976-1993 and 1994-2015. The reasons are as follows:

1) The data quality might be different because of the logbook format change.
2) The gear configuration of Japanese longline fishery drastically changed in the middle of the 1990s (Figure 5). In detail, hooks between floats (HBF) changed from shallow to deep sets operation (Figure 5).
3) The operated vessels were decreased in the middle of the 1990s (Figure 2).

Considering these facts, I divided data sets into two time periods.

Statistical models

I used NB-GLM, NB-GLMM, and ZINB-GLMM for the CPUE standardization. The random effect is appropriate to consider the vessel name and 5x5 area effect because there are a lot of variables. The zero-inflated model estimates "true" zero catch. To consider these technical needs, I used R software package glmmTMB which can estimate parameters of complex model using the Template Model Builder (Brooks et al., 2017). Japanese logbook data is a big data. I used Bayesian information criterion (BIC) to consider the effect of the number of the data sets for the model selection. I also used the R software package lsmeans to calculate the standardized striped marlin CPUE (Lenth 2016). Lsmeans needs additional R script from the GitHub (https://github.com/glmmTMB) to apply glmmTMB.
The simple negative binomial GLM can be described as follows,

$$Catch_i \sim NB(\mu_i, k),$$

$$E(Catch_i) = \mu_i,\ \mathrm{var}(Catch_i) = \mu_i(1 + \mu_i/k) \text{ and}$$

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

Where $catch_i$ is the catch number of the operation i. μ_i is expected catch number of the operation i. k is the dispersion parameter. The link function was used for log 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.

In the NB-GLMM, I used random intercept model for vessel names. Alternatively, I applied 5x5 grid area effect as random part. The detail of the NB-GLMM is

$$Catch_i \sim NB(\mu_i, k),$$

$$E(Catch_i) = \mu_i,\ \mathrm{var}(Catch_i) = \mu_i(1 + \mu_i/k) \text{ and}$$

$$\log(\mu_i) = \beta_0 + \mathbf{X}_i\boldsymbol{\beta} - \log(hooks_i) + v_i,\ v_i \sim N(0, \sigma^2_{vessel}) \text{ or}$$

$$\log(\mu_i) = \beta_0 + \mathbf{X}_i\boldsymbol{\beta} - \log(hooks_i) + v_i + a_i,\ v_i \sim N(0, \sigma^2_{vessel})\ a_i \sim N(0, \sigma^2_{area}).$$

Where v_i is the random effect of vessels, and that variance is σ^2_{vessel}, a_i is the random effect for 5x5 area and that variance is σ^2_{area}.

Finally, I applied ZINB-GLMM to handle the zero-catch data and vessel effect

$$Catch_i \sim NB(\pi_i, \mu_i, k),$$
$$E(Catch_i) = \mu_i(1 - \pi_i),$$
$$\mathrm{var}(Catch_i) = (1 - \pi_i)\mu_i(1 + \pi_i\mu_i + \mu_i/k),$$
$$\log(\mu_i) = \beta_0 + \mathbf{X}_i\boldsymbol{\beta} - \log(hooks_i) + v_i + a_i,$$
$$\mathrm{logit}(\pi_i) = \gamma_0 + \mathbf{Z}_i\boldsymbol{\gamma} + v*_i,$$
$$v_i \sim N(0, \sigma^2_{vessel}),\ a_i \sim N(0, \sigma^2_{area}) \text{ and } v*_i \sim N(0, \sigma^2_{*vessel}).$$

Where π_i is the probability of zero catch of the operation *i*. π_i is estimated by logit link function that variable matrix is $\mathbf{Z}_i$ and the covariate vector is $\boldsymbol{\gamma}$ respectively. We applied the random effect for vessel name and 5x5 area. However, ZINB-GLMM did not convergence when the random effect of 5x5 area was used for the zero-part regression.

For all models, I used the fixed effect variables that are the year, the quarter, the 5×5 area, and the two type gear sets (Sallow sets: HBF<15, Deep sets: HBF>=15). All variables were applied the categorical variables. In the model selection, I used the BIC rather than AIC. It needs to consider the data size effect for the model selection because Japanese logbook data is a big data. I also calculated the Pearson residual of the selected models for the model validation. I did not use the interaction for all models to avoid overfitting. However, there might be a correlation between year and area. To consider this phenomenon, I addressed the random slope GLMM to treat annual interactions for the vessels. However, this model did not converge.

Result and Discussion

In the early period, large CPUE decline was occurred between 1976 and 1981 in NE, NW, and SW area especially for NW area (Figure. 8). CPUE of NW and NE area shows similar trend in the later period (Figure. 8). Because of pirate effect, there are no longline operation at NW area in 2011 (Figure. 8). In the later period, CPUE of SE and SW area fluctuated near zero values (Figure. 8).

North East area (Early period:1976-1993)

The selected model was NB-GLMM that variables for random effect are the vessel name and the 5x5 area and that fixed effect variables are the year, the quarter and the gear (Table. 5).

The trend of standardized CPUE was smaller than the nominal CPUE after 1985 (Table 1, Figure. 9(a)). The Pearson residuals against zero predicted values were large (Figure. 9(b)). The Pearson residuals were almost uniformly distributed by the year, the quarter and the gear covariate (Figure. 9 (c)-(e)). From the tendency of these Pearson residuals, the selected model was not the good fit for zero catches however, this model is approximately well estimated.

North East area (Late period:1994-2015)

The selected model was ZINB-GLMM that the random effect of the count part were the vessel name and the 5x5 area, and that fixed effects were the year, the quarter and the gear. The covariate of zero parts was selected same as the count part model (Table. 6).

After 1998, the transition of standardized CPUE was higher than the nominal CPUE (Figure. 10 (a)). The Pearson residuals showed high values for near the zero-estimated catch (Figure. 10 (b)). There was no typical tendency in the Pearson residuals for each variable (Figure. 10 (c)-(e)). Therefore, it seems that this model was approximately well estimated.

North West area (Early period:1976-1993)

The selected model was ZINB-GLMM that the random effect of the count part were the vessel name and the 5x5 area, and that fixed effects were the year, the quarter and the gear. The covariate of zero parts was the year and that random effect is the 5x5 area (Table. 7).

Before 1980, the standardized CPUE was lower than the nominal CPUE (Figure. 11 (a)). The Pearson residuals were randomly plotted against the estimated catches (Figure. 11 (b)). There was no typical tendency in the Pearson residuals for each variable (Figure. 10 (c)-(e)). Therefore, it seems that this model is well estimated.

North West area (Late period:1994-2015)

The selected model was ZINB-GLMM that the random effect of the count part were the vessel name and the 5x5 area, and that fixed effects were the year, the quarter and the gear. The covariate of zero parts is the year, the quarter and the gear (Table. 8).

The standardized CPUE showed the similar trend as the nominal CPUE (Figure. 12 (a)). The Pearson residuals showed against the zero estimated catches (Figure. 12 (b)). There was no typical tendency in the Pearson residuals for each variable (Figure. 12 (c)-(e)). Therefore, it seems that this model is approximately well estimated.

South East area (Early period:1976-1993)

The selected model was ZINB-GLMM that the random effect of the count part were the vessel name and the 5x5 area, and that fixed effects were the year, the quarter and the gear. The covariate of zero parts were the year and the quarter and that random effect was the area (Table. 9).

The standardized CPUE showed the flat and gradually low trajectory (Figure. 13 (a)). The Pearson residuals showed the high value against the zero estimated catches (Figure. 13 (b)). There was no typical tendency in the Pearson residuals for the year and quarter variable (Figure. 13 (c)-(d)). However, Pearson residuals of the shallow sets was larger than the deep sets (Figure. 13 (e)). This model seems not to be well estimated.

South East area (Late period:1994-2015)

The selected model was ZINB-GLMM that the random effect of the count part were the vessel name and the 5x5 area, and that fixed effects were the year, the quarter and the gear. The covariate of zero parts were the year, the quarter, and the gear and that random effect is the 5x5 area (Table. 10).

The standardized CPUE showed the flat trajectory near the zero CPUE (Figure. 14 (a)). The Pearson residuals showed the high value against the zero estimated catches (Figure. 14 (b)). There was no typical tendency in the Pearson residuals (Figure. 14 (c)-(e)). Consider almost catch of sets are zero (Figure. 6), this model seems not to be well estimated.

South West area (Early period:1976-1993)

The selected model was ZINB-GLMM that the random effect of the count part were the vessel name and the 5x5 area, and that fixed effects were the year, the quarter and the gear. The covariate of zero parts were the year and the quarter and that random effect was the 5x5 area (Table. 11).

The standardized CPUE was larger than the nominal CPUE (Figure. 15 (a)). The Pearson residuals showed the high value against the zero estimated catches (Figure. 15 (b)). There was typical tendency in the Pearson residuals (e.g., Quarter 3 and Shallow sets) (Figure. 15 (c)-(e)). Considering almost catch of sets are zero (Figure. 6), this model seems not to be well estimated.

South West area (Late period:1994-2015)

The selected model was ZINB-GLMM that the random effect of the count part were the vessel name and the 5x5 area, and that fixed effects were the year, the quarter and the gear. The covariate of zero parts were the year and the quarter and that random effect was the 5x5 area (Table. 12).

The standardized CPUE showed the similar trends as the nominal CPUE (Figure. 16 (a)). The Pearson residuals showed the high value against the zero estimated catches (Figure. 16 (b)). There was no typical tendency in the Pearson residuals (Figure. 16 (c)-(e)). Considering almost catch of sets were zero (Figure. 6) and the trends of Pearson residuals, this model seems not to be well estimated.

References

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Table 1. Standardized striped marlin CPUE for the North East Indian Ocean calculated by Japanese longline fishery (1976-1993 and 1994-2015).

Year	Nominal CPUE	Standardized CPUE	lower	upper
1976	1.06	0.86	0.61	1.20
1977	2.60	2.99	2.15	4.16
1978	1.59	2.29	1.65	3.17
1979	1.54	1.72	1.24	2.38
1980	3.43	1.97	1.43	2.71
1981	4.74	1.89	1.38	2.60
1982	1.18	1.43	1.04	1.97
1983	0.80	0.87	0.63	1.19
1984	0.84	0.96	0.70	1.32
1985	1.31	0.98	0.72	1.34
1986	1.39	1.05	0.77	1.44
1987	1.14	0.65	0.47	0.89
1988	0.59	0.34	0.25	0.46
1989	0.55	0.23	0.17	0.32
1990	0.34	0.15	0.11	0.21
1991	0.47	0.22	0.16	0.30
1992	1.41	0.58	0.42	0.80
1993	0.47	0.29	0.21	0.41
1994	0.83	0.87	0.66	1.15
1995	0.72	0.63	0.48	0.82
1996	1.07	1.07	0.81	1.40
1997	0.77	0.80	0.62	1.03
1998	0.30	0.39	0.30	0.51
1999	0.19	0.42	0.32	0.55
2000	0.14	0.25	0.19	0.33
2001	0.13	0.26	0.20	0.35
2002	0.10	0.48	0.35	0.66
2003	0.08	0.36	0.25	0.53
2004	0.09	0.21	0.14	0.31
2005	0.08	0.22	0.14	0.35
2006	0.10	0.24	0.17	0.32
2007	0.07	0.11	0.08	0.15
2008	0.15	0.34	0.25	0.47
2009	0.04	0.11	0.08	0.15
2010	0.08	0.17	0.12	0.25
2011	0.05	0.14	0.08	0.24
2012	0.05	0.09	0.06	0.14
2013	0.07	0.24	0.16	0.36
2014	0.07	0.19	0.13	0.30
2015	0.03	0.09	0.05	0.16

Table 2. Standardized striped marlin CPUE for the North West Indian Ocean calculated by Japanese longline fishery (1976-1993 and 1994-2015).

Year	Nominal CPUE	Standardized CPUE	lower	upper
1976	5.77	4.00	3.08	5.20
1977	8.11	6.23	4.79	8.09
1978	7.43	4.01	3.11	5.16
1979	8.20	4.06	3.14	5.25
1980	4.43	3.59	2.78	4.64
1981	1.52	1.36	1.06	1.76
1982	1.44	1.44	1.12	1.85
1983	0.97	0.74	0.57	0.95
1984	1.69	1.41	1.10	1.81
1985	1.54	1.35	1.05	1.73
1986	1.84	1.58	1.23	2.03
1987	0.99	0.94	0.73	1.21
1988	0.53	0.51	0.39	0.66
1989	0.41	0.46	0.35	0.59
1990	0.32	0.42	0.32	0.56
1991	0.79	0.61	0.47	0.79
1992	0.52	0.72	0.55	0.96
1993	0.53	0.60	0.46	0.78
1994	0.81	0.96	0.76	1.22
1995	0.81	0.87	0.68	1.10
1996	0.56	0.87	0.69	1.10
1997	0.48	0.53	0.42	0.67
1998	0.32	0.43	0.34	0.54
1999	0.46	0.39	0.31	0.50
2000	0.62	0.54	0.43	0.68
2001	0.18	0.30	0.23	0.39
2002	0.20	0.22	0.17	0.28
2003	0.11	0.13	0.10	0.17
2004	0.13	0.18	0.14	0.24
2005	0.07	0.08	0.06	0.10
2006	0.10	0.11	0.08	0.13
2007	0.07	0.06	0.05	0.08
2008	0.20	0.20	0.16	0.25
2009	0.05	0.05	0.04	0.07
2010	0.29	0.32	0.24	0.43
2011				
2012	2.02	1.13	0.77	1.67
2013	1.52	1.11	0.76	1.60
2014	0.21	0.23	0.15	0.35
2015	0.10	0.16	0.09	0.28

Table 3. Standardized striped marlin CPUE for the South East Indian Ocean calculated by Japanese longline fishery (1976-1993 and 1994-2015).

Year	Nominal CPUE	Standardized CPUE	lower	upper
1976	0.04	0.17	0.08	0.39
1977	0.21	0.17	0.08	0.37
1978	0.61	0.28	0.14	0.58
1979	0.19	0.27	0.13	0.57
1980	0.40	0.23	0.11	0.49
1981	0.19	0.10	0.05	0.22
1982	0.31	0.20	0.10	0.42
1983	0.24	0.19	0.09	0.40
1984	0.93	0.26	0.13	0.54
1985	0.21	0.22	0.11	0.46
1986	0.10	0.13	0.06	0.27
1987	0.16	0.27	0.13	0.57
1988	0.14	0.12	0.06	0.26
1989	0.15	0.17	0.08	0.36
1990	0.04	0.08	0.04	0.18
1991	0.03	0.03	0.01	0.06
1992	0.04	0.03	0.01	0.06
1993	0.01	0.06	0.02	0.15
1994	0.03	0.07	0.05	0.11
1995	0.03	0.08	0.06	0.12
1996	0.03	0.03	0.02	0.04
1997	0.03	0.03	0.02	0.04
1998	0.03	0.04	0.03	0.07
1999	0.04	0.06	0.04	0.09
2000	0.07	0.06	0.04	0.09
2001	0.07	0.08	0.05	0.11
2002	0.08	0.27	0.19	0.39
2003	0.03	0.06	0.04	0.09
2004	0.04	0.11	0.07	0.17
2005	0.05	0.15	0.10	0.23
2006	0.11	0.18	0.12	0.26
2007	0.03	0.11	0.06	0.20
2008	0.07	0.18	0.12	0.28
2009	0.08	0.08	0.05	0.13
2010	0.08	0.10	0.06	0.16
2011	0.16	0.10	0.06	0.15
2012	0.06	0.04	0.02	0.07
2013	0.02	0.06	0.03	0.12
2014	0.02	0.10	0.06	0.18
2015	0.02	0.04	0.02	0.07

Table 4. Standardized striped marlin CPUE for the South West Indian Ocean calculated by Japanese longline fishery (1976-1993 and 1994-2015).

Year	Nominal CPUE	Standardized CPUE	lower	upper
1976	0.24	0.39	0.28	0.54
1977	0.43	2.03	1.37	3.01
1978	0.59	1.06	0.78	1.43
1979	0.62	0.82	0.62	1.09
1980	0.64	0.66	0.50	0.89
1981	0.23	0.26	0.20	0.34
1982	0.07	0.18	0.13	0.24
1983	0.09	0.29	0.21	0.40
1984	0.14	0.53	0.39	0.72
1985	0.20	0.37	0.28	0.49
1986	0.29	0.57	0.43	0.75
1987	0.18	0.51	0.38	0.69
1988	0.22	0.34	0.26	0.45
1989	0.05	0.14	0.10	0.19
1990	0.05	0.06	0.04	0.08
1991	0.14	0.10	0.07	0.13
1992	0.13	0.13	0.10	0.18
1993	0.08	0.11	0.08	0.15
1994	0.07	0.13	0.09	0.17
1995	0.12	0.19	0.14	0.26
1996	0.10	0.16	0.12	0.22
1997	0.08	0.11	0.08	0.15
1998	0.08	0.11	0.08	0.14
1999	0.14	0.14	0.11	0.19
2000	0.09	0.11	0.08	0.15
2001	0.06	0.08	0.06	0.11
2002	0.03	0.03	0.02	0.05
2003	0.02	0.02	0.01	0.03
2004	0.02	0.02	0.02	0.03
2005	0.01	0.01	0.01	0.02
2006	0.03	0.02	0.02	0.03
2007	0.02	0.02	0.01	0.03
2008	0.05	0.04	0.03	0.05
2009	0.07	0.06	0.04	0.09
2010	1.00	0.79	0.59	1.06
2011	1.24	1.02	0.76	1.37
2012	0.49	0.45	0.33	0.60
2013	0.35	0.29	0.21	0.39
2014	0.25	0.18	0.13	0.25
2015	0.11	0.07	0.05	0.10

Table 5. Deviance table for the striped marlin CPUE in the North East Indian Ocean by Japanese longline fishery (1976-1993). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	103424	103450	103418	NA	NA
yr+offset(log(hooks/1000))	19	107816	107978	107778	0	1
yr+offset(log(hooks/1000))+(1|fleet)	20	101657	101828	101617	6160.5473	<0.0001
yr+qtr+offset(log(hooks/1000))	22	107109	107297	107065	0	1
yr+qtr+offset(log(hooks/1000))+(1|fleet)	23	101158	101355	101112	5952.302	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	**25**	**92665**	**92879**	**92615**	**8497.4815**	**<0.0001**
yr+offset(log(hooks/1000)) yr	37	NA	NA	NA	NA	NA
yr+qtr+offset(log(hooks/1000)) yr+qtr	43	106164	106533	106078	6	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	43	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	44	92647	93024	92559	1	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|area)	44	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|area)	45	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|fleet)	45	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	46	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	47	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|fleet)	47	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	47	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|fleet)	48	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)+(1|fleet)	49	NA	NA	NA	NA	NA
yr+qtr+area+offset(log(hooks/1000))	66	94561	95126	94429	17	NA
yr+qtr+area+gear2+offset(log(hooks/1000))	67	94562	95136	94428	1.0364	0.30866
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	67	92506	93080	92372	2055.8097	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	68	92503	93086	92367	4.4819	0.03425
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	131	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	133	NA	NA	NA	NA	NA

Table 6. Deviance table for the striped marlin CPUE in the North East Indian Ocean by Japanese longline fishery (1994-2015). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	63670	63698	63664	NA	NA
yr+offset(log(hooks/1000))	23	64337	64549	64291	0	1
yr+offset(log(hooks/1000))+(1|fleet)	24	61511	61733	61463	2828	<0.0001
yr+qtr+offset(log(hooks/1000))	26	63871	64111	63819	0	1
yr+qtr+offset(log(hooks/1000))+(1|fleet)	27	61208	61458	61154	2665	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	29	57080	57348	57022	4132	<0.0001
yr+offset(log(hooks/1000)) yr	45	NA	NA	NA	NA	NA
yr+qtr+offset(log(hooks/1000)) yr+qtr	51	63236	63707	63134	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	51	56827	57298	56725	6409	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	52	56770	57251	56666	58	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|area)	52	56553	57034	56449	217	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|area)	53	56555	57045	56449	0	0.8236
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|fleet)	53	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	54	56801	57300	56693	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	55	56777	57286	56667	25	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|fleet)	55	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	55	56408	56917	56298	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)	56	56410	56928	56298	0	0.5834
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)+(1|fleet)	**57**	**56112**	**56639**	**55998**	**300**	**<0.0001**
yr+qtr+area+offset(log(hooks/1000))	65	58108	58709	57978	0	1
yr+qtr+area+gear2+offset(log(hooks/1000))	66	58074	58684	57942	36	<0.0001
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	66	56978	57589	56846	1096	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	67	56959	57578	56825	22	<0.0001
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	129	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	131	NA	NA	NA	NA	NA

Table 7. Deviance table for the striped marlin CPUE in the North West Indian Ocean by Japanese longline fishery (1976-1993). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	228625	228652	228619	NA	NA
yr+offset(log(hooks/1000))	19	224864	225038	224826	3792	<0.0001
yr+offset(log(hooks/1000))+(1|fleet)	20	219627	219809	219587	5240	<0.0001
yr+qtr+offset(log(hooks/1000))	22	221418	221619	221374	0	1
yr+qtr+offset(log(hooks/1000))+(1|fleet)	23	216809	217020	216763	4610	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	25	210693	210922	210643	6120	<0.0001
yr+offset(log(hooks/1000)) yr	37	224601	224940	224527	0	1
yr+qtr+offset(log(hooks/1000)) yr+qtr	43	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	43	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	44	210582	210984	210494	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|fleet)	44	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|area)	**44**	**210237**	**210639**	**210149**	**NA**	**NA**
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|area)	45	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	46	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	47	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	47	210240	210669	210146	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)	48	210239	210678	210143	2	0.125572
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)+(1|fleet)	49	NA	NA	NA	NA	NA
yr+qtr+area+offset(log(hooks/1000))	59	212927	213467	212809	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000))	60	212911	213459	212791	19	<0.0001
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	60	210541	211089	210421	2370	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	61	210535	211093	210413	8	0.005139
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	117	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	119	NA	NA	NA	NA	NA

Table 8. Deviance table for the striped marlin CPUE in the North West Indian Ocean by Japanese longline fishery (1994-2015). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	118424	118453	118418	NA	NA
yr+offset(log(hooks/1000))	22	116026	116237	115982	2436	<0.0001
yr+offset(log(hooks/1000))+(1|fleet)	23	111999	112220	111953	4029	<0.0001
yr+qtr+offset(log(hooks/1000))	25	114888	115128	114838	0	1
yr+qtr+offset(log(hooks/1000))+(1|fleet)	26	111064	111313	111012	3826	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	28	108989	109258	108933	2079	<0.0001
yr+offset(log(hooks/1000)) yr	43	NA	NA	NA	NA	NA
yr+qtr+offset(log(hooks/1000)) yr+qtr	49	114091	114560	113993	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	49	108695	109165	108597	5395	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	50	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|area)	50	108519	108998	108419	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|area)	51	108520	109009	108418	1	0.4396
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	52	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	**53**	**108259**	**108767**	**108153**	**NA**	**NA**
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	53	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|fleet)	54	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)	54	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)+(1|fleet)	55	NA	NA	NA	NA	NA
yr+qtr+area+offset(log(hooks/1000))	63	111559	112163	111433		
yr+qtr+area+gear2+offset(log(hooks/1000))	64	111559	112172	111431	2	0.1232
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	64	108894	109507	108766	2665	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	65	108862	109485	108732	34	<0.0001
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	125	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	127	NA	NA	NA	NA	NA

Table 9. Deviance table for the striped marlin CPUE in the South East Indian Ocean by Japanese longline fishery (1976-1993). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	40127	40154	40121	NA	NA
yr+offset(log(hooks/1000))	19	43794	43967	43756	0	1
yr+offset(log(hooks/1000))+(1|fleet)	20	39223	39405	39183	4573	<0.0001
yr+qtr+offset(log(hooks/1000))	22	40658	40859	40614	0	1
yr+qtr+offset(log(hooks/1000))+(1|fleet)	23	35053	35263	35007	5607	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	25	27521	27749	27471	7536	<0.0001
yr+offset(log(hooks/1000)) yr	37	NA	NA	NA	NA	NA
yr+qtr+offset(log(hooks/1000)) yr+qtr	43	37453	37845	37367	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	43	27417	27809	27331	10036	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	44	27419	27820	27331	0.447	0.5037456
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|fleet)	44	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|area)	45	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|fleet)	45	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	46	27310	27729	27218	1	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	47	27312	27740	27218	0	0.9094269
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|fleet)	47	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	**47**	**26731**	**27160**	**26637**	**0**	**NA**
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)	48	26733	27171	26637	0	0.9100347
yr+qtr+area+offset(log(hooks/1000))	78	28892	29603	28736	0	1
yr+qtr+area+gear2+offset(log(hooks/1000))	79	28882	29602	28724	12	0.00049
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	79	27382	28103	27224	1500	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	80	27373	28103	27213	11	0.0009191
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	155	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	157	NA	NA	NA	NA	NA

Table 10. Deviance table for the striped marlin CPUE in the South East Indian Ocean by Japanese longline fishery (1994-2015). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	39463	39492	39457	NA	NA
yr+offset(log(hooks/1000))	23	40629	40853	40583	0	1
yr+offset(log(hooks/1000))+(1|fleet)	24	38804	39037	38756	1827	<0.0001
yr+qtr+offset(log(hooks/1000))	26	39871	40123	39819	0	1
yr+qtr+offset(log(hooks/1000))+(1|fleet)	27	38148	38411	38094	1724	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	29	35356	35638	35298	2796	<0.0001
yr+offset(log(hooks/1000)) yr	45	40306	40743	40216	0	1
yr+qtr+offset(log(hooks/1000)) yr+qtr	51	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	51	35096	35592	34994	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	52	35069	35574	34965	29	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|area)	52	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|fleet)	53	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	54	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	55	34606	35141	34496	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|fleet)	55	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	55	34208	34742	34098	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)	**56**	**34188**	**34732**	**34076**	**22**	**<0.0001**
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)+(1|fleet)	57	NA	NA	NA	NA	NA
yr+qtr+area+offset(log(hooks/1000))	82	36687	37484	36523	25	NA
yr+qtr+area+gear2+offset(log(hooks/1000))	83	36689	37496	36523	0	1
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	83	35196	36002	35030	1494	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	84	35195	36012	35027	3	0.1086
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	163	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	165	NA	NA	NA	NA	NA

Table 11. Deviance table for the striped marlin CPUE in the South West Indian Ocean by Japanese longline fishery (1976-1993). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	59917	59945	59911	NA	NA
yr+offset(log(hooks/1000))	19	64534	64710	64496	0	1
yr+offset(log(hooks/1000))+(1|fleet)	20	58028	58212	57988	6509	<0.0001
yr+qtr+offset(log(hooks/1000))	22	55620	55823	55576	2412	<0.0001
yr+qtr+offset(log(hooks/1000))+(1|fleet)	23	50144	50357	50098	5478	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	25	47132	47363	47082	3016	<0.0001
yr+offset(log(hooks/1000)) yr	37	63902	64244	63828	0	1
yr+qtr+offset(log(hooks/1000)) yr+qtr	43	52713	53110	52627	11201	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	43	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	44	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|area)	44	46530	46936	46442	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|area)	45	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	46	46646	47071	46554	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	47	46632	47066	46538	16	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|fleet)	47	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	**47**	**44961**	**45395**	**44867**	**NA**	**NA**
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)	48	44953	45396	44857	10	0.001706
yr+qtr+area+offset(log(hooks/1000))	54	49689	50188	49581	0	1
yr+qtr+area+gear2+offset(log(hooks/1000))	55	49684	50193	49574	7	0.007854
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	55	47032	47540	46922	2653	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	56	47033	47550	46921	1	0.419004
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	107	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	109	NA	NA	NA	NA	NA

Table 12. Deviance table for the striped marlin CPUE in the South West Indian Ocean by Japanese longline fishery (1994-2015). Bold is the best model selected by BIC.

Model (Count part / Zero part)	Df	AIC	BIC	deviance	Chisq	Pr(>Chisq)
offset(log(hooks/1000))+(1|fleet)	3	114305	114335	114299	NA	NA
yr+offset(log(hooks/1000))	23	110146	110377	110100	4198	<0.0001
yr+offset(log(hooks/1000))+(1|fleet)	24	105541	105782	105493	4607	<0.0001
yr+qtr+offset(log(hooks/1000))	26	104964	105225	104912	581	<0.0001
yr+qtr+offset(log(hooks/1000))+(1|fleet)	27	100729	101000	100675	4237	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area)	29	97556	97847	97498	3176	<0.0001
yr+offset(log(hooks/1000)) yr	45	NA	NA	NA	NA	NA
yr+qtr+offset(log(hooks/1000)) yr+qtr	51	101208	101720	101106	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr	51	97069	97581	96967	4139	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2	52	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|fleet)	52	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+(1|area)	52	95832	96354	95728	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|area)	53	95833	96365	95727	2	0.175474
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+gear2+(1|fleet)	53	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr	54	95878	96420	95770	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2	55	95580	96132	95470	300	<0.0001
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+(1|area)	**55**	**94431**	**94983**	**94321**	**1149**	**<0.0001**
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|fleet)	56	NA	NA	NA	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)	56	94431	94993	94319	NA	NA
yr+qtr+gear2+offset(log(hooks/1000))+(1|fleet)+(1|area) yr+qtr+gear2+(1|area)+(1|fleet)	57	NA	NA	NA	NA	NA
yr+qtr+area+offset(log(hooks/1000))	62	100783	101405	100659		
yr+qtr+area+gear2+offset(log(hooks/1000))	63	100776	101408	100650	9	0.003022
yr+qtr+area+offset(log(hooks/1000))+(1|fleet)	63	97458	98090	97332	3318	<0.0001
yr+qtr+area+gear2+offset(log(hooks/1000))+(1|fleet)	64	97460	98103	97332	0	1
yr+qtr+area+offset(log(hooks/1000)) yr+qtr+area	123	NA	NA	NA	NA	NA
yr+qtr+area+gear2+offset(log(hooks/1000)) yr+qtr+area+gear2	125	NA	NA	NA	NA	NA

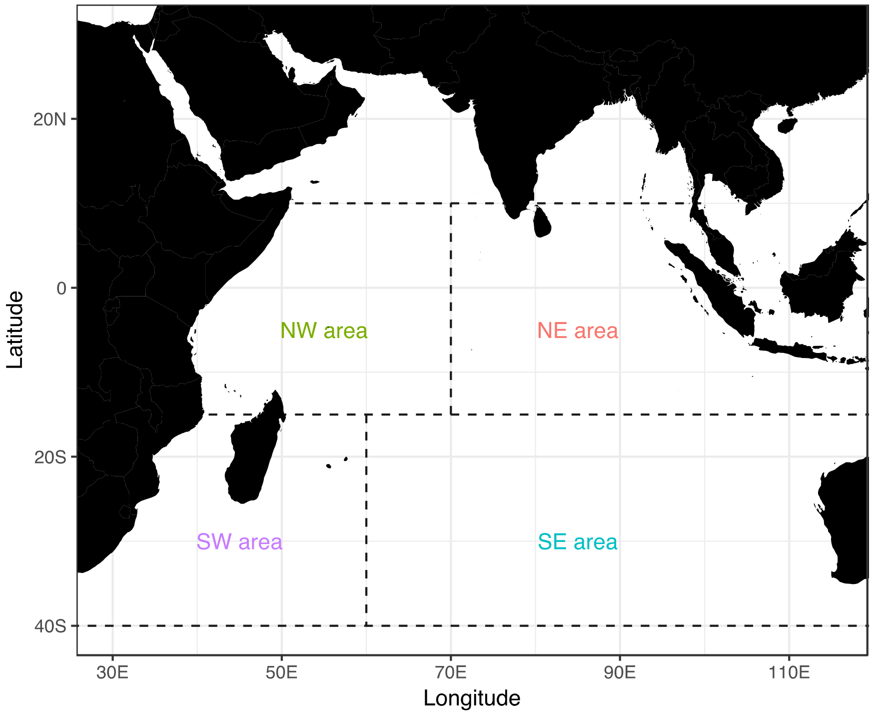

Figure 1. Analysis area for the striped marlin CPUE standardization given by Japanese longline fishery in the Indian Ocean.

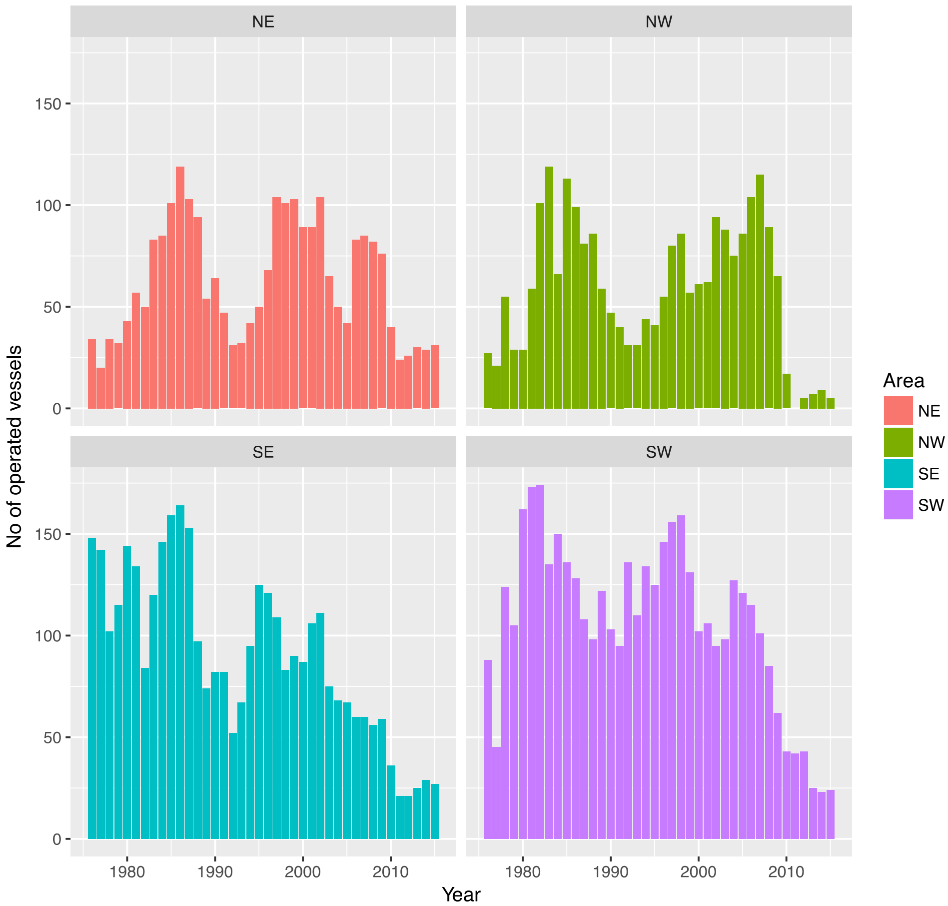

Figure 2. Historical change of the number of the operated Japanese vessel in Indian Ocean.

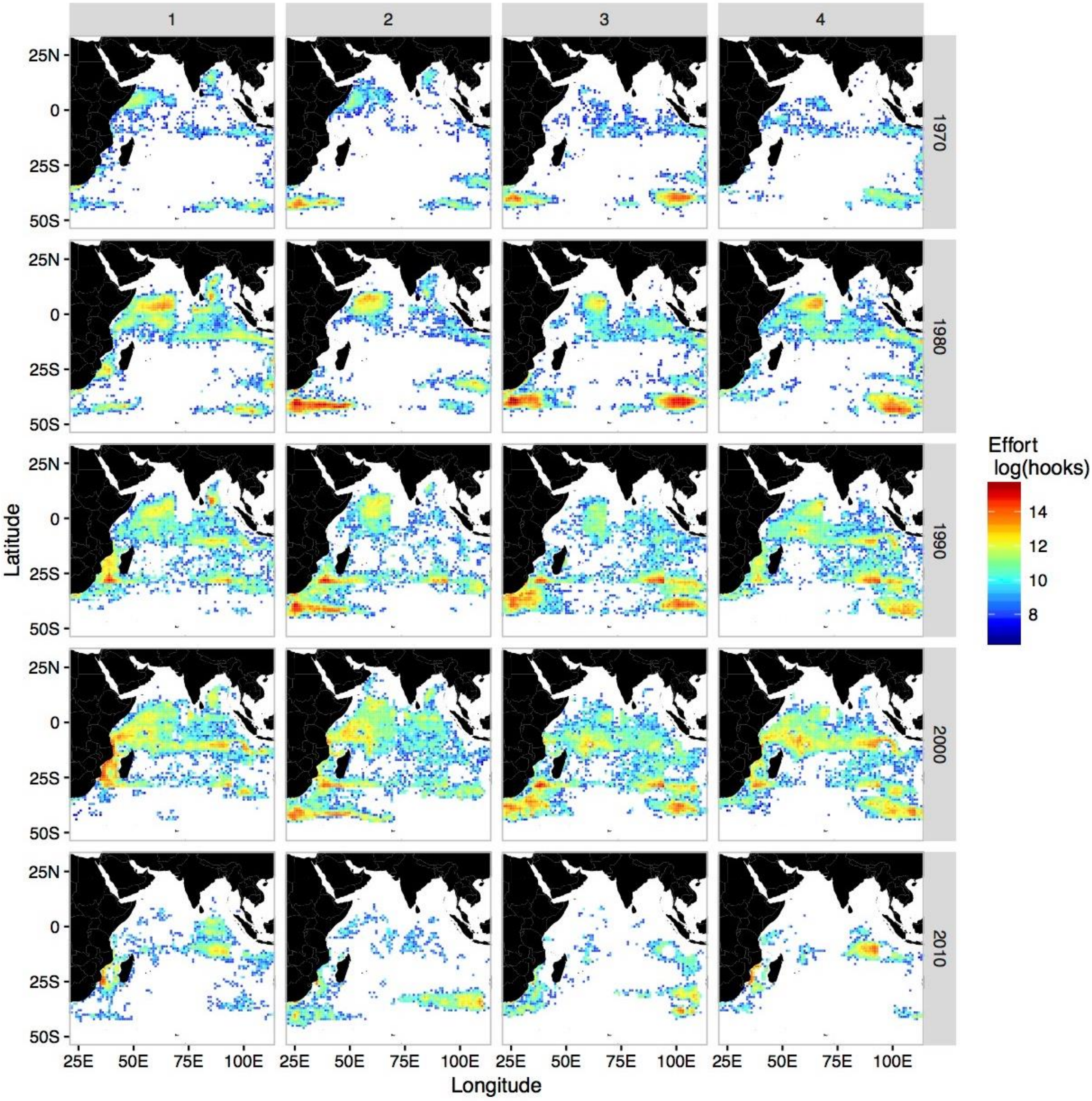

Figure3. Time spatial change of the effort of Japanese distant water longline in Indian Ocean.

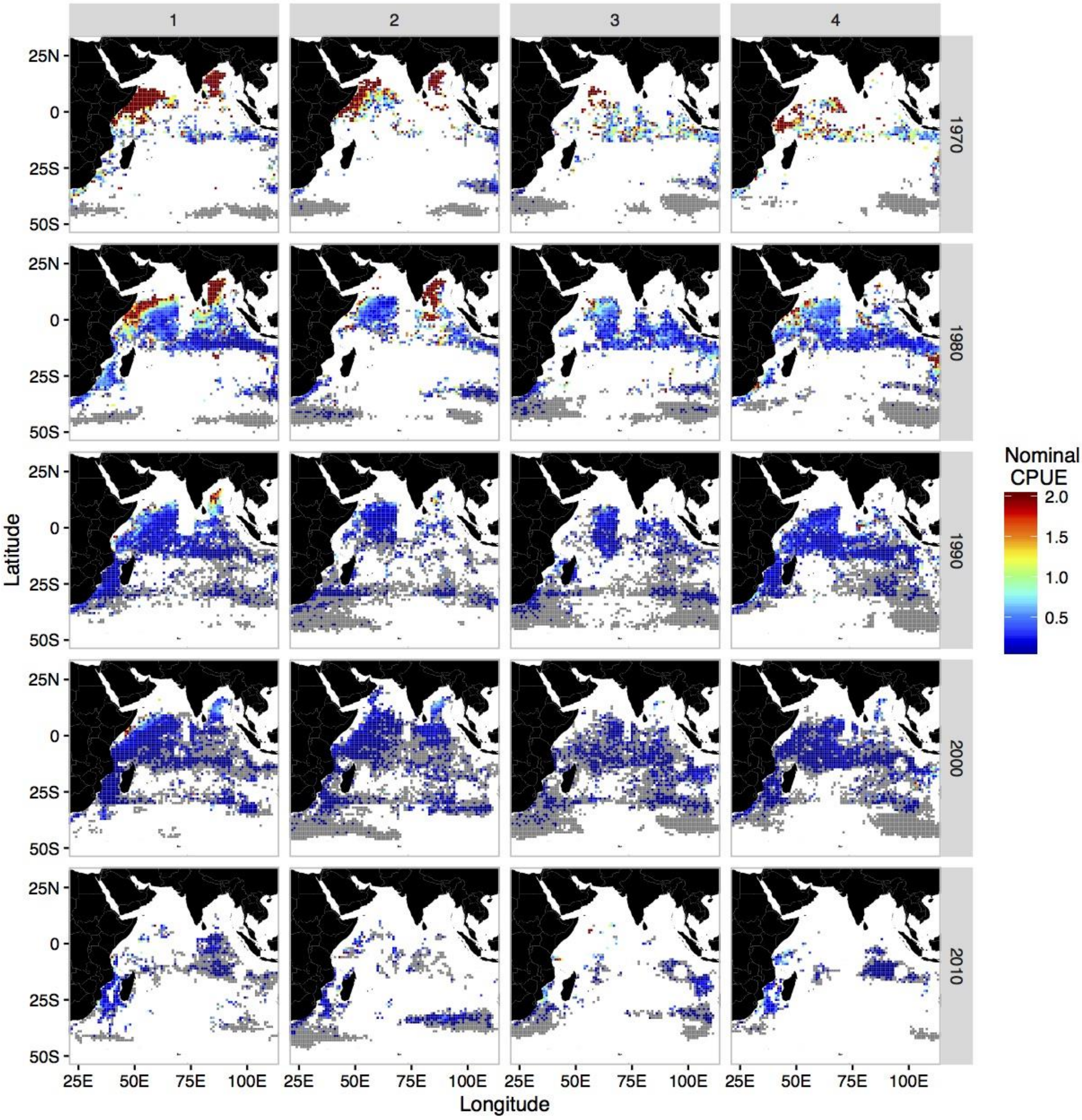

Figure 4. Time spatial change of the nominal striped marlin CPUE by Japanese distant water longline in Indian Ocean.

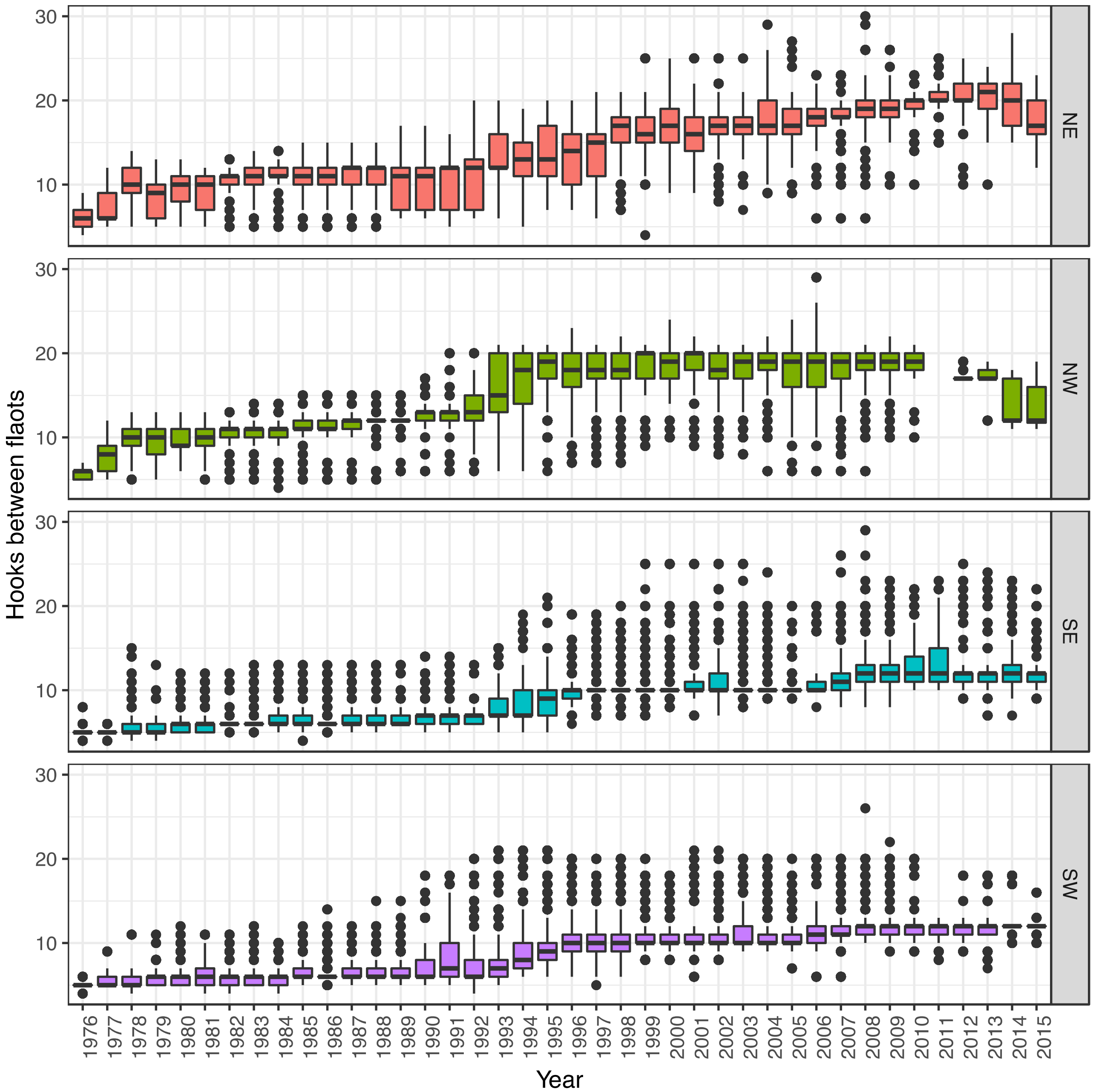

Figure 5. Historical change of the hooks between floats in Indian Ocean.

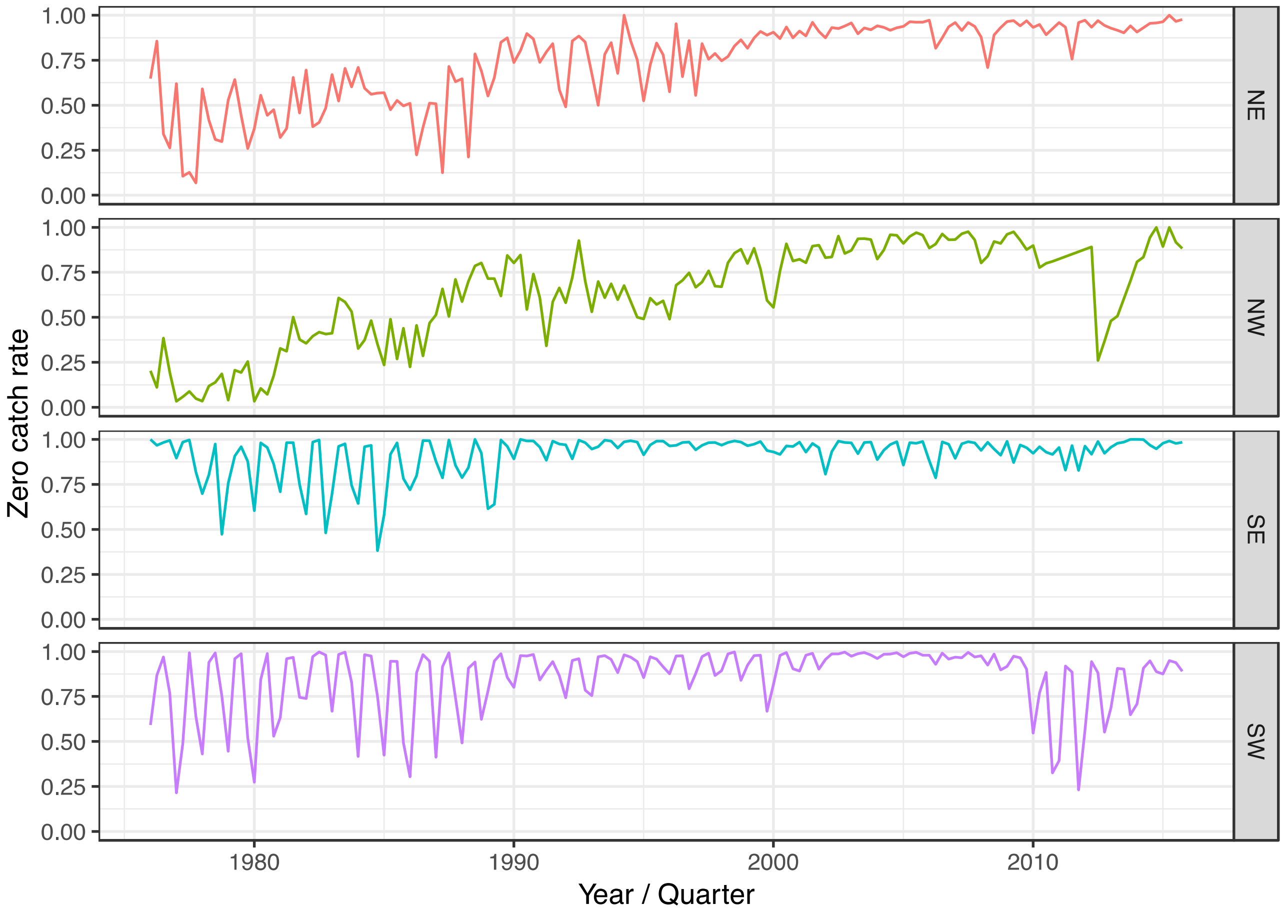

Figure 6. Zero catch rate of striped marlin by Japanese long line fishery.

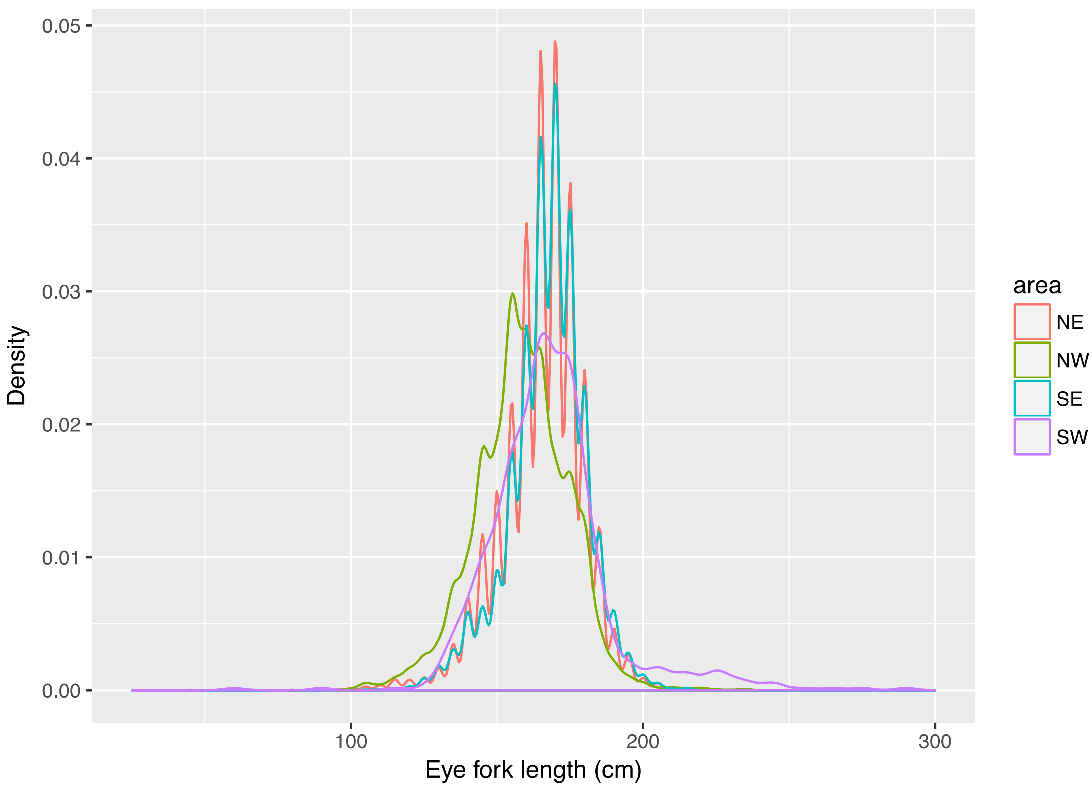

Figure 7. Length frequency of striped marlin observed in Indian Ocean.

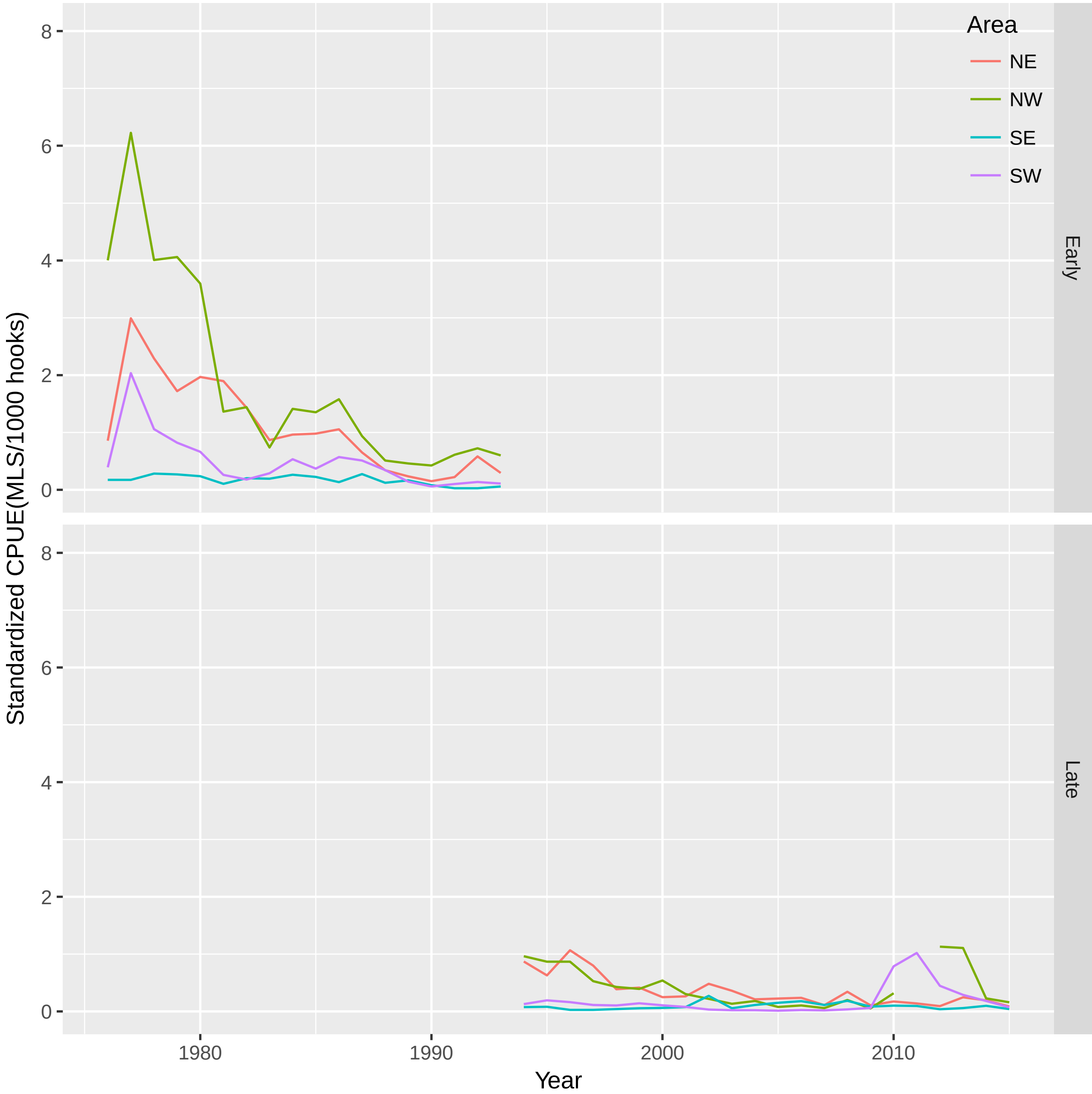

Figure 8. Standardized striped marlin CPUE (Least squares mean) by Japanese longline fishery. The best models were selected by BIC. Filled areas denote 95% confidence interval of standardized CPUE.

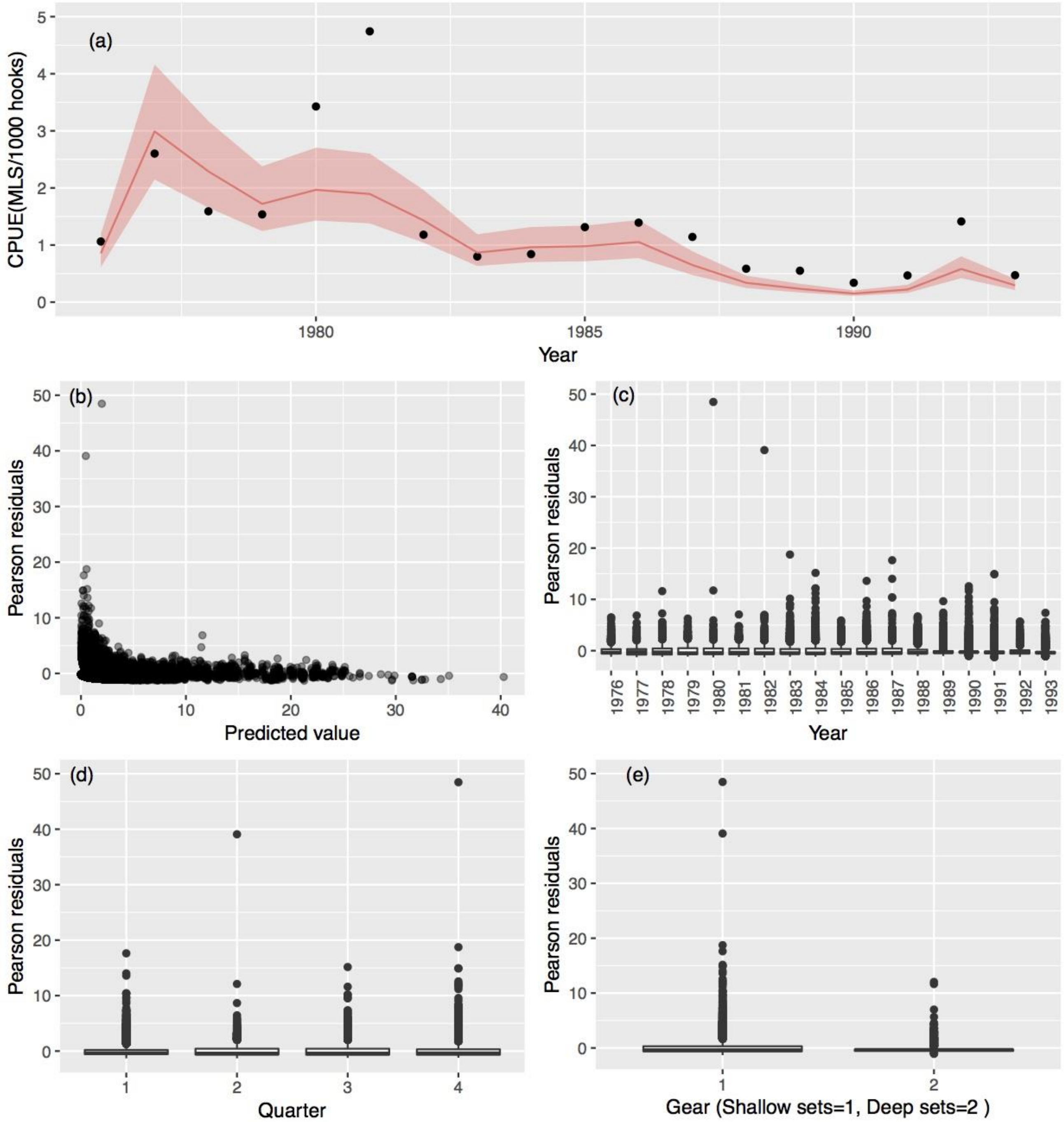

Figure 9. The result of CPUE standardization analysis of North East Indian Ocean striped marlin by Japanese longline fishery (1976-1993). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(e) The plots of the Pearson residual trend.

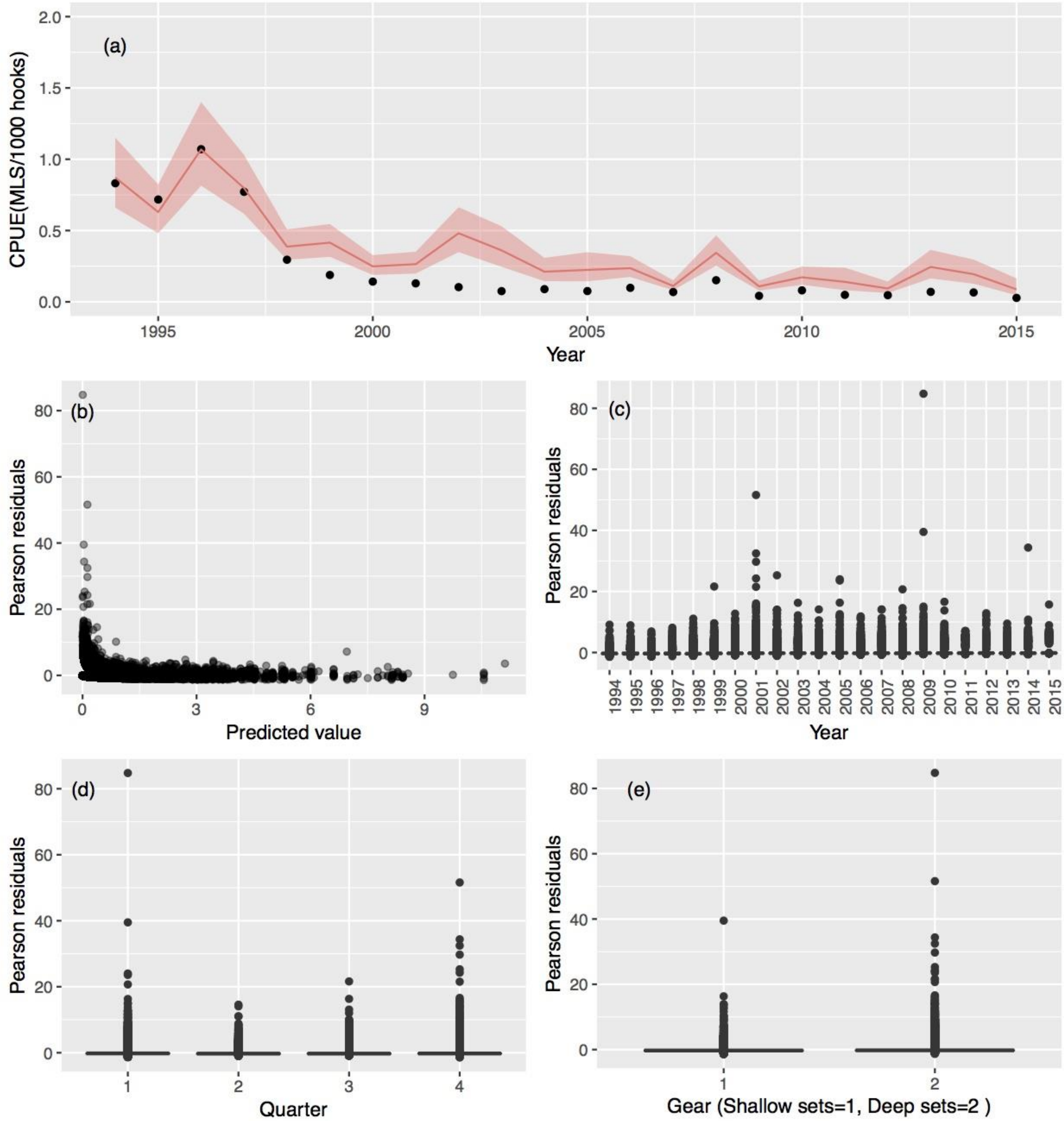

Figure 10. The result of CPUE standardization analysis of North East Indian Ocean striped marlin by Japanese longline fishery (1994-2015). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(d) The plots of the Pearson residual trend.

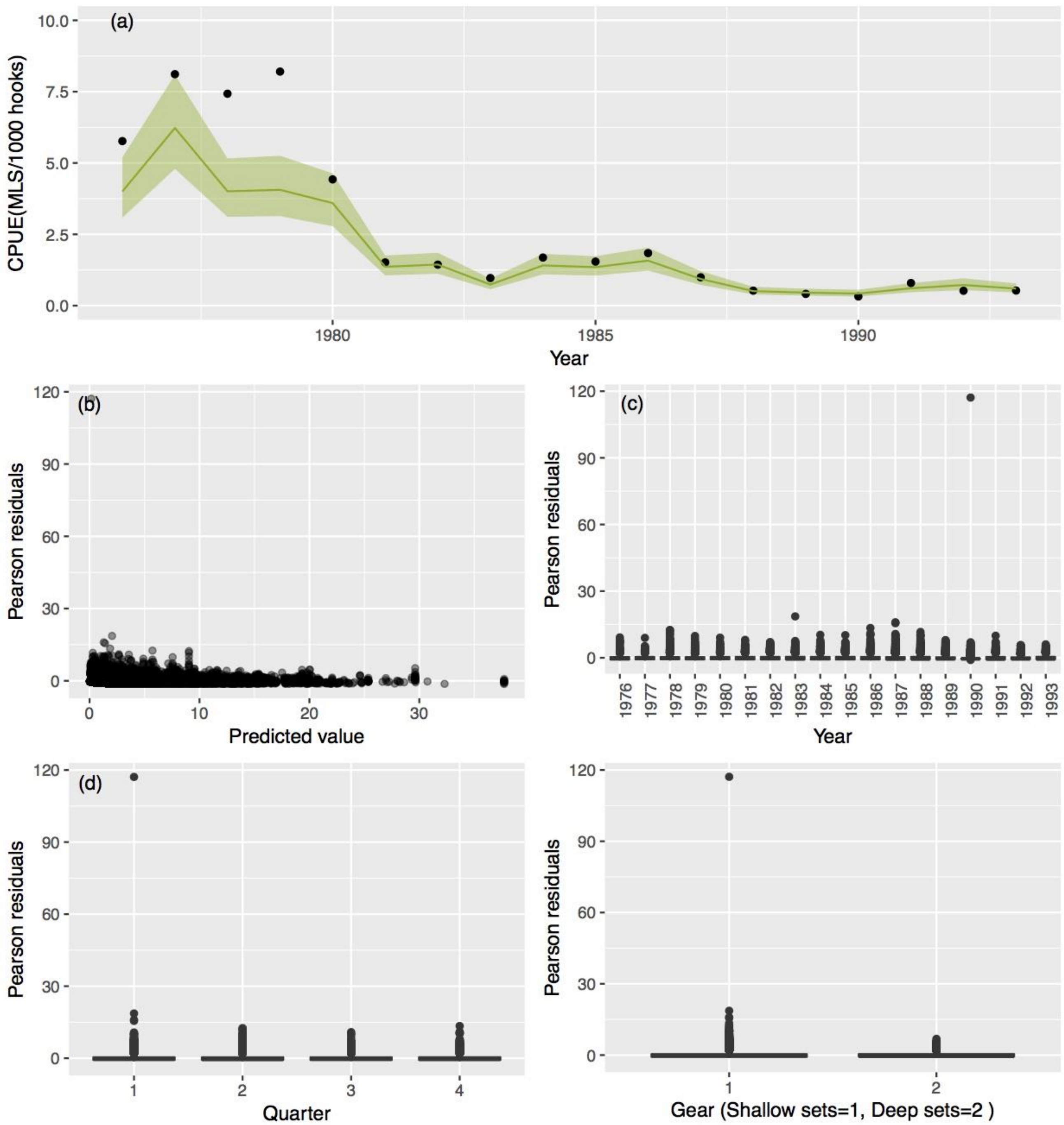

Figure 11. The result of CPUE standardization analysis of North West Indian Ocean striped marlin by Japanese longline fishery (1976-1993). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(e) The plots of the Pearson residual trend.

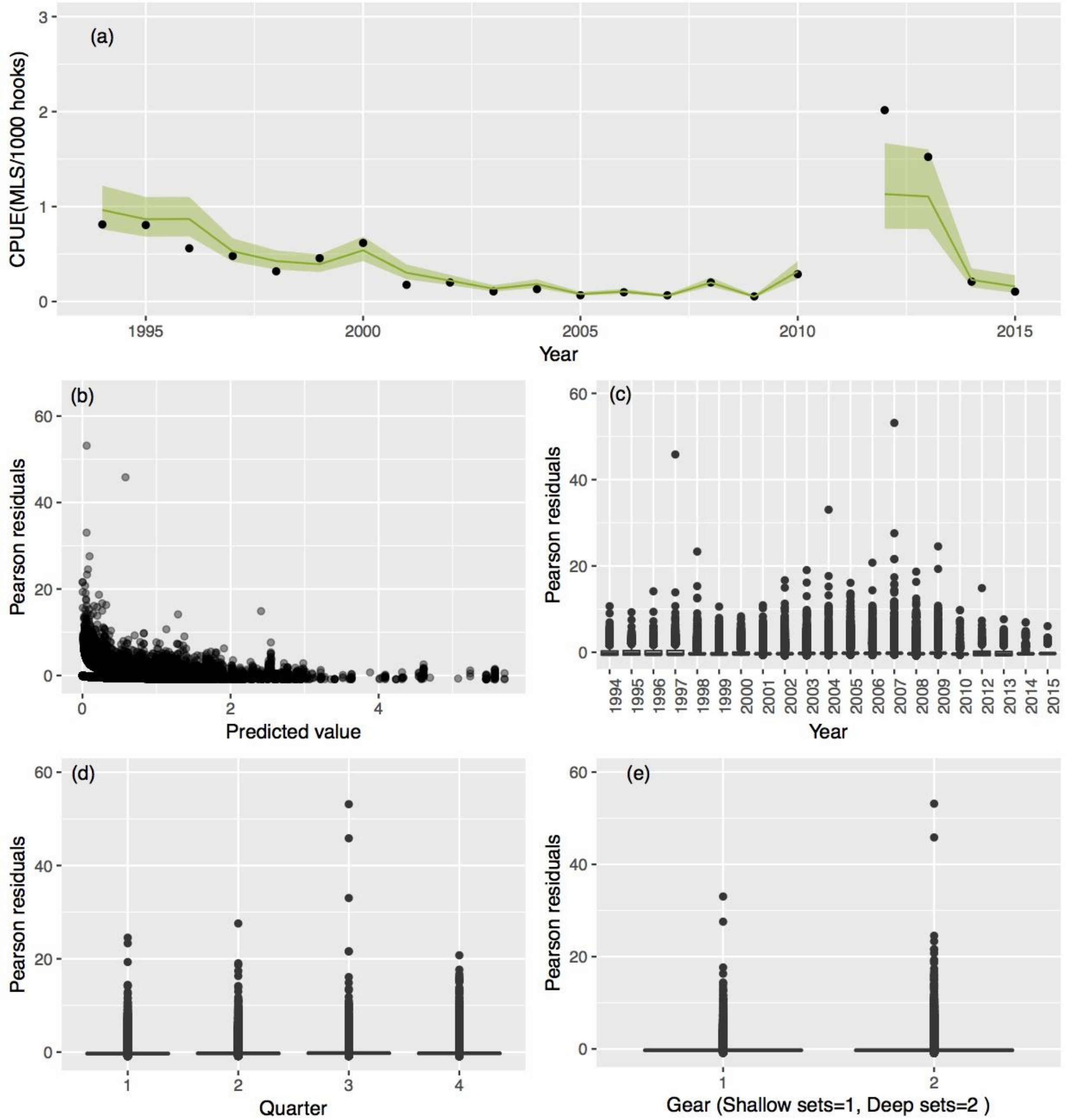

Figure 12. The result of CPUE standardization analysis of North West Indian Ocean striped marlin by Japanese longline fishery (1994-2015). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(e) The plots of the Pearson residual trend.

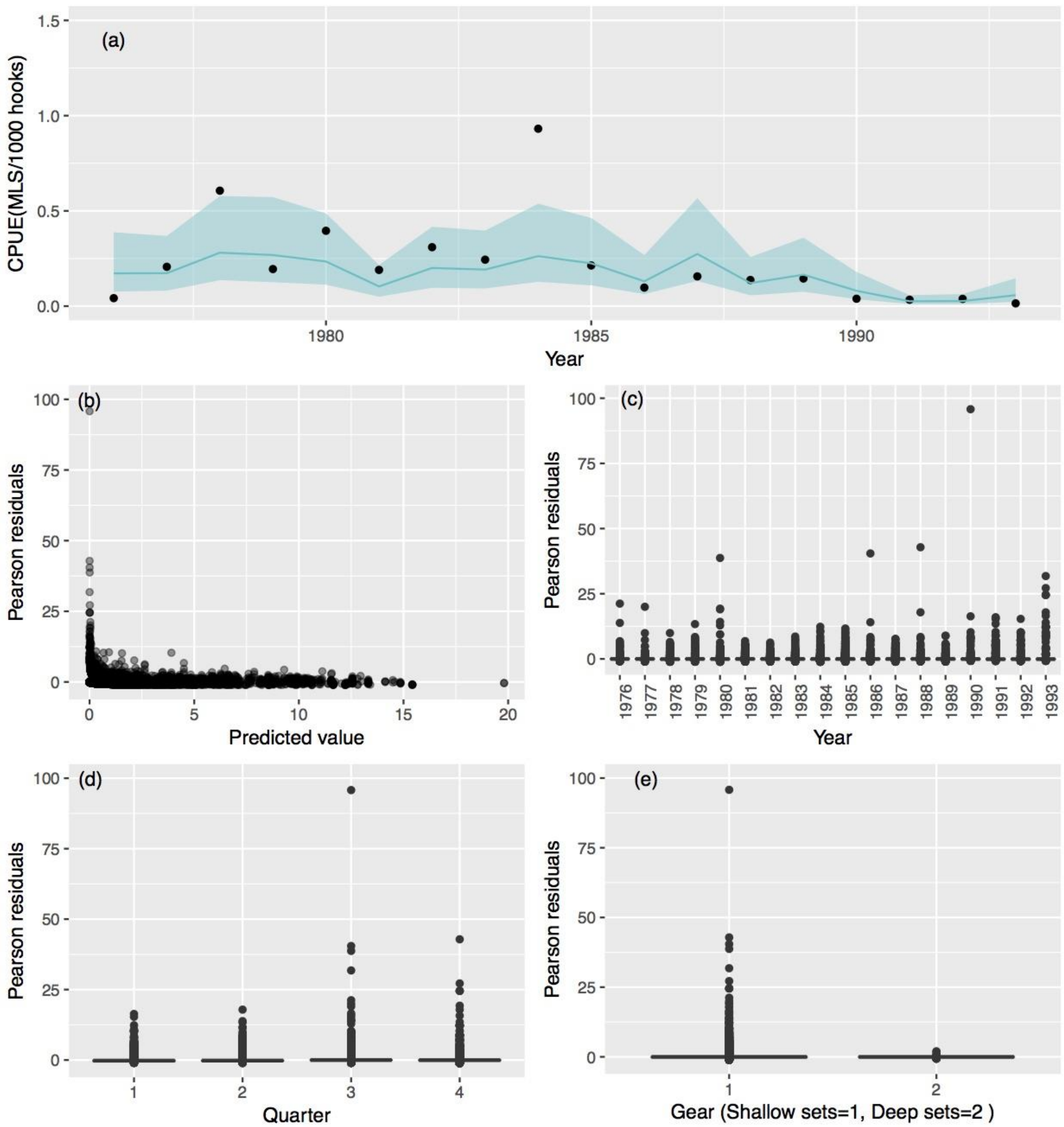

Figure 13. The result of CPUE standardization analysis of South East Indian Ocean striped marlin by Japanese longline fishery (1976-1993). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(e) The plots of the Pearson residual trend.

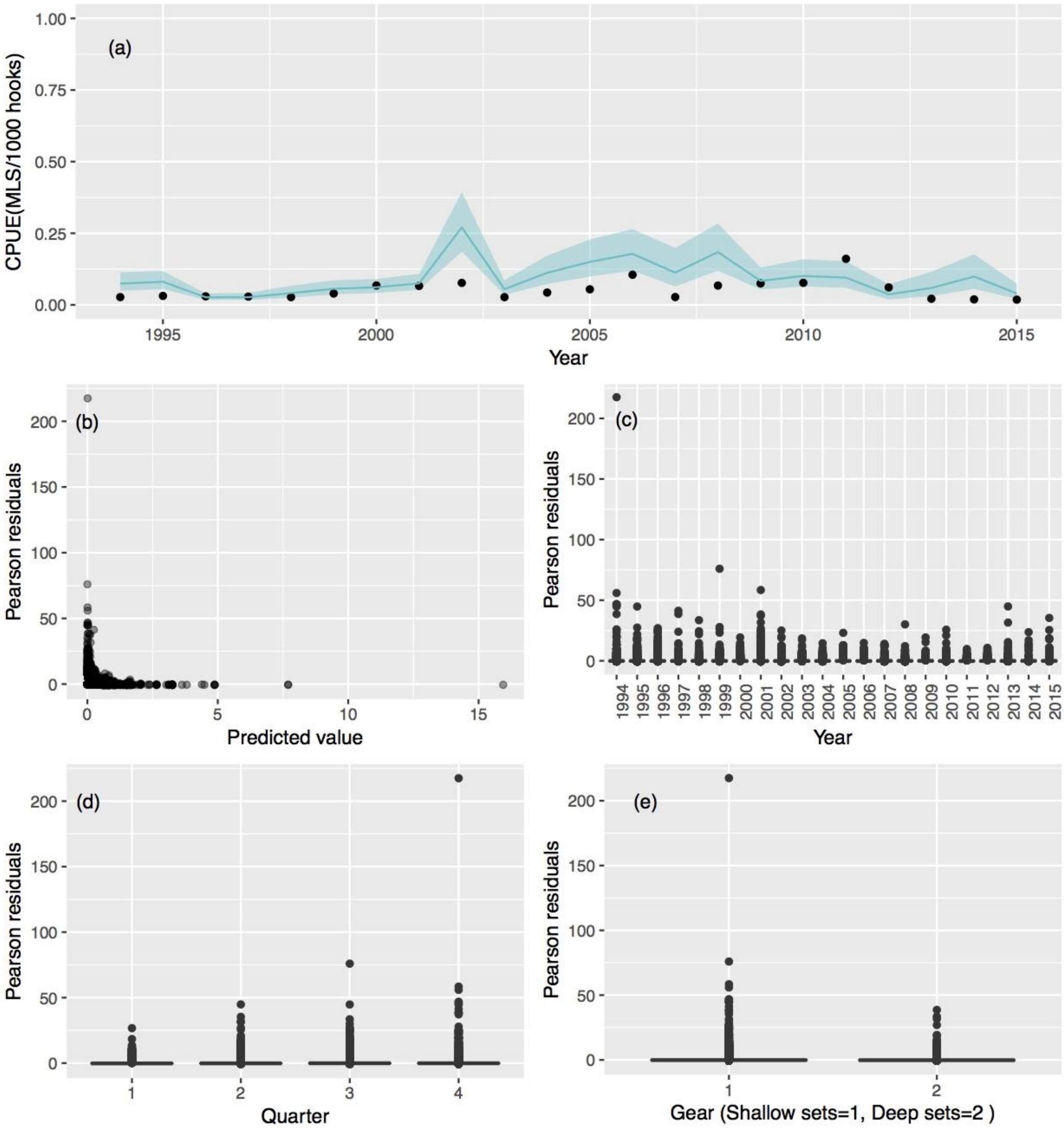

Figure 14. The result of CPUE standardization analysis of South East Indian Ocean striped marlin by Japanese longline fishery (1994-2015). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(e) The plots of the Pearson residual trend.

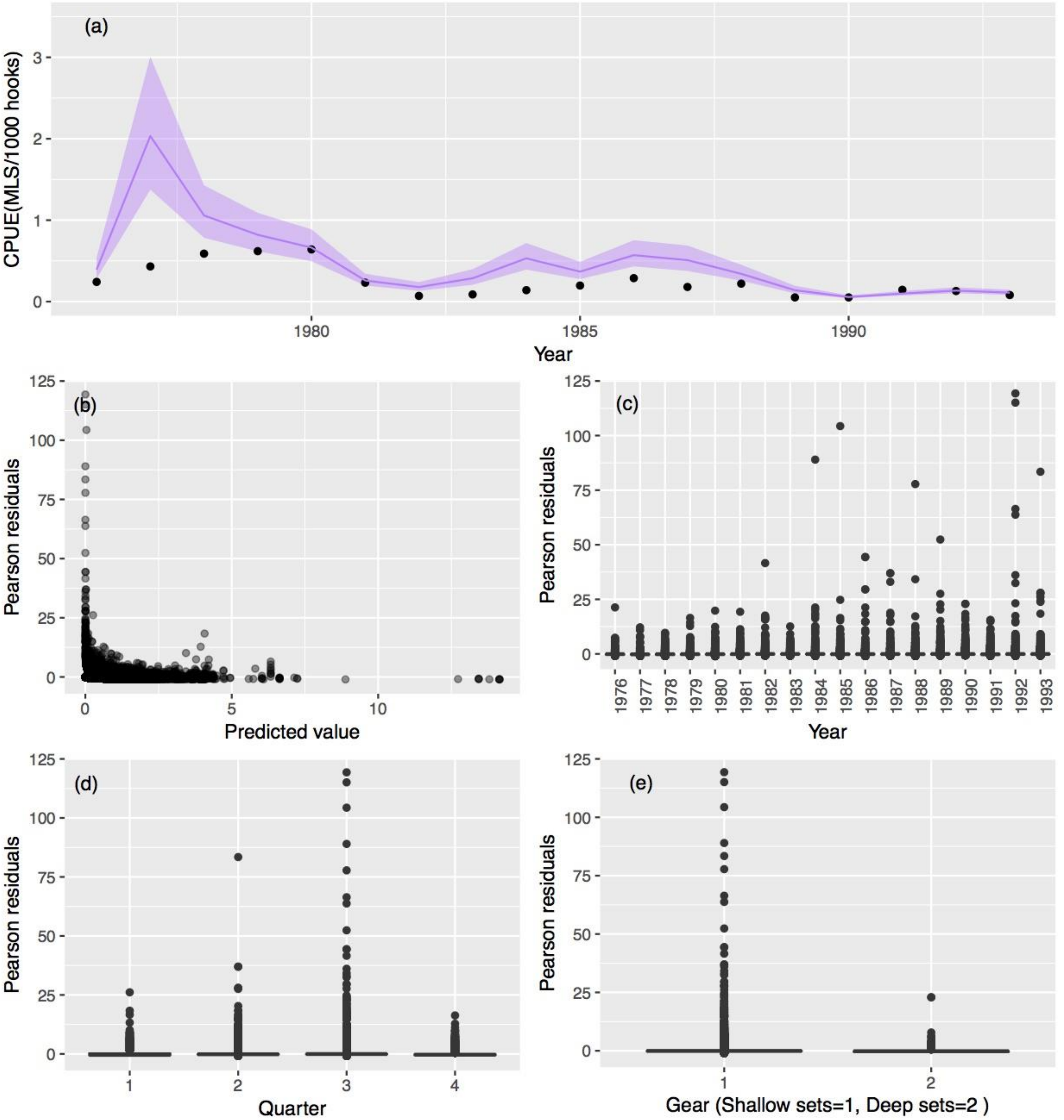

Figure 15. The result of CPUE standardization analysis of South West Indian Ocean striped marlin by Japanese longline fishery (1976-1993). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(e) The plots of the Pearson residual trend.

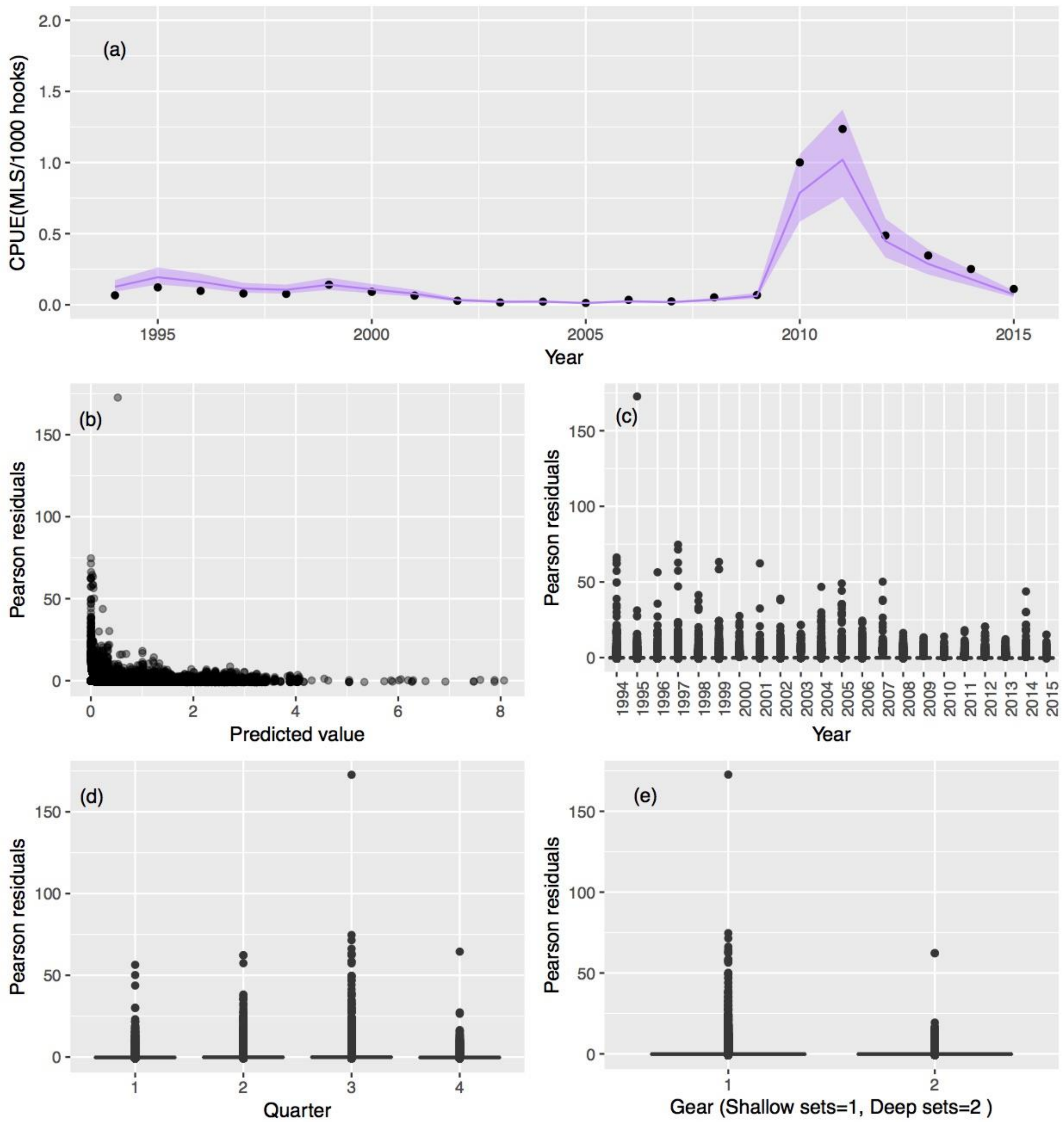

Figure 16. The result of CPUE standardization analysis of South West Indian Ocean striped marlin by Japanese longline fishery (1994-2015). (a) The comparison between nominal and standardized CPUE (Lines denote standardized CPUE, Points denote nominal CPUE, and filled areas denote 95% confidence interval of standardized CPUE). (b)-(e) The plots of the Pearson residual trend.