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@Virtual

Standardized abundance index for recruitment of chub mackerel from Northwest Pacific summer surveys up to 2024

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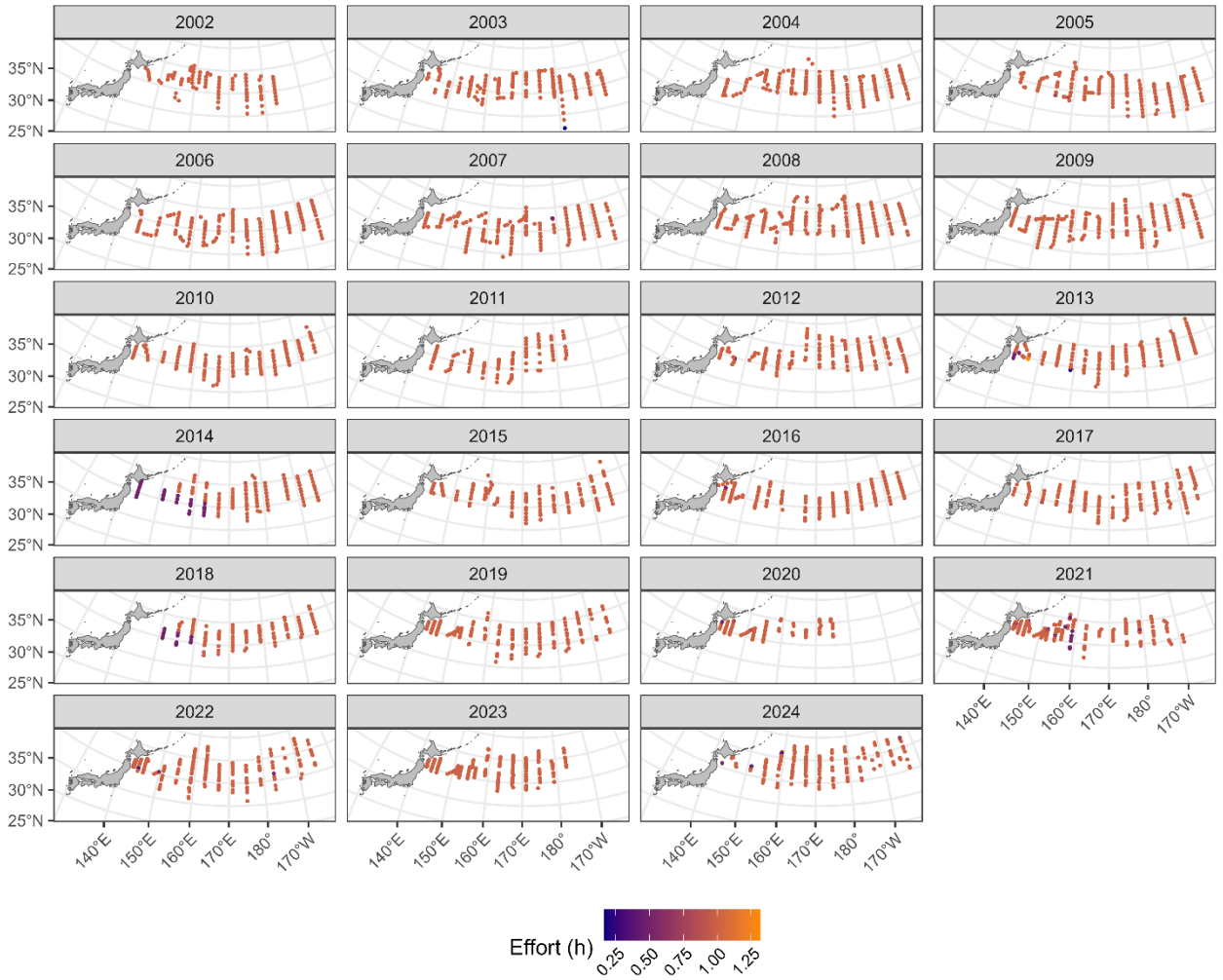
Summer surveys by Japan

Fig. 1A



- The standardized CPUE (catch number divided by sweeping time) of age 0 fish of CM has long been used as a recruitment index in the Japanese domestic stock assessment

Table 1

Year	Number of observations (stations)	Total sweeping time (h)	Total swept area (km^2)	Total catch (ind)	Number of observations with positive catch	Percentage of positive catch (%)
2001	58	59.00	12.02	113.5	9	15.52
2002	93	93.00	18.26	259.0	17	18.28
2003	157	155.37	30.55	4063.8	15	9.55
2004	179	178.50	36.35	21262.5	24	13.41
2005	164	162.95	31.12	2389.0	16	9.76
2006	163	162.63	30.19	39.0	3	1.84
2007	155	154.50	29.58	36441.0	24	15.48
2008	169	169.00	33.08	6024.0	16	9.47
2009	168	168.02	39.43	5568.0	25	14.88
2010	126	126.18	24.88	2504.0	18	14.29
2011	97	97.00	17.48	363.5	12	12.37
2012	135	134.85	25.12	4745.5	20	14.81
2013	125	122.48	26.27	183151.5	17	13.60
2014	122	108.95	20.29	884.8	5	4.10
2015	121	121.00	22.99	4358.6	19	15.70
2016	122	121.47	22.73	81005.6	32	26.23
2017	129	128.65	24.18	68441.9	18	13.95
2018	104	97.93	18.74	192845.9	23	22.12
2019	134	134.00	28.27	9998.5	26	19.40
2020	67	66.20	11.53	29231.4	28	41.79
2021	143	136.45	32.21	250694.6	60	41.96
2022	156	154.61	30.76	100144.9	55	35.26
2023	143	142.77	28.44	41228.2	53	37.06
2024	139	136.97	23.88	35726.4	20	14.39

- 100~300 individuals of 'mackerel' (chub + blue) were sampled per station
- Percentages of positive catch were over 35%, but became less than 15% in 2024
- Sampling stations in 2001 and some stations without water temperature data were removed

Map of catch and CPUE of age-0 CM fish

Fig. 1B: Catch

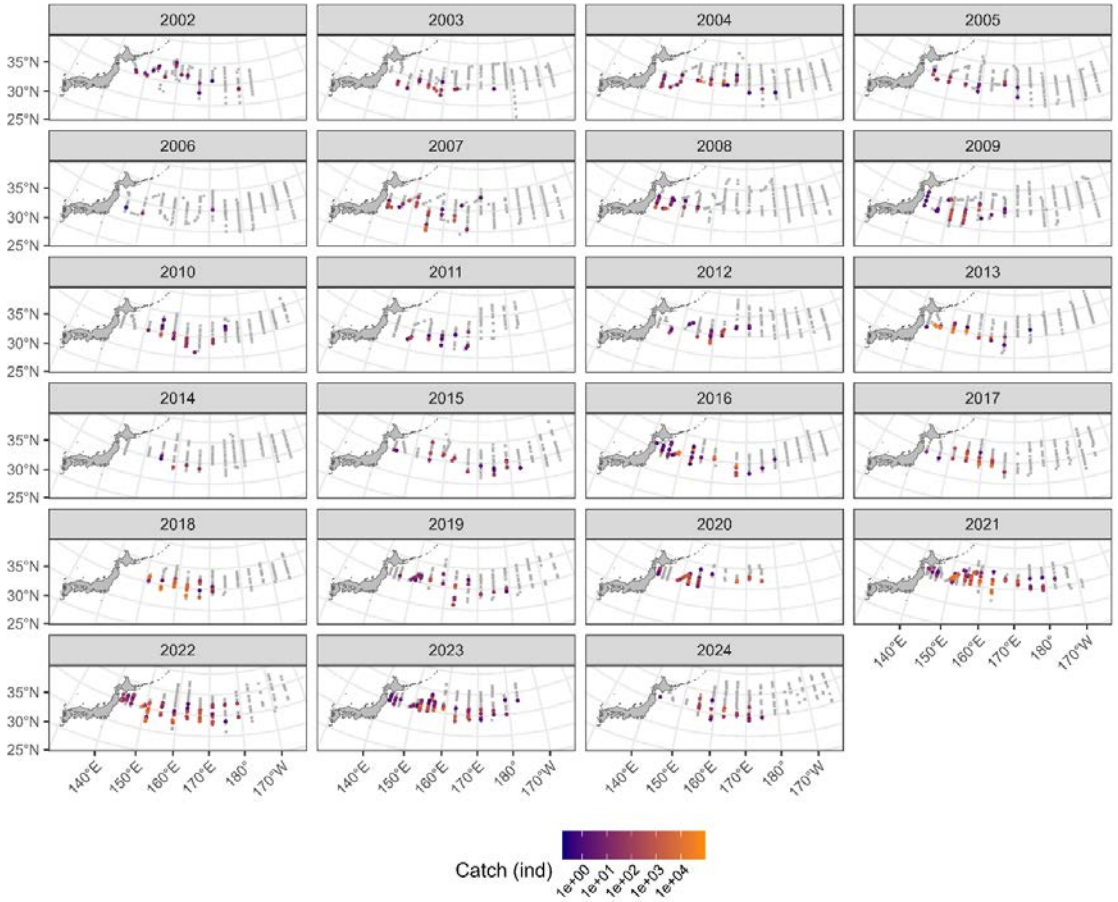
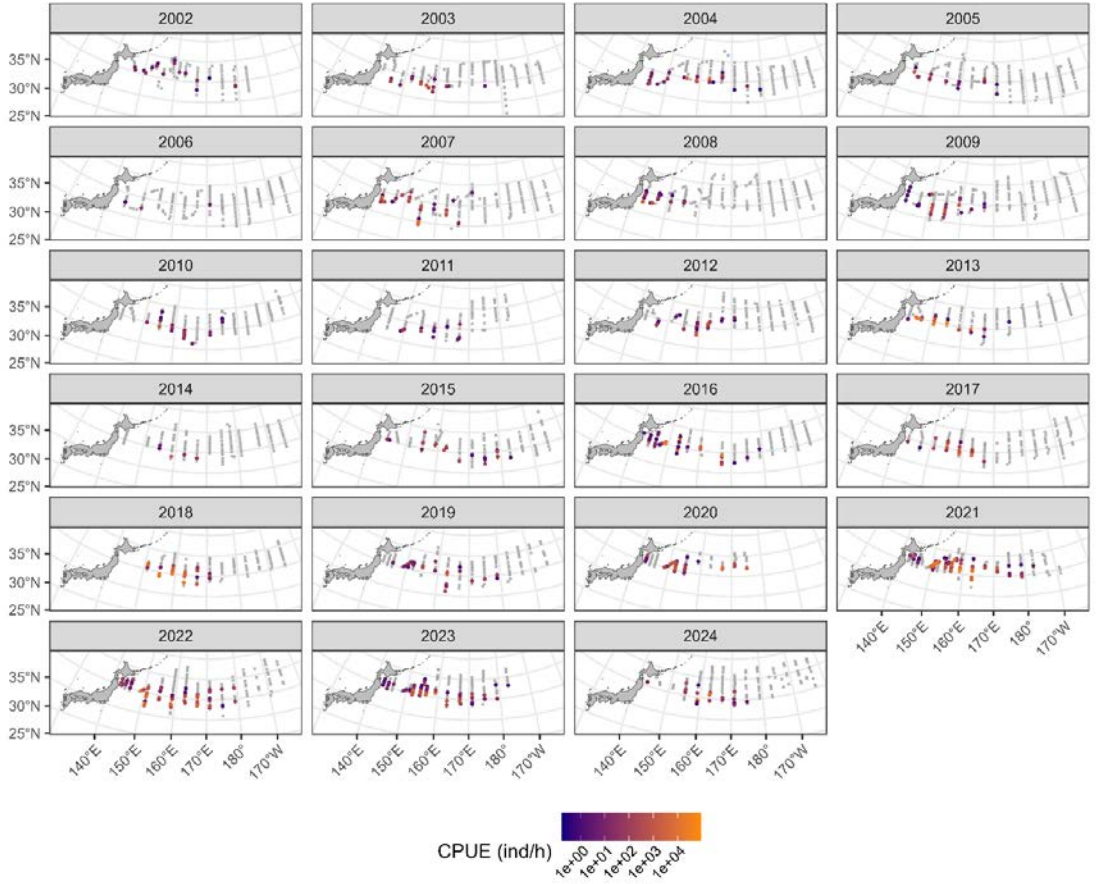


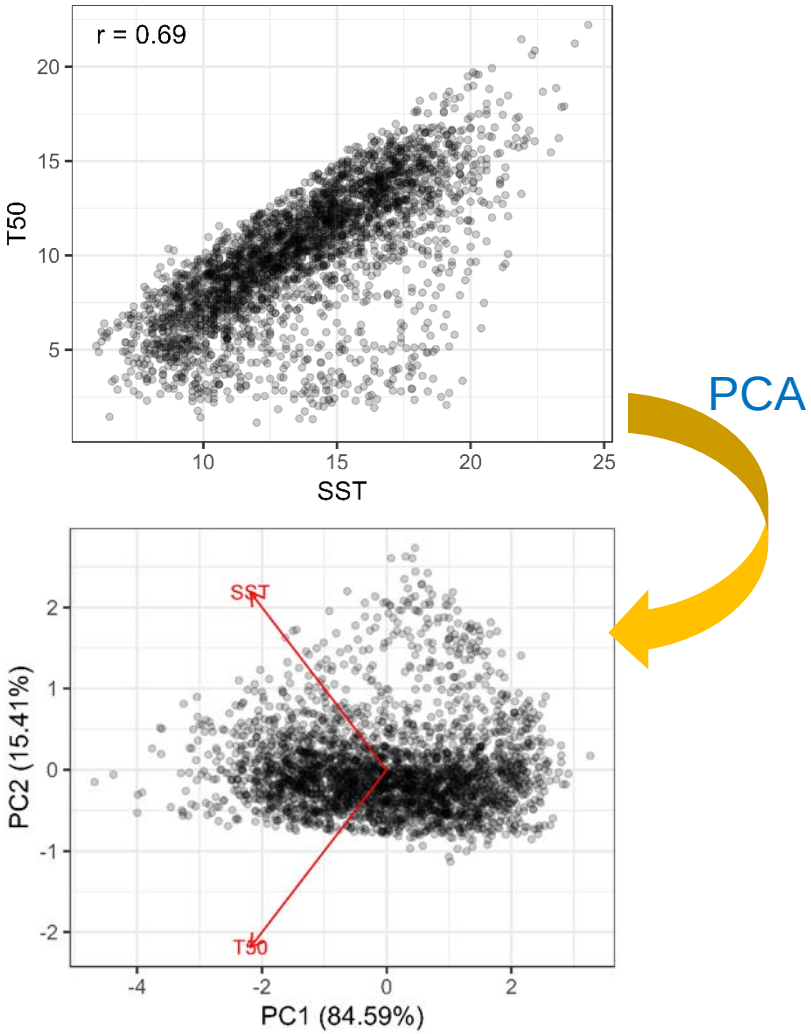
Fig. 1C: CPUE



- Catch and CPUE patterns are quite similar because of effort is almost 1 (hour)
- Age 0 fish of CM were likely to be caught in southern areas

Principal component analysis (PCA)

Fig. 2



- Collinearity in covariates could destabilize parameter estimates

  →problematic in the interpretation of results and model predictions
- Conducted the PCA and used PC1 and PC2 calculated from the analysis as orthogonal covariates
- PC1 was negatively correlated with SST and T50, indicating a common component of SST and T50.
- PC2 was positively correlated with SST but negatively with T50, reflecting a difference between SST and T50.

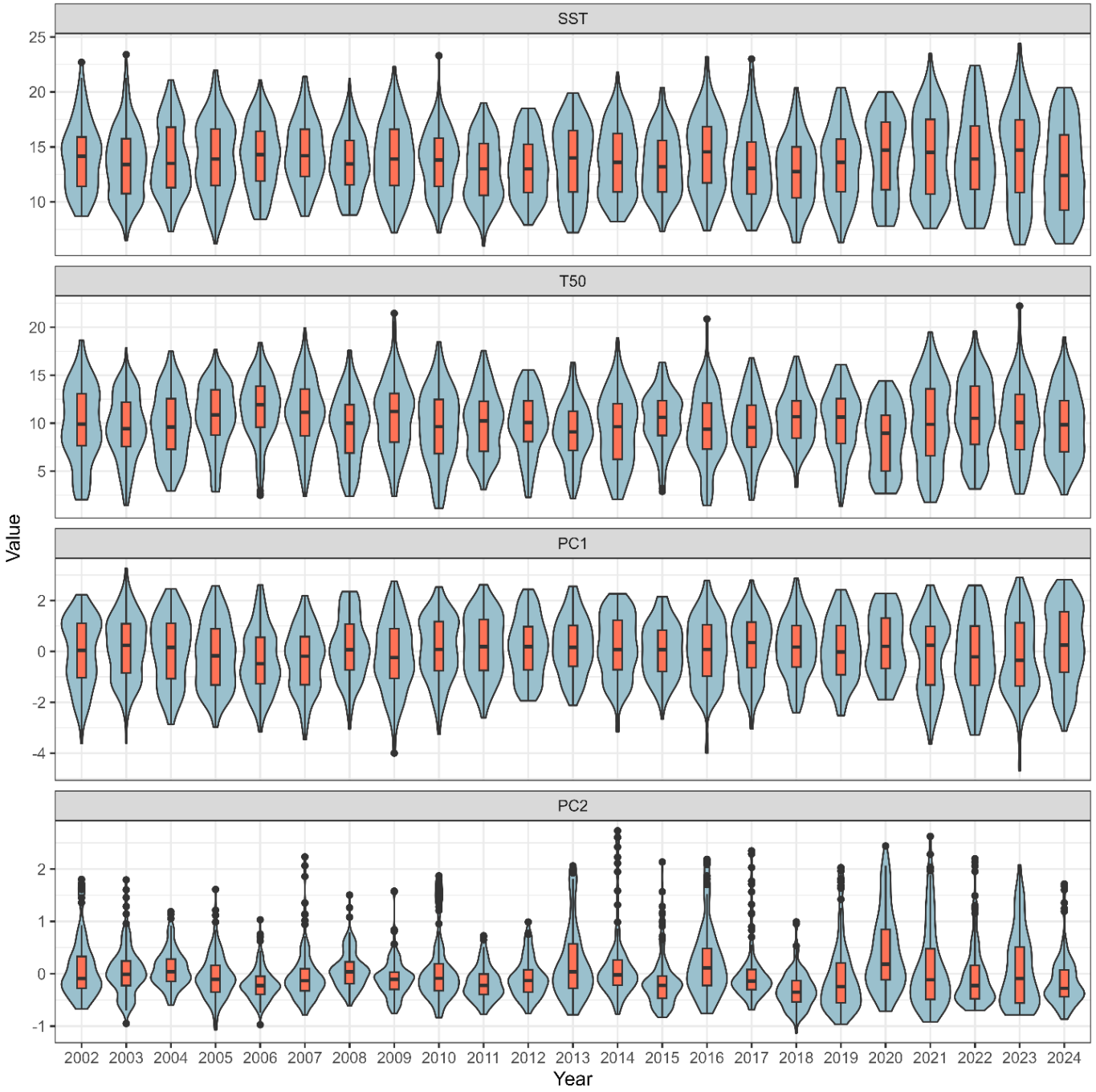


Fig. 3

SST, T50, PC1, and PC2 did not show any systematic patterns over the years

Model description of the VAST

1st predictor for encounter probability

$$p_1(i) = \beta_1(t_i) + \omega_1(s_i) + \varepsilon_1(s_i, t_i) + \sum_{k_1}^{n_{k1}} \lambda_1(k_1) Q_i(i, k_1)$$

2nd predictor for positive catch rate when encountered

$$p_2(i) = \underbrace{\beta_2(t_i)}_{\text{temporal}} + \underbrace{\omega_2(s_i)}_{\text{spatial}} + \underbrace{\varepsilon_2(s_i, t_i)}_{\text{spatio-temporal}} + \underbrace{\sum_{k_2}^{n_{k2}} \lambda_2(k_2) Q_i(i, k_2)}_{\text{catchability covariate}}$$

The encounter probability transformed the inverse function of logit link

$$r_1(i) = \text{logit}^{-1} p_1(i)\,,$$

The positive catch rate transformed the inverse function of log (i.e., exp)

$$r_2(i) = a_i \times \log^{-1} p_2(i)\,. \qquad (a_i = 1 \text{ in this study})$$

The probability density function

Binomial model

$$\Pr(b_i = B) = \begin{cases} 1 - r_1(i) & \text{if } B = 0 \\ r_1(i) \times g\{B | r_2(i), \sigma_m^2\} & \text{if } B > 0 \end{cases}$$

Function for Gamma distribution

Used covariates and other settings

Table 3

Variable	Symbol[1]	Number of categories	Detail	Note
Year	$\beta(t)$	23	2002-2024	Categorical variable with fixed effect
Spatial	$\omega(s)$	-	Average over years	- Estimated as random effects by SPDE approximation - Turned off in the second predictor
Spatio-temporal	$\varepsilon(s,t)$	-	Assume independence of each year	Estimated as random effects by SPDE approximation
PC1	$\lambda(k)Q_i(i,k))$	-	Negative correlation for SST and T50	Continuous variable as a catchability covariate
PC1 squared	$\lambda(k)Q_i(i,k))$	-	Squared PC1	Continuous variable as a catchability covariate
PC2	$\lambda(k)Q_i(i,k))$	-	Positive correlation for SST and negative correlation for T50	Continuous variable as a catchability covariate
PC2 squared	$\lambda(k)Q_i(i,k))$	-	Squared PC1	Continuous variable as a catchability covariate
PC1 X PC2	$\lambda(k)Q_i(i,k))$	-	Interaction between the two PC axes	Continuous variable as a catchability covariate

Basic information

- The number of knots was set as 100
- The effect of year was estimated as a categorical variable by fixed effects
- PC1, PC2, their squared terms, and their 1st order interaction were treated as catchability

Update from 2023

- turned off the spatial effect in the second predictor

Model selection

Table 4

Rank	PC1	PC1 squared	PC2	PC2 squared	PC1xPC2	Df
1	B,G	B	B,G	B,G	B	60
2	B,G	B	B,G	B	B	59
3	B,G	B,G	B,G	B,G	B	61
4	B,G	B,G	B,G	B	B	60
5	B,G	B,G	B,G	B,G	B,G	62
6	B,G	B,G	B,G	B	B,G	61
7	B,G	B	B,G	B,G	B,G	61
8	B,G	B	B,G	G	B	59
9	B,G	B	B,G		B	58
10	B,G	B,G	B,G	G	B	60
11	B,G	B,G	B,G		B	59
12	B,G	B,G	B	B	B	59
13	B,G	B,G	B,G	G	B,G	61
14	B,G	B	B,G	B	B,G	60
15	B,G	B	B,G		B,G	59
16	B,G	B	B,G	G	B,G	60
17	B,G	B	B		B	57
18	B	B	B		B	56
19	B	B	B,G	G	B	58
20	B,G	B	B,G			57

- Model selection was conducted using exhaustive search based on Akaike Information Criterion with correction (AICc).
- Only PC1 squared and 1st order interaction of PC1 and PC2 were not selected for positive catch rate when encountered (G) in the best model

Model diagnostics for scaled residuals

- Generated scaled residuals using the R package ‘DHARMa’ (Hartig 2022) for model diagnostics
- This package enables to simulate the scaled residuals which should theoretically follow the uniform distribution from zero to one

Fig. 5

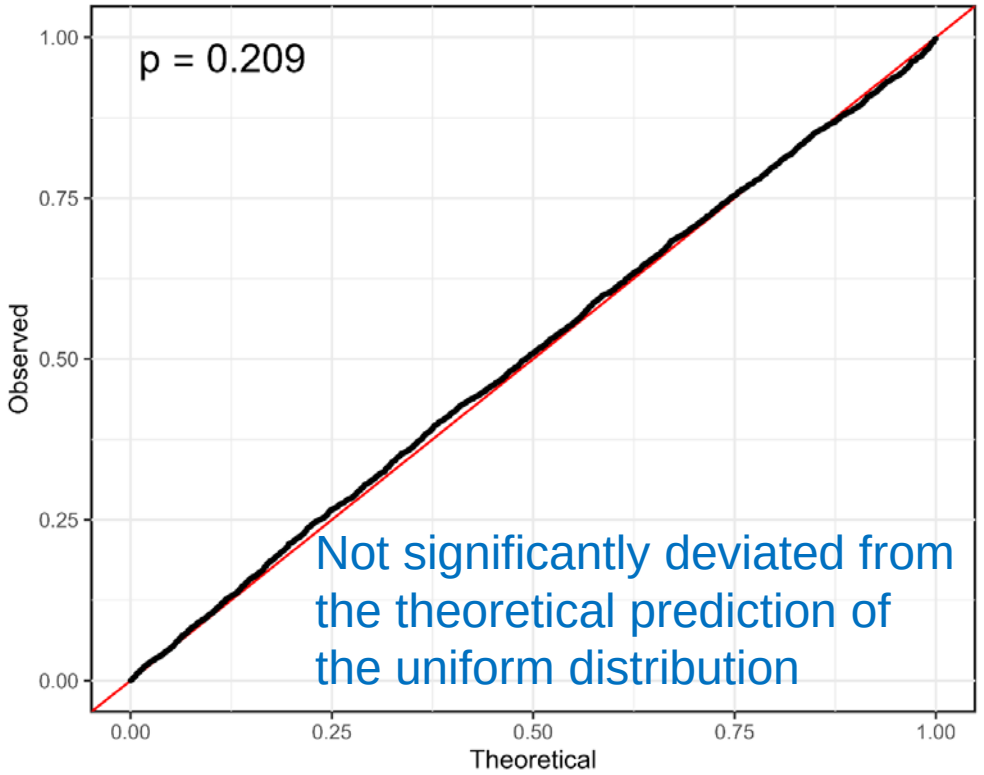
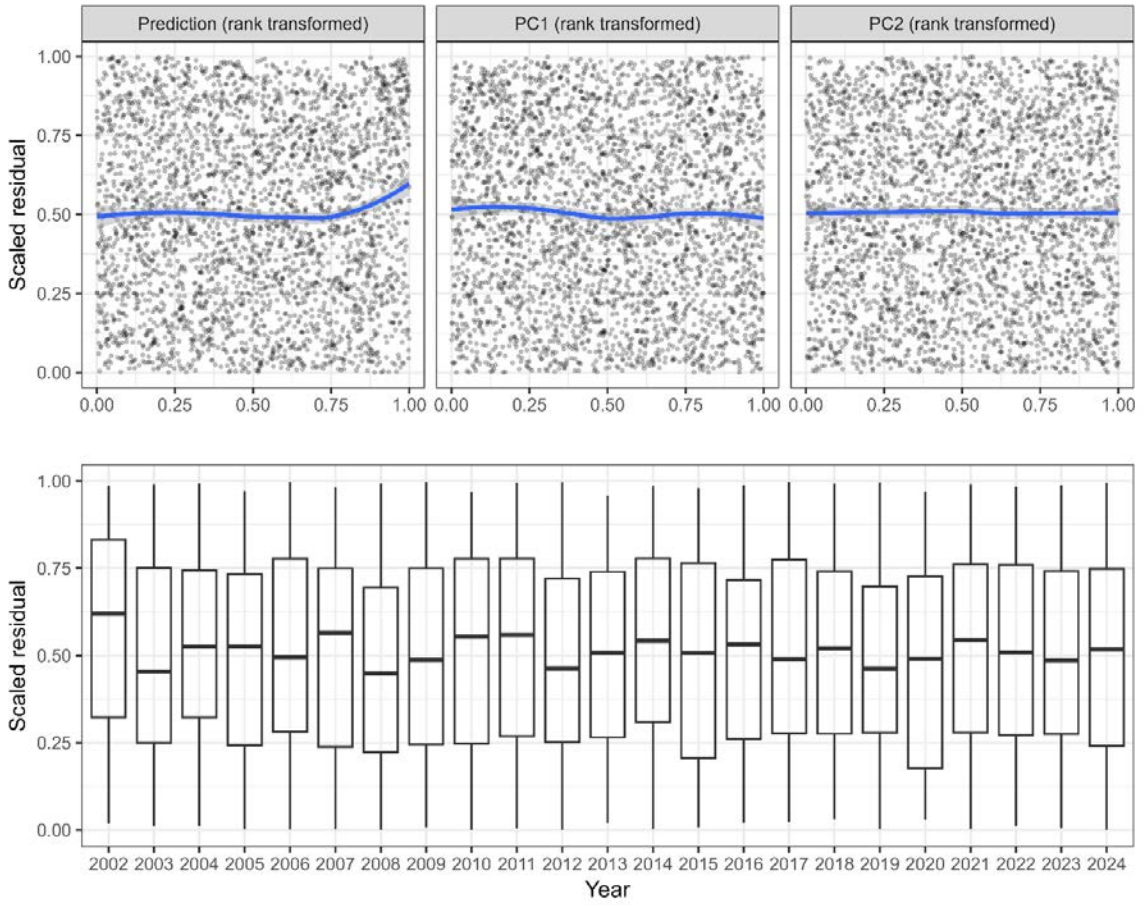


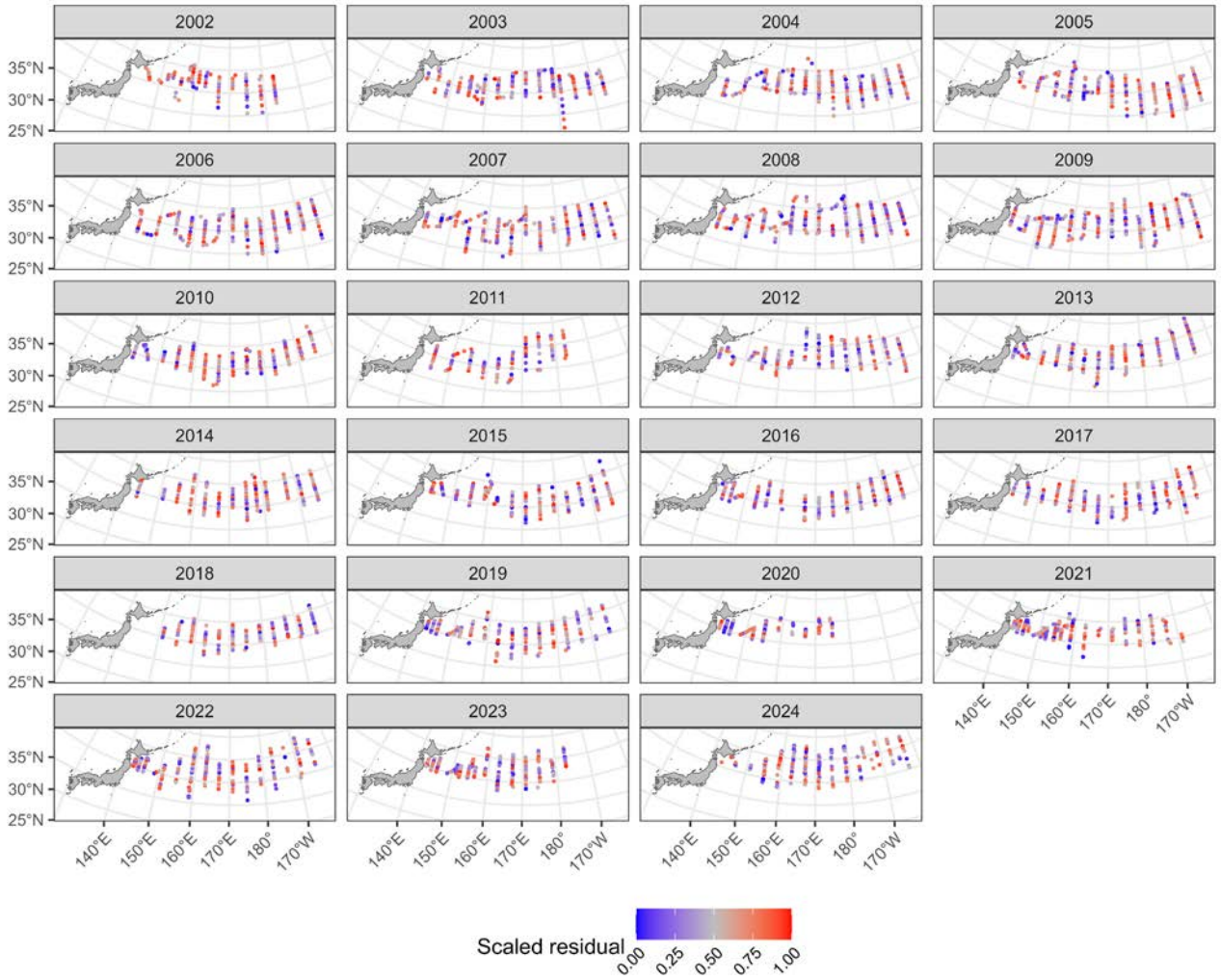
Fig. 6

The averages were not deviated from the theoretical average (0.5) in response to predicted values and covariates



Map of scaled residuals in each year

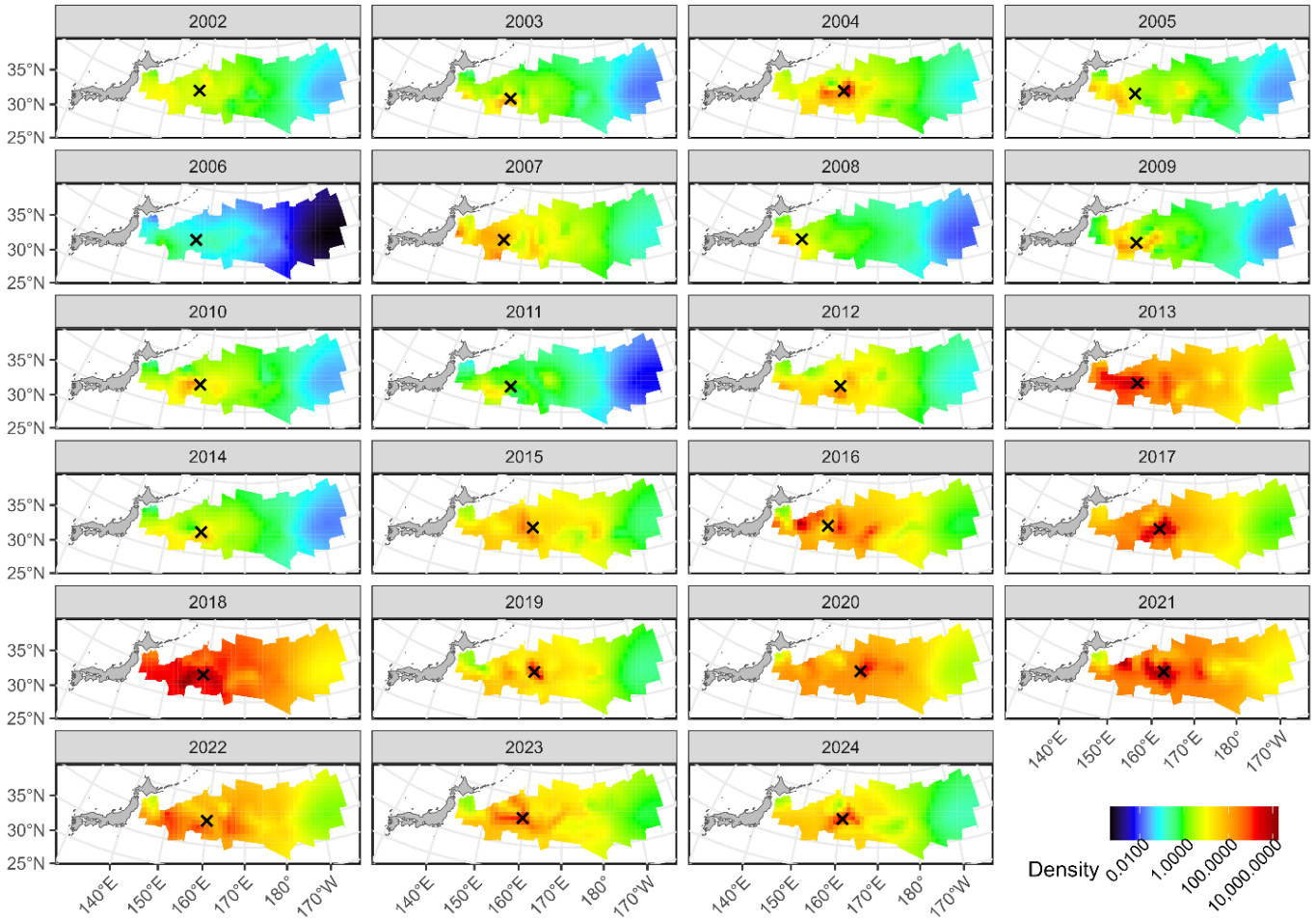
Fig. 7



No systematic spatial patterns in scaled residuals

Map of estimated densities

Fig. 8



- Local densities were estimated from the product of encounter probability and positive catch rate when encountered

$$d(s,t) = r_1^*(s,t) \times r_2^*(s,t)$$

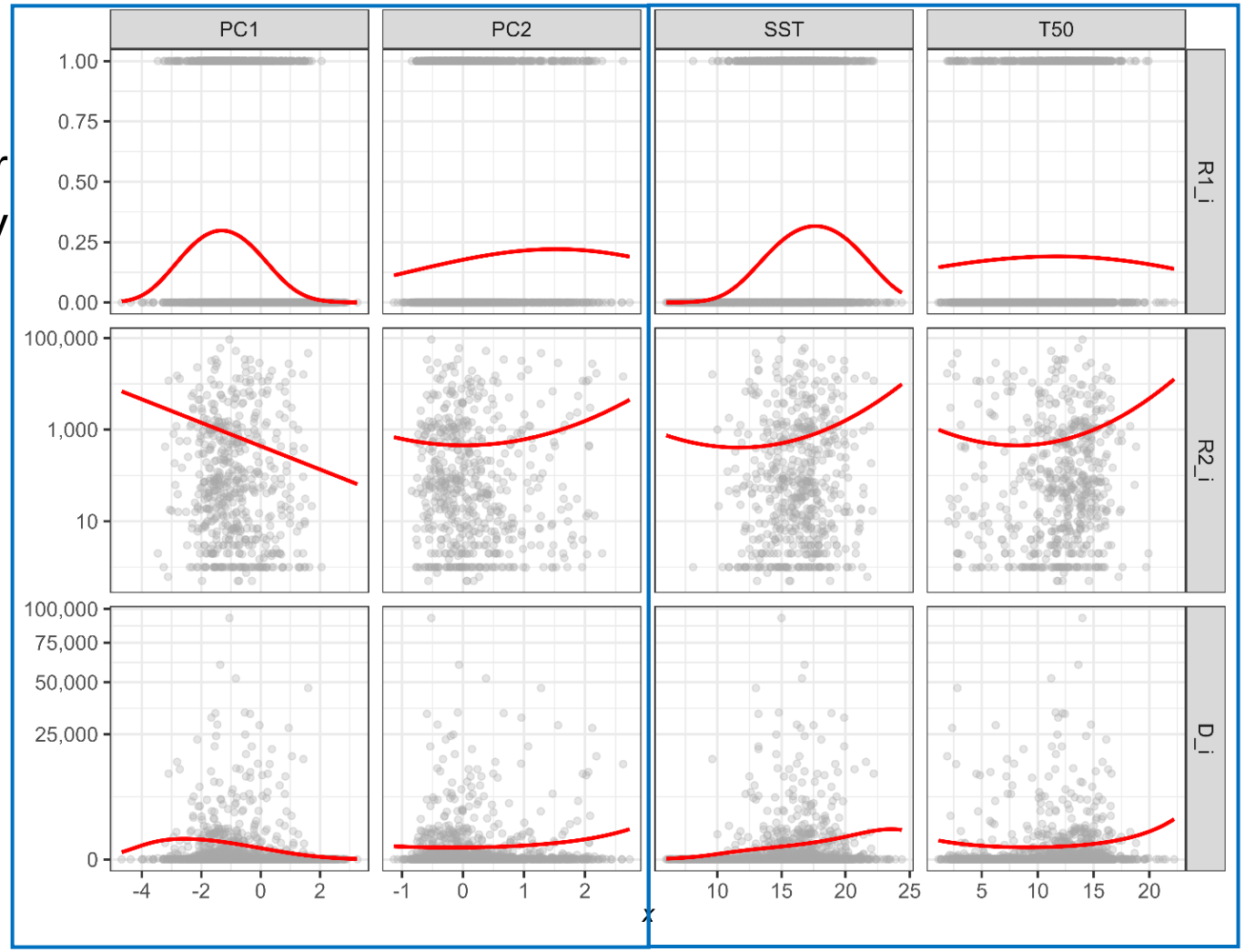
- The terms of catchability covariates were dropped off (assuming $\lambda = 0$)

- Estimated densities of young-of-the-year (YOY) fish had been high until 2021, but decreasing thereafter

- The centroid of fish distributions was relatively constant over the years

Relationships between covariates and CPUE

Fig. 9: Partial dependence plots



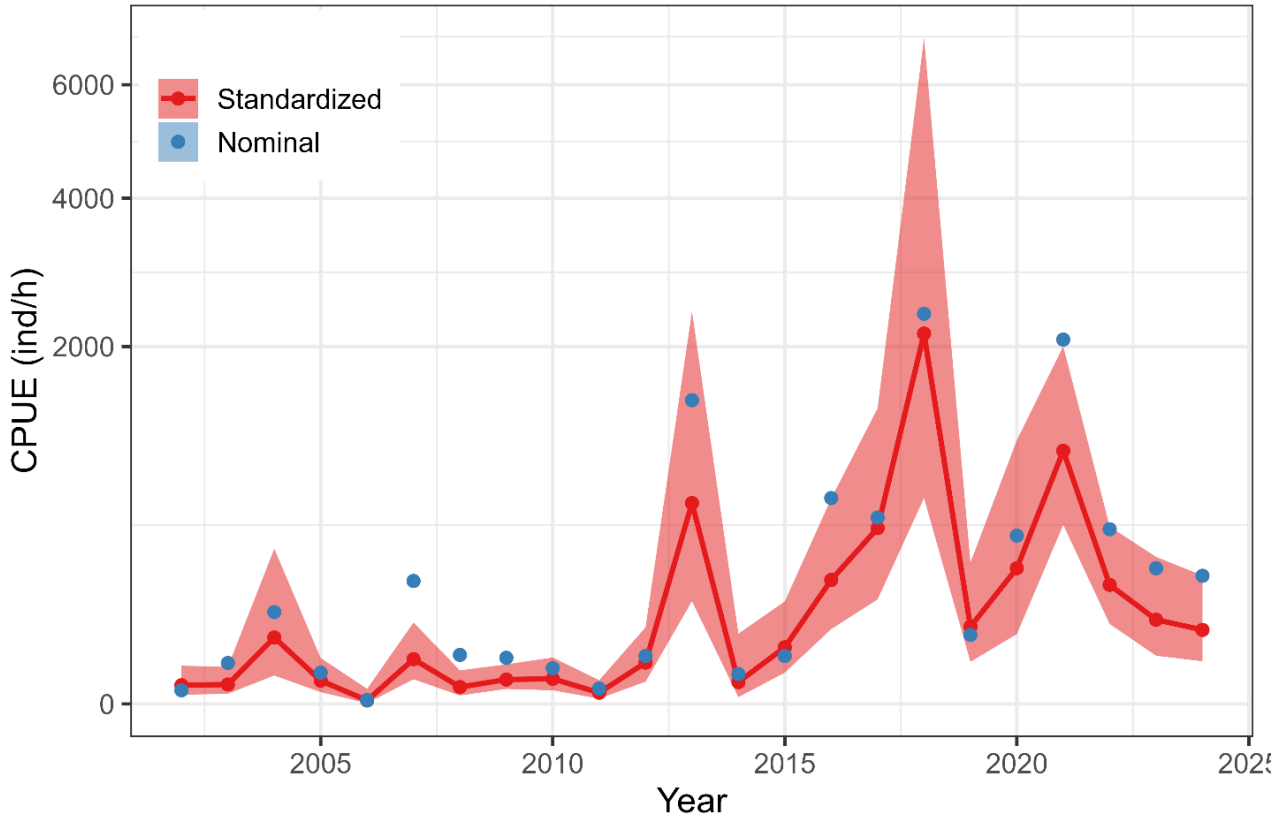
- Concave-down responses of encounter probability to PC1 and PC2
- a negative response for PC1, a concave-up response for PC2
- SST had a greater influence than T50.
- The probability of positive catch peaked around 17.5° C for SST,
- The overall CPUE is highest at temperatures exceeding 20° C.

Yearly trends of nominal and standardized CPUE

area density

Average density (CPUE) $I(t) = \frac{\sum_{s=1}^{n_s}\left(a(s) \times d(s,t)\right)}{\sum_{s=1}^{n_S} a(s)}$ Abundance / Total area

Fig. 10



- Standardized CPUE remained low until 2012, but high values were frequently observed since 2013
- Especially in 2013, 2018, and 2021, the values were the highest, but the values are decreasing in the recent 3 years (2022–2024)
- The yearly trend of the standardized CPUE was not greatly different from that of the nominal CPUE

Values and uncertainties of the nominal and standardized CPUE

Table 6

Year	Nominal (ind/h)	Standardized (ind/h)	CV	Lower 95%CI	Upper 95%CI
2002	2.94	5.49	0.27	1.31	22.91
2003	26.22	5.93	0.29	1.64	21.48
2004	132.07	69.13	0.39	12.68	377.02
2005	15.31	8.53	0.28	2.20	33.02
2006	0.24	0.19	0.50	0.01	3.57
2007	236.63	31.40	0.26	9.51	103.67
2008	37.65	4.48	0.32	1.14	17.64
2009	33.33	9.31	0.24	3.53	24.51
2010	19.97	9.92	0.25	2.92	33.78
2011	3.75	1.97	0.29	0.44	8.82
2012	35.95	26.78	0.24	7.79	92.03
2013	1443.45	631.49	0.28	165.37	2411.42
2014	14.03	7.50	0.40	0.73	77.27
2015	36.02	50.23	0.23	15.34	164.45
2016	663.42	240.65	0.25	87.69	660.43
2017	543.68	483.91	0.22	171.17	1368.04
2018	2382.26	2146.30	0.24	663.32	6944.81
2019	74.62	93.35	0.23	27.86	312.76
2020	443.27	288.37	0.26	76.37	1088.86
2021	2077.32	1002.57	0.17	502.14	2001.75
2022	477.73	221.93	0.18	100.04	492.32
2023	288.17	111.15	0.26	36.49	338.55
2024	257.07	85.78	0.24	28.51	258.12

- The coefficient of variation (CV) of the standardized CPUE was in the range of 0.22−0.50 for almost all years