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Standardized Abundance Indices for Ages 0 and 1 Fish of Chub Mackerel from Northwest Pacific Autumn Surveys up to 2023

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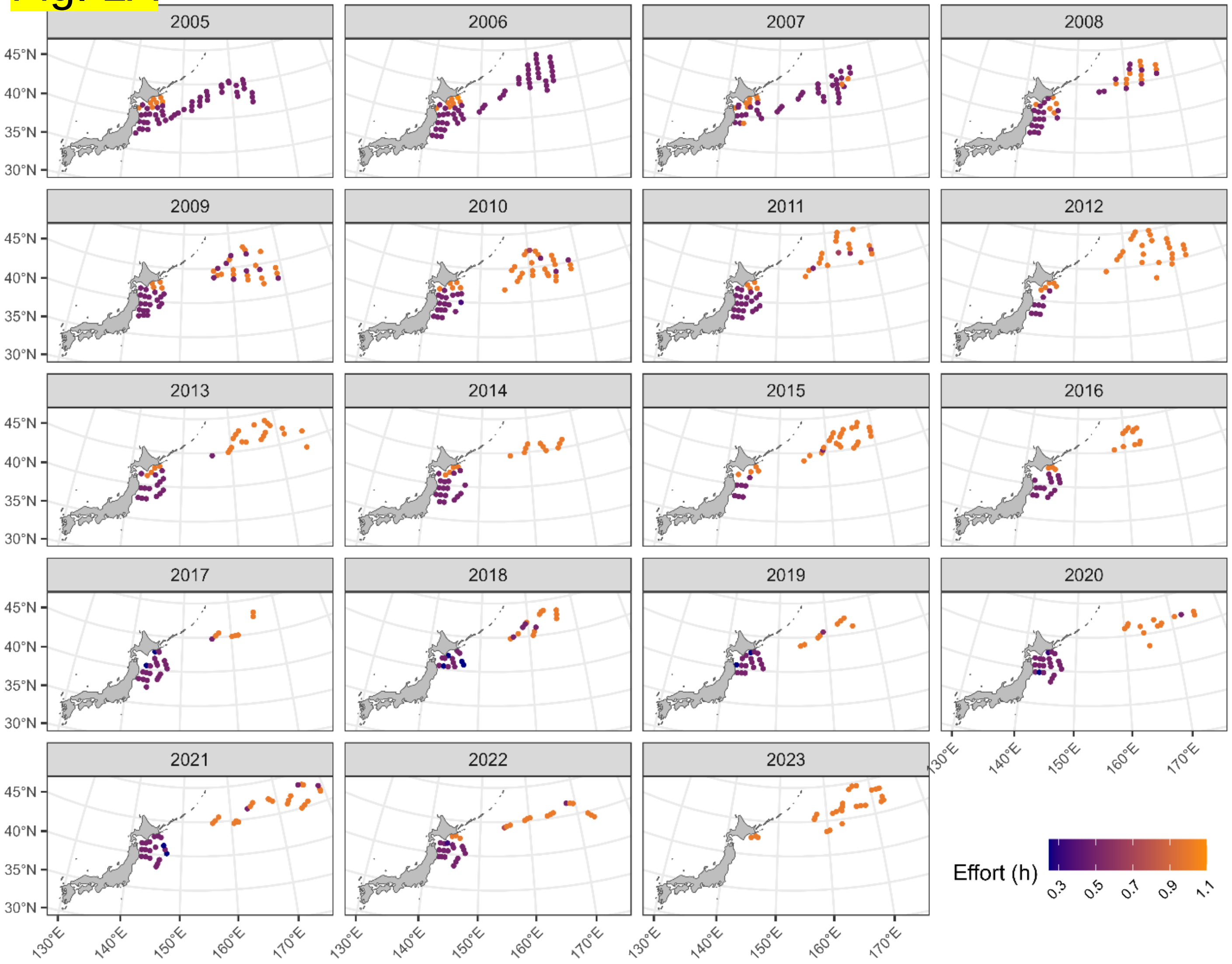
Summary

- We conducted CPUE standardization of surface trawl surveys in autumn for Pacific chub mackerel using the Vector Autoregressive Spatio-Temporal (VAST) model
- We estimated local densities of 0-year-old fish and 1-year-old fish in the Northwest Pacific from 2005 to 2023 with consideration for environmental factors of sea surface temperature (SST) and 30m-depth temperature as well as spatial autocorrelation
- The analysis showed high levels of abundances frequently occurred since 2013 Model diagnostics found no serious problems in residual patterns
- We propose the standardized indices to be utilized as the abundance indices of age-0-fish and age-1-fish in the Technical Working Group for the Chub Mackerel Stock Assessment (TWG CMSA).

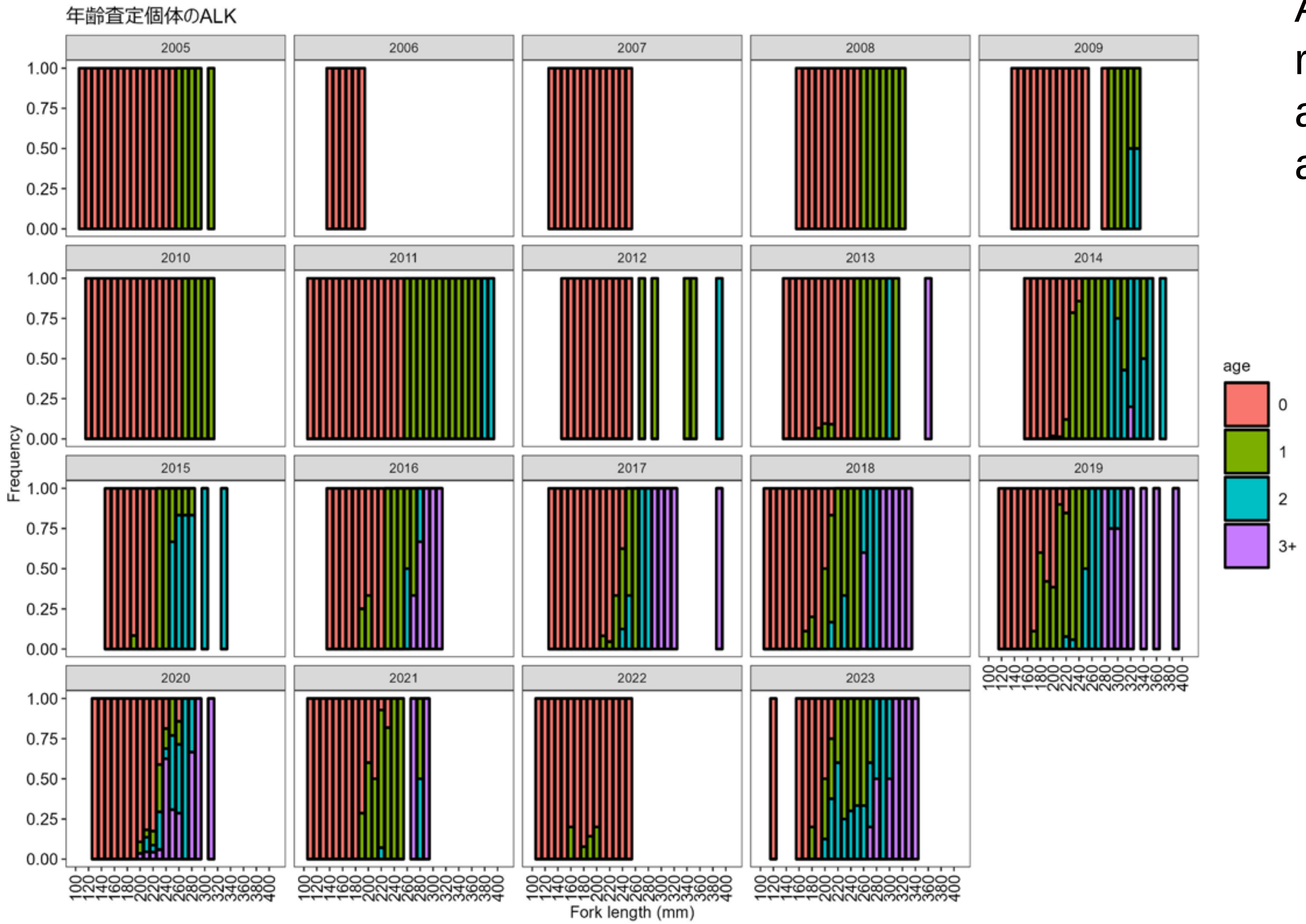
Autumn surveys by Japan

Fig. 1A



- Japan (FRA) has conducted sea surface trawl surveys in the Northwest Pacific Ocean from September to October annually to collect biological and abundance information on small pelagic fish including chub mackerel
- The standardized CPUE of young-of-the-year (YOY) fish from this survey had long been used in the Japanese domestic stock assessment of chub mackerel and was submitted to TWG CMSA as working papers several times (e.g., Nishijima et al. 2022)
- In addition to age 0 fish, FRA has completed age identification for 1-year-old (YO) fish of chub mackerel in the autumn survey samples, and then newly used the standardized CPUE of age 1 fish in the latest Japanese domestic stock assessment (Yukami et al. 2023).

Development of Age-Length Key



An age determination was conducted by reading the transverse sections of otoliths for an average of 100 chub mackerel individuals annually

Changes since the last document

	Previous WP	Current WP
Objective	Age 0	Ages 0 and 1
Model	Delta-GLM-tree (Hashimoto et al. 2019)	VAST (Thorson et al. 2019)
Environmental covariate	SST, 30m-depth temperature (T30)	Principal components (PC1, PC2)
Years	2005-2021	2005-2021

- The objective of CPUE standardization is to the development of not only age-0-fish but also age-1-fish of CM
- VAST was found to outperform the delta-GLM-tree in terms of Akaike Information Criterion (AIC) (Yukami et al. 2023)
- We used principal component analysis (PCA) to resolve a high correlation between SST and T30
- We extended the duration of years into 2023

Catch and effort information

Table 1

Year	Number of observations (stations)	Trawling time (hour)	Catch of age 0 fish (ind)	Number of positive catch (age 0)	% positive catch (age 0)	Catch of age 1 fish (ind)	Number of positive catch (age 1)	% positive catch (age 1)
2005	54	30.6	640.0	14	25.9	50.0	5	9.3
2006	59	33.1	34.0	5	8.5	0.0	0	0.0
2007	46	28.0	233.0	13	28.3	0.0	0	0.0
2008	41	28.0	202.0	9	22.0	75.0	4	9.8
2009	49	34.5	1843.7	22	44.9	14.8	4	8.2
2010	50	39.0	647.3	19	38.0	27.7	5	10.0
2011	44	31.9	114.0	12	27.3	51.0	6	13.6
2012	37	33.0	607.9	16	43.2	6.1	4	10.8
2013	39	31.0	38953.4	26	66.7	1910.5	24	61.5
2014	32	23.0	3265.6	23	71.9	7918.6	24	75.0
2015	34	30.0	4970.4	18	52.9	116.0	17	50.0
2016	29	21.5	36196.8	15	51.7	1412.3	11	37.9
2017	29	17.5	14436.5	14	48.3	965.2	13	44.8
2018	28	18.5	99627.2	26	92.9	13808.4	26	92.9
2019	26	16.6	3801.4	20	76.9	7193.8	20	76.9
2020	35	23.6	21006.7	26	74.3	379.9	24	68.6
2021	43	31.5	24969.5	31	72.1	1029.1	21	48.8
2022	35	25.6	14713.4	26	74.3	1397.8	21	60.0
2023	27	27.0	1898.2	8	29.6	1218.3	8	29.6

- 100~300 individuals of 'mackerel' (chub + blue) were sampled per station, when more than 100 individuals were caught, for species identification and length measurement
- Trawling time (effort) is generally half to one hour
- The proportions of positive catch were lower than 45% for age 0 and 15% for age 1 until 2012 but became higher than 45% for age 0 and 20% for age 1 from 2013 to 2022
- In 2023, however, the proportions of positive catch decreased to 30% for both ages 0 and 1.
- Used all samples (N = 737) because survey areas did not greatly vary, and all the samples recorded necessary information for the analysis (catch, effort, location, and environmental variables)

Map of catch and CPUE of age-0 CM fish

Fig. 1B: Catch

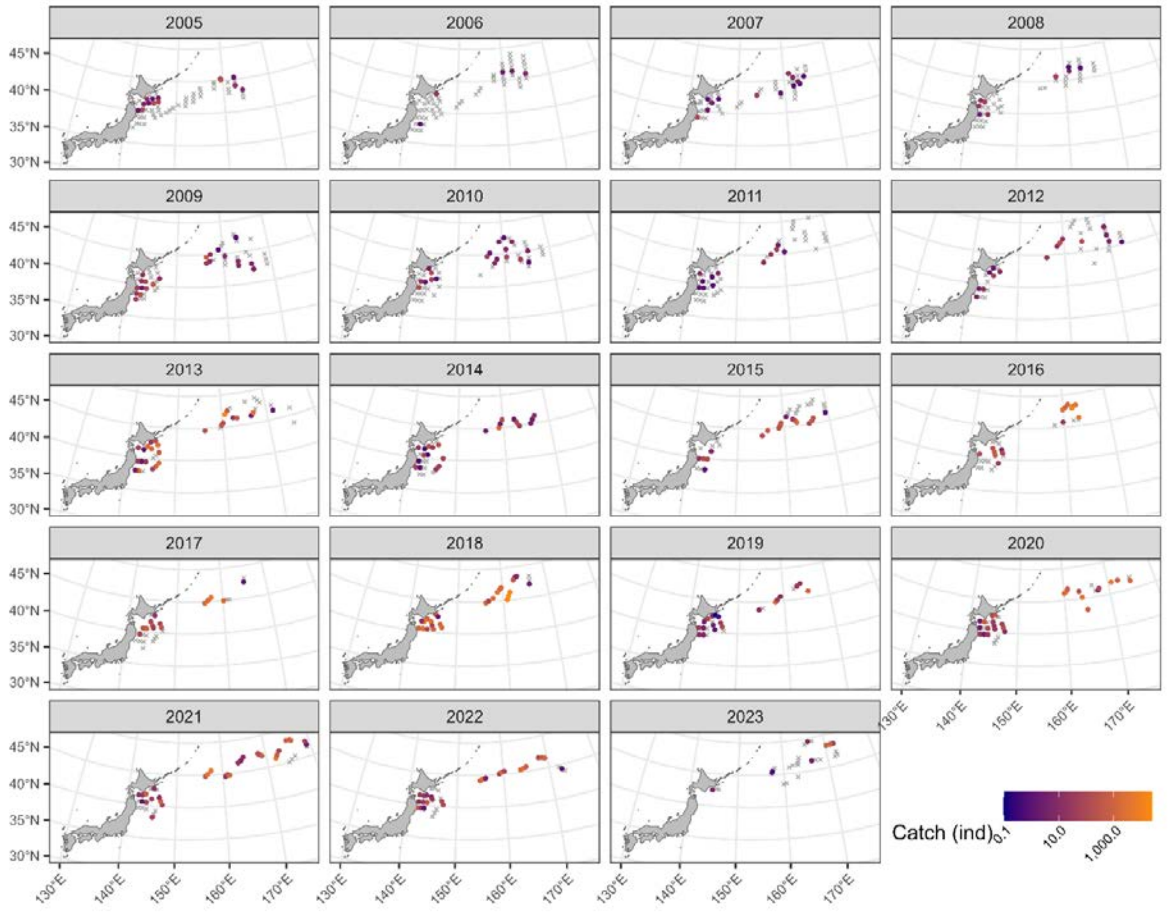
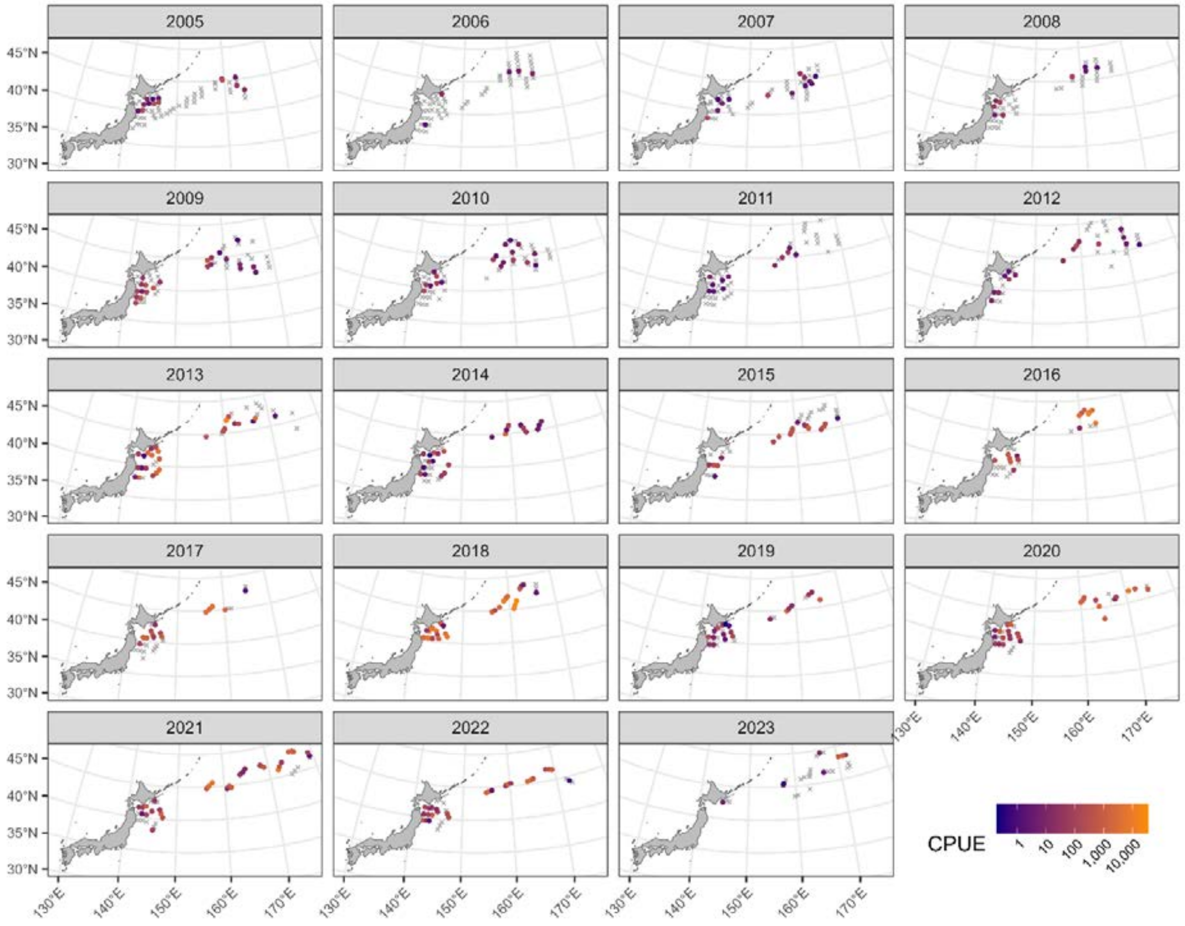


Fig. 1C: CPUE



Map of catch and CPUE of age-1 CM fish

Fig. 1D: Catch

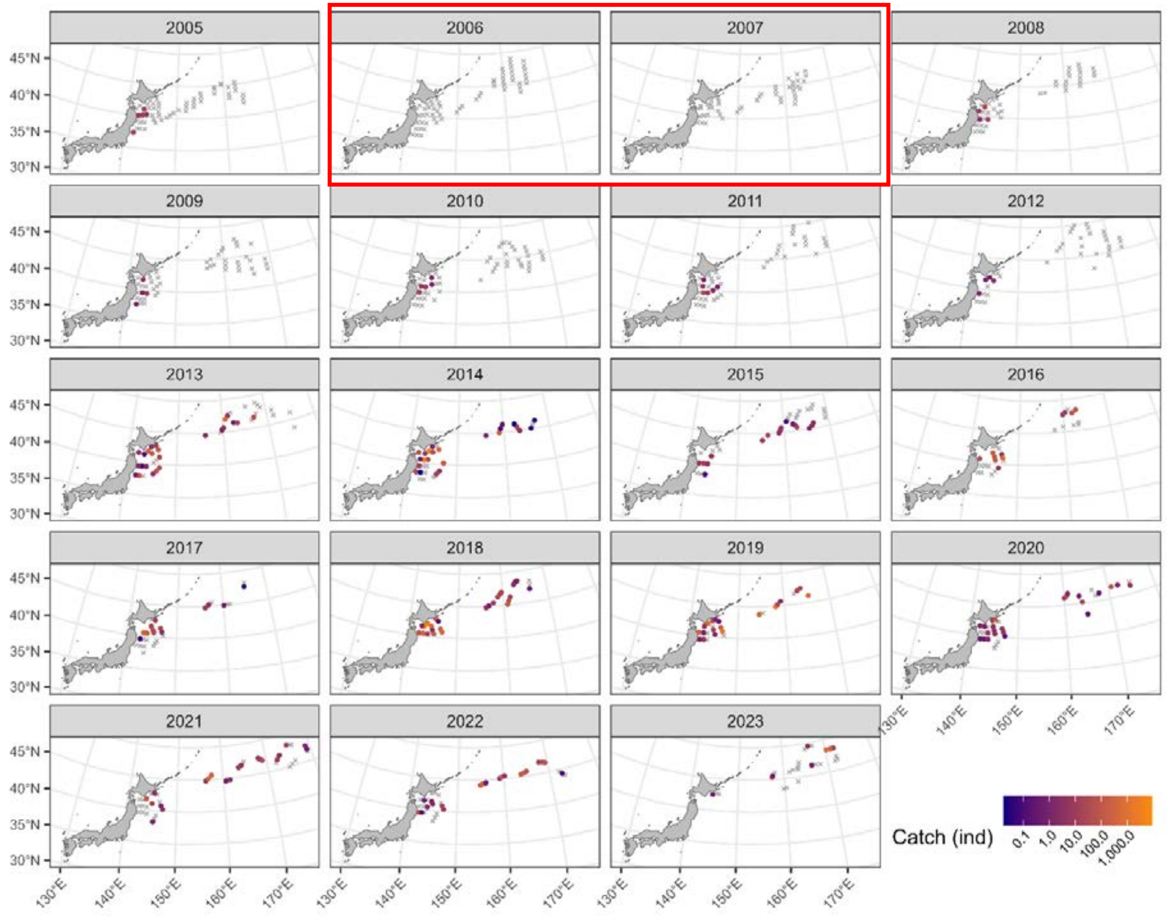
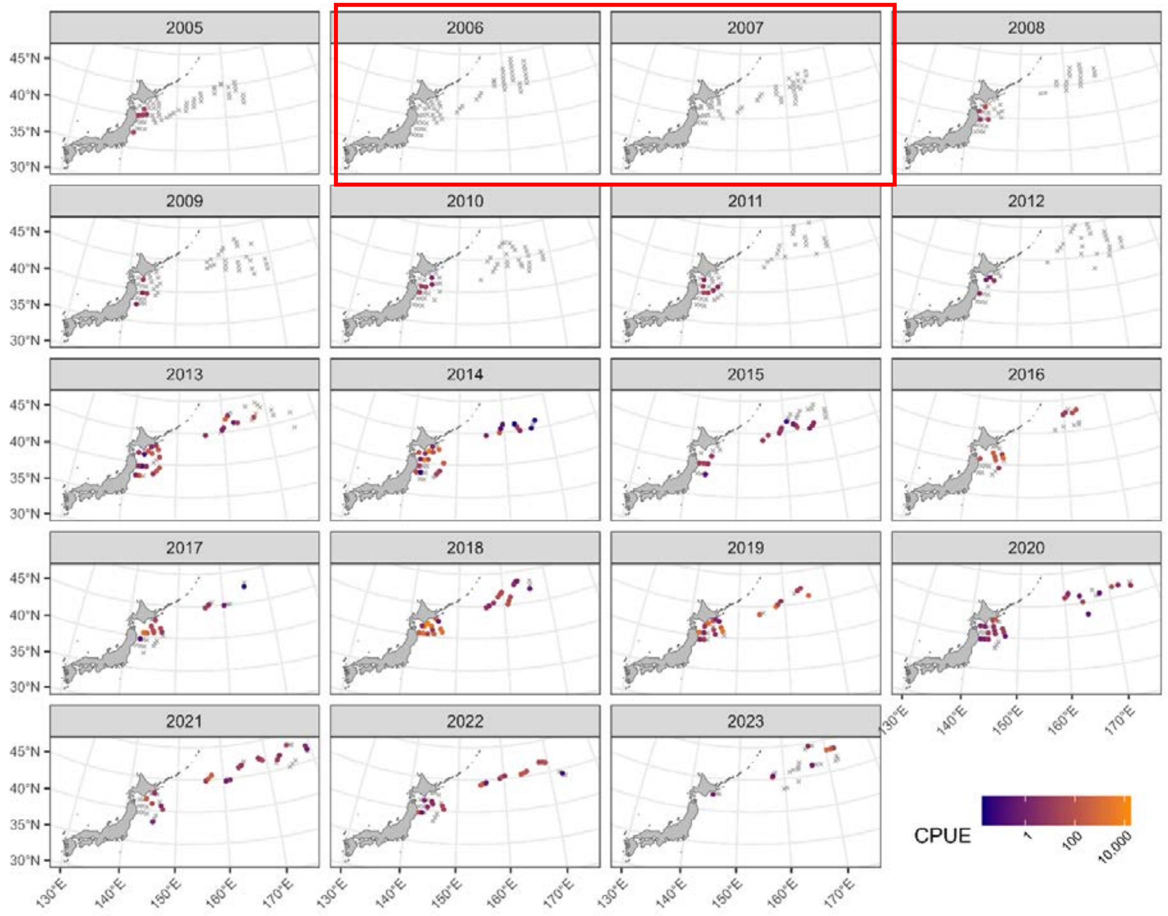


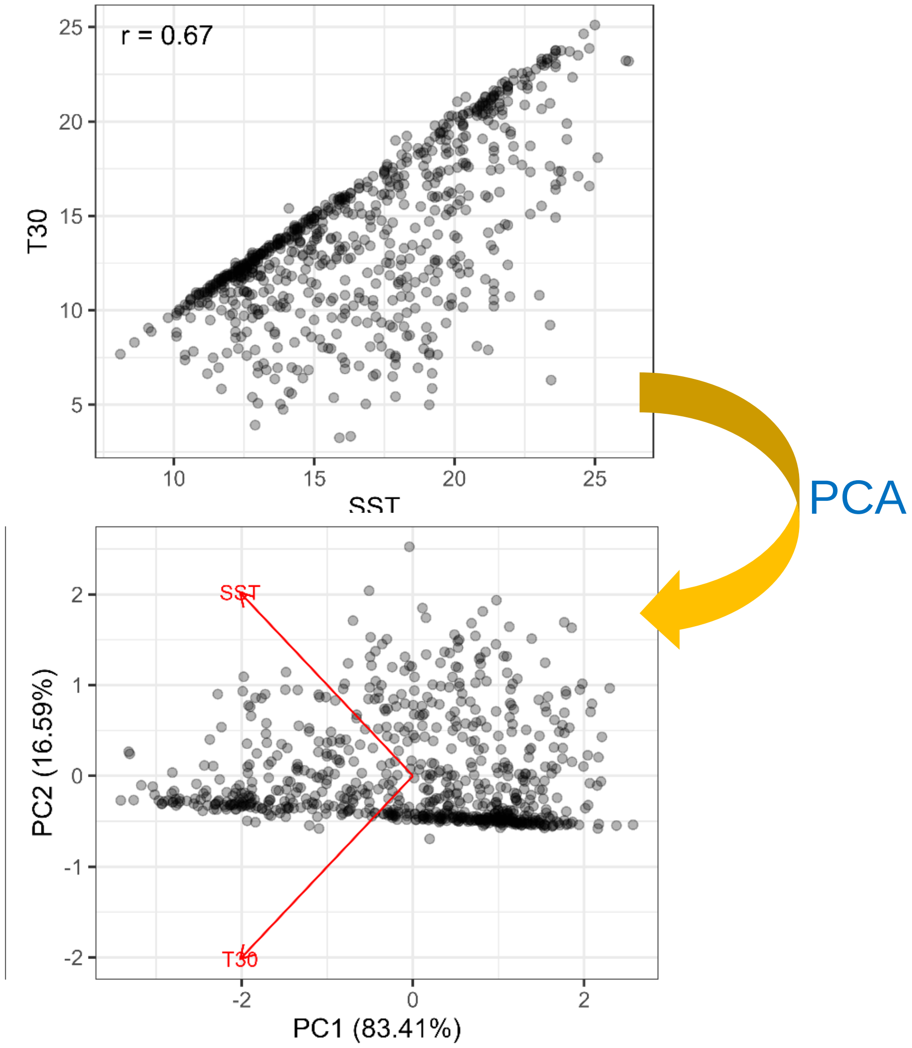
Fig. 1E: CPUE



No individuals of age 1 were captured in 2006 and 2007

Principal component analysis (PCA)

Fig. 2



Almost same as the summer survey

- *In situ* SST and T30 were highly correlated with r = 0.67 of Pearson's correlation coefficient
- Such collinearity in multiple regression models could destabilize parameter estimates and prediction to new data, suggesting that it might be problematic in the interpretation of results and model predictions in CPUE standardization
- Conducted the PCA and used PC1 and PC2 calculated from the analysis as orthogonal covariates
- PC1 was negatively correlated with SST and T30, indicating a common component of SST and T30.
- PC2 was positively correlated with SST but negatively with T30, reflecting a difference between SST and T30.
- The proportion of variance of PC1 and PC2 were 83.4% and 16.6%, respectively

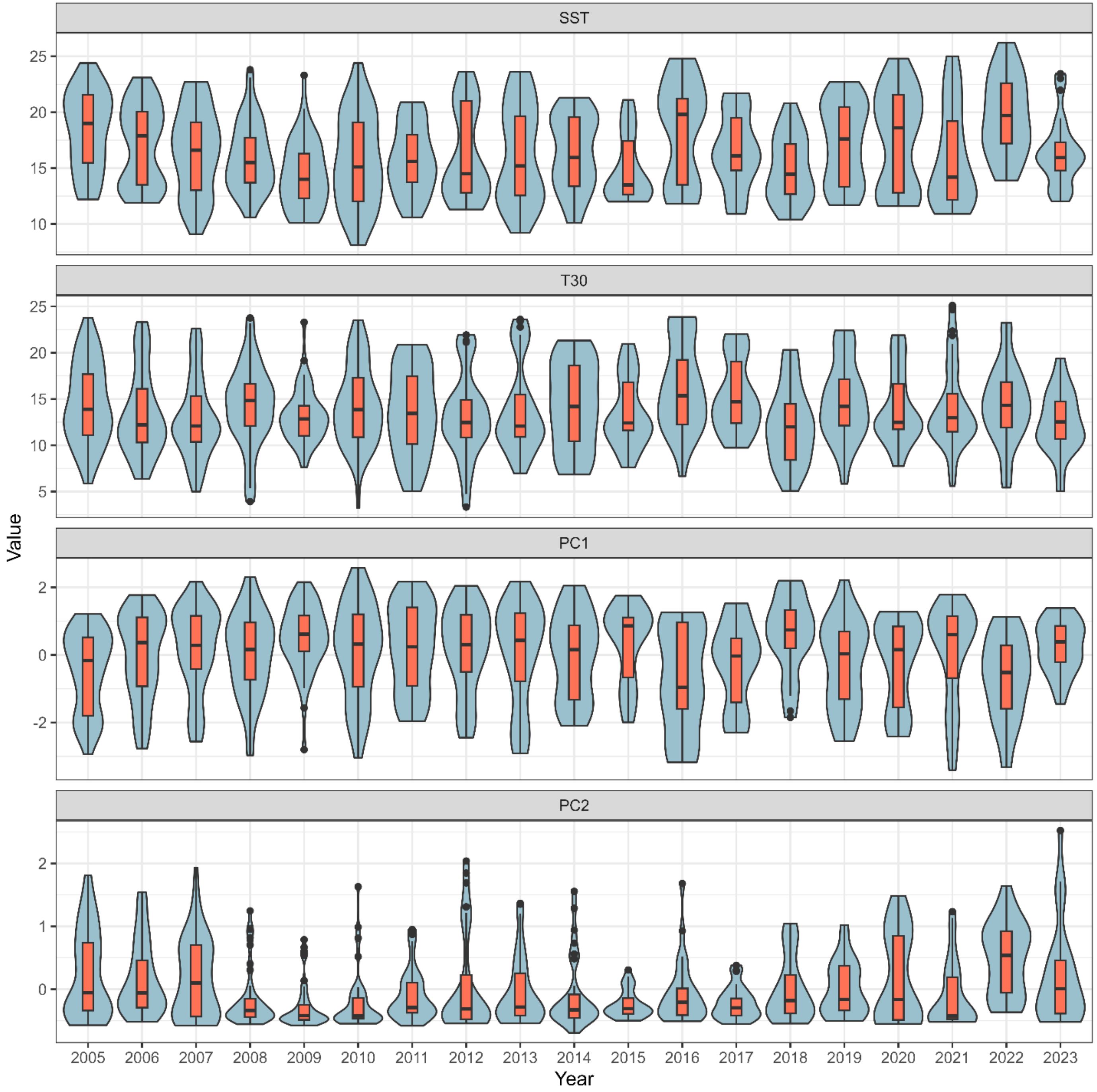


Fig. 3

- SST, PC1, and PC2 moderately varied over the years
- T30 seemed to be relatively stable

Spatial patterns of SST and T30 in each year

Fig. 4A

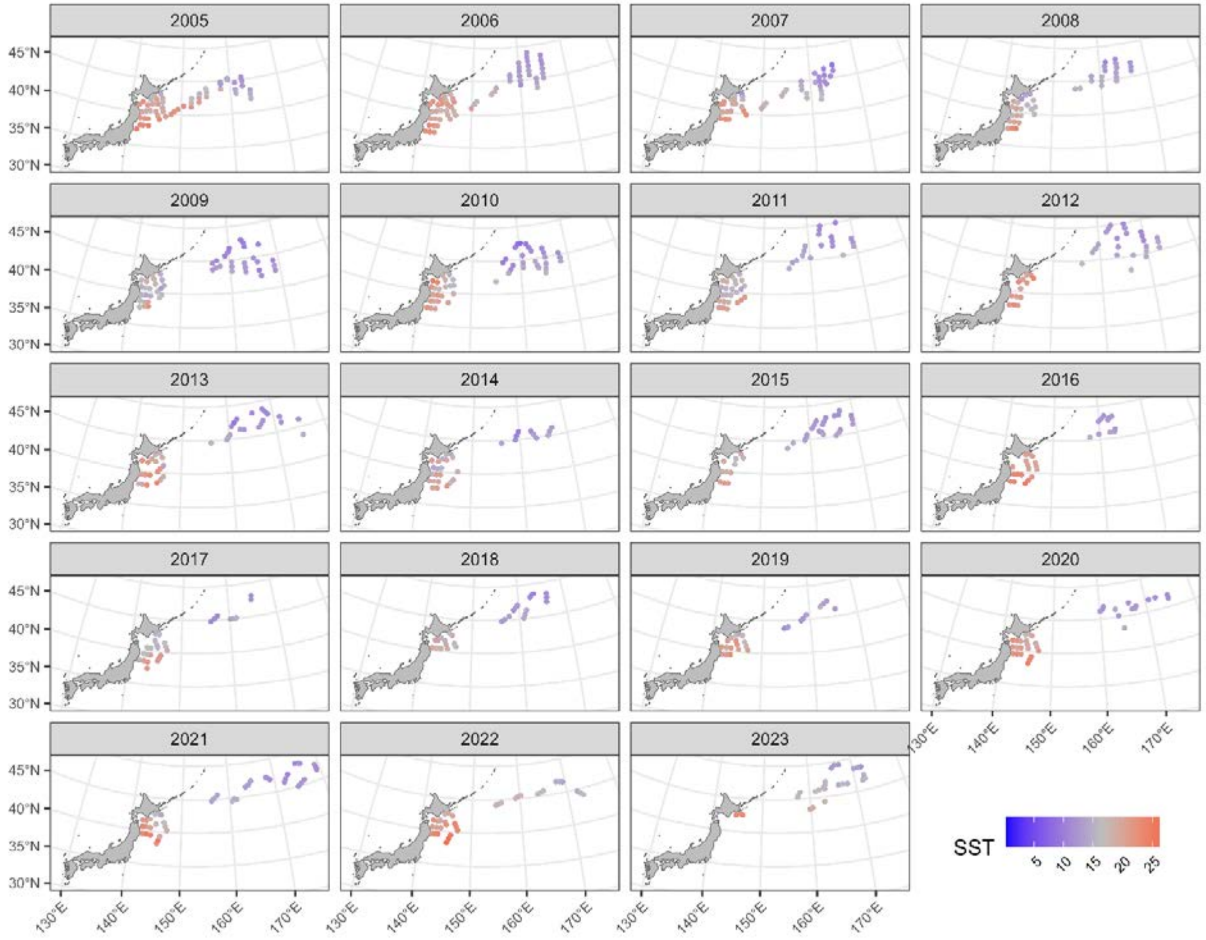


Fig. 4B

- SST and T30 tended to be higher in the southwest than in the northeast

Spatial patterns of PC1 and PC2 in each year

Fig. 4C

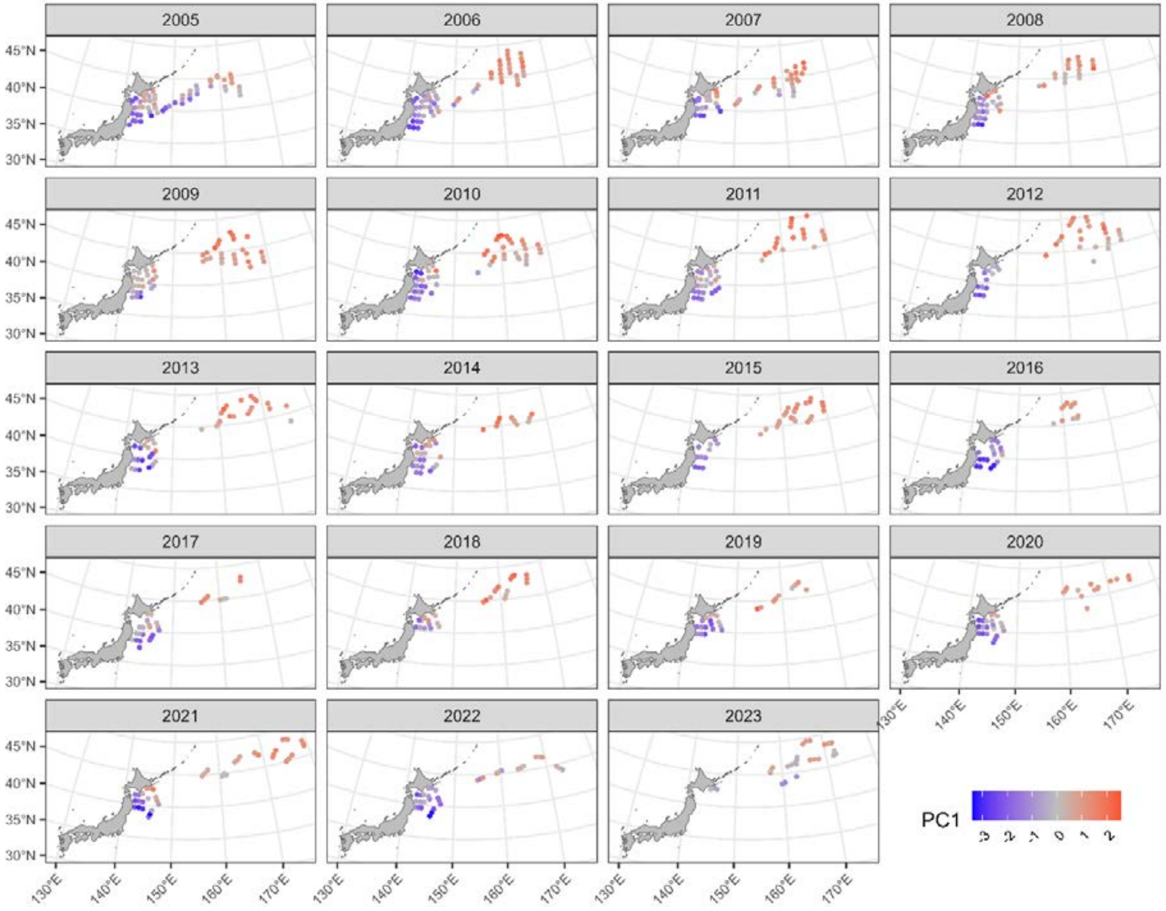
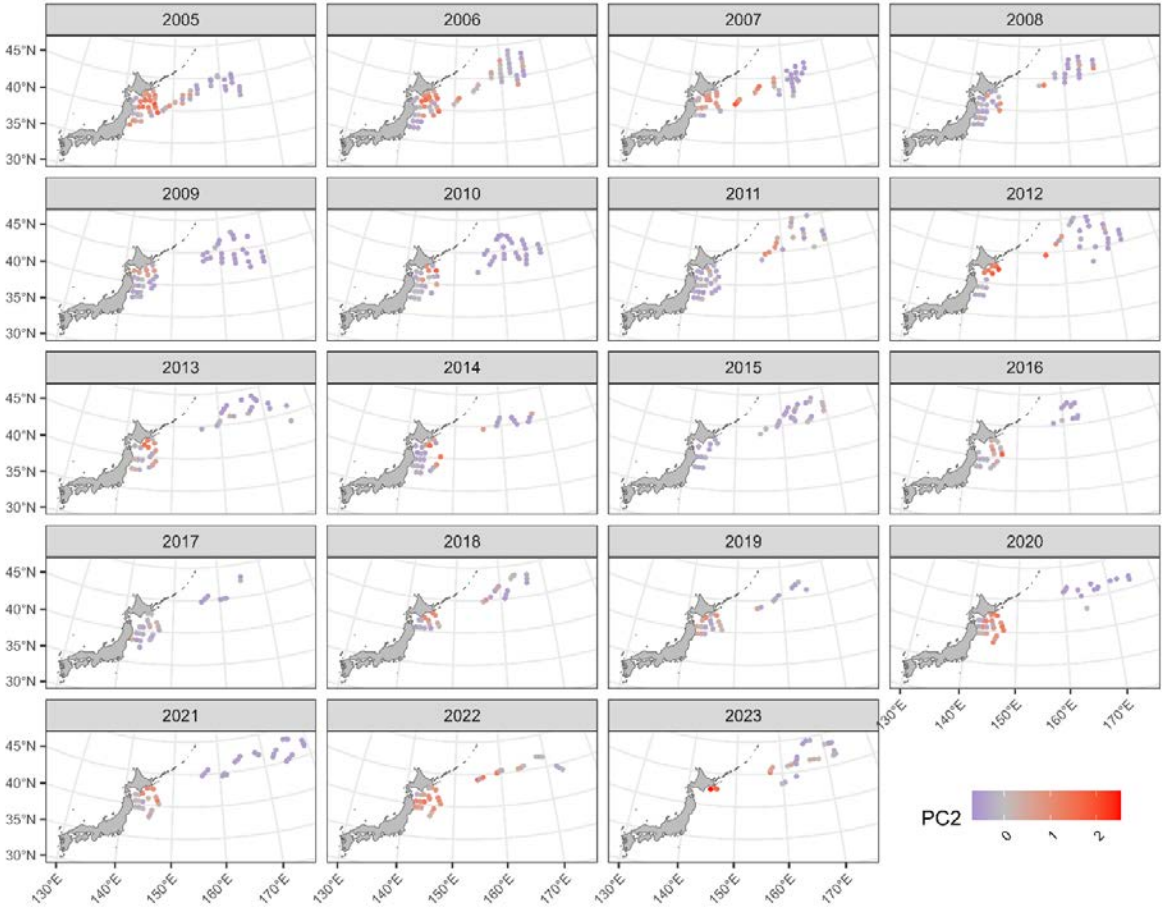


Fig. 4D



- PC1, which was negatively correlated with SST and T30, was thus higher in the northeast
- PC2 tended to be higher close to Hokkaido

Model description of the VAST

Same as the summer survey

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

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

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

$$r_2(i) = a_i \times \log^{-1} p_2(i)\,.$$

($a_i = 1$ in this study)

Binomial model

The probability density function

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

Function for Gamma distribution

Specific settings for temporal, spatial, and spatio-temporal effects

Changed from the default settings of VAST due to the nature of data and estimated parameters

Age 0

$$p_1(i) = \underbrace{\beta_1(t_i)}_{\text{Fixed effects}} + \omega_1(s_i) + \underbrace{\cancel{\varepsilon_1(s_i, t_i)}}_{\text{Turn off}} + \sum_{k_1}^{n_{k1}} \lambda_1(k_1) Q_i(i, k_1)$$

$$p_2(i) = \underbrace{\beta_2(t_i)}_{\text{Fixed effects}} + \underbrace{\cancel{\omega_2(s_i)}}_{\text{Turn off}} + \underbrace{\varepsilon_2(s_i, t_i)}_{\text{Temporally independent}} + \sum_{k_2}^{n_{k2}} \lambda_2(k_2) Q_i(i, k_2)$$

Turned-off the spatial effect in the 1st predictor and the spatio-temporal effect in the 2nd predictor by following suggestions from the *check_fit* function

Age 1

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

$$p_2(i) = \underbrace{\beta_2(t_i)}_{\text{IID}} + \underbrace{\cancel{\omega_2(s_i)}}_{\text{Turn off}} + \underbrace{\varepsilon_2(s_i, t_i)}_{\text{AR(1)}} + \sum_{k_2}^{n_{k2}} \lambda_2(k_2) Q_i(i, k_2)$$

- Used random effects for the year effect to treat year with no catch
- Turned-off the spatial effect in the 2nd predictor by following suggestions from the *check_fit* function
- Assumed temporal autocorrelation for the spatio-temporal effect

Used covariates and other settings

Table 2

Variable	Symbol[1]	Number of categories	General description	Configuration of age-0-fish analysis	Configuration of age-1-fish analysis
Year	$\beta(t)$	18	2005-2023	Categorical variable with fixed effects in both the first and second predictor	- Estimated as random effects - Assume random walk in the first predictor (encounter probability) - Assume IID in the second predictor (positive CPUE when encountered)
Spatial	$\omega(s)$	-	Estimated as random effects by SPDE approximation	Turn off in the second predictor (positive CPUE when encountered)	Turn off in the second predictor (positive CPUE when encountered)
Spatio-temporal	$\varepsilon(s,t)$	18 (the number of years)	Estimated as random effects by SPDE approximation	- Turn-off in the first predictor - Assume independence of each year in the second predictor	- Assume random walk for the first predictor - Assume AR(1) for the second predictor
PC1	$\lambda(k)Q_i(i,k))$	-	- Negative correlation for SST and T30 - Continuous variable as a catchability covariate	No specific configurations for age 0	No specific configurations for age 1
PC1 squared	$\lambda(k)Q_i(i,k))$	-	Continuous variable as a catchability covariate	No specific configurations for age 0	No specific configurations for age 1
PC2	$\lambda(k)Q_i(i,k))$	-	- Positive correlation for SST and negative correlation for T30 - Continuous variable as a catchability covariate	No specific configurations for age 0	No specific configurations for age 1
PC2 squared	$\lambda(k)Q_i(i,k))$	-	Continuous variable as a catchability covariate	No specific configurations for age 0	No specific configurations for age 1
PC1 X PC2	$\lambda(k)Q_i(i,k))$	-	- Interaction between the two PC axes - Continuous variable as a catchability covariate	No specific configurations for age 0	No specific configurations for age 1

- The specific settings above explained are summarized in Table 2
- The number of knots was set as 100
- PC1, PC2, their squared terms, and their 1st order interaction were treated as catchability covariates because it was assumed that they reflected local conditions at observation affecting catchability rather than abundance of the year

Model selection for age 0

Table 3

Rank	PC1	PC1 squared	PC2	PC2 squared	PC1 x PC2	Df	logLik	AICc	ΔAICc
1	B,G	B,G				47	-2559.87	5220.30	0.00
2	B,G	B,G	B			48	-2559.58	5221.99	1.69
3	B,G	B,G	G			48	-2559.84	5222.52	2.23
4	B,G	B,G	G		G	49	-2558.79	5222.71	2.41
5	B,G	B,G	B		B	49	-2558.96	5223.06	2.77
6	B,G	B,G	B,G			49	-2559.54	5224.22	3.92
7	B,G	B,G	B	B		49	-2559.57	5224.27	3.98
8	B,G	B,G	B,G		G	50	-2558.49	5224.42	4.12
9	B,G	B,G	G	G		49	-2559.84	5224.82	4.52
10	B,G	B,G	G	G	G	50	-2558.78	5224.99	4.70
11	B,G	B,G	B,G		B	50	-2558.93	5225.30	5.00
12	B,G	B,G	B	B	B	50	-2558.96	5225.35	5.05
13	B,G	B,G	B,G		B,G	51	-2557.88	5225.50	5.21
14	B,G	B,G	B,G	B		50	-2559.54	5226.51	6.22
15	B,G	B,G	B,G	G		50	-2559.54	5226.52	6.22
16	B,G	B,G	B,G	G	G	51	-2558.48	5226.70	6.41
17	B,G	B,G	B,G	B	G	51	-2558.49	5226.71	6.42
18	B,G	B,G	B,G	B	B	51	-2558.93	5227.59	7.30
19	B,G	B,G	B,G	G	B	51	-2558.93	5227.61	7.31
20	B,G	B,G	B,G	G	B,G	52	-2557.87	5227.80	7.50

- Model selection was conducted using exhaustive search based on Akaike Information Criterion with correction (AICc).
- Only PC1 and its squared term were selected in the best model for both binomial (B) and gamma (G) distributions
- The percent deviance explained was 47.9%.

Model selection for age 1

Table 4

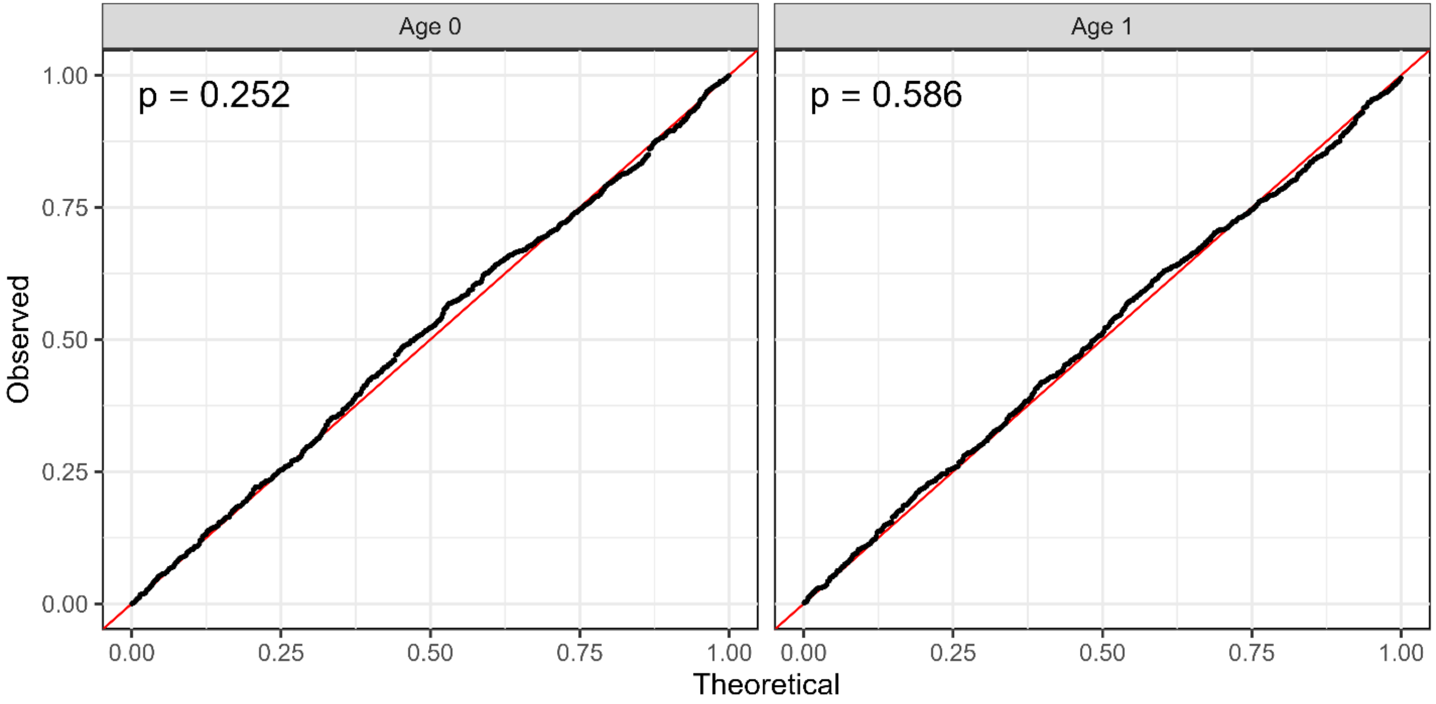
Rank	PC1	PC1 squared	PC2	PC2 squared	PC1 x PC2	Df	logLik	AICc	ΔAICc
1	B,G	G	B		B	16	-1454.40	2941.56	0.00
2	B,G	G	B,G	G	B	18	-1452.36	2941.67	0.11
3	B,G	B,G	B		B	17	-1453.55	2941.94	0.38
4	B,G	B,G	B,G	G	B	19	-1451.50	2942.06	0.50
5	B,G	G	B,G		B	17	-1453.72	2942.29	0.73
6	B,G	B,G	B,G		B	18	-1452.86	2942.68	1.12
7	B,G	G	B	B	B	17	-1454.40	2943.65	2.09
8	B,G	G	B,G	G	B,G	19	-1452.33	2943.72	2.16
9	B,G	G	B,G	B,G	B	19	-1452.36	2943.77	2.21
10	B,G	G	B,G		B,G	18	-1453.42	2943.79	2.23
11	B,G	B,G	B	B	B	18	-1453.53	2944.02	2.46
12	B,G	B,G	B,G	G	B,G	20	-1451.47	2944.12	2.56
13	B,G	B,G	B,G	B,G	B	20	-1451.49	2944.15	2.59
14	B,G	B,G	B,G		B,G	19	-1452.56	2944.18	2.62
15	B,G	B,G				15	-1456.78	2944.23	2.67
16	B,G	B,G	G	G		17	-1454.74	2944.33	2.77
17	B,G	G	B,G	B	B	18	-1453.72	2944.39	2.83
18	B,G	B,G	B,G	B	B	19	-1452.85	2944.76	3.20
19	B,G	B,G	G			16	-1456.10	2944.96	3.40
20	B,G	B,G	B			16	-1456.416	2945.58	4.02

- In the best model for age 1 fish, PC1, PC2, and their interaction were selected for the binomial distribution, while PC1 and its squared term were selected for the gamma model
- The percent deviance explained was 58.6%.

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



Not significantly deviated from the theoretical prediction of the uniform distribution for both age 0 and age 1

Model diagnostics for scaled residuals

Fig. 6A: Age 0

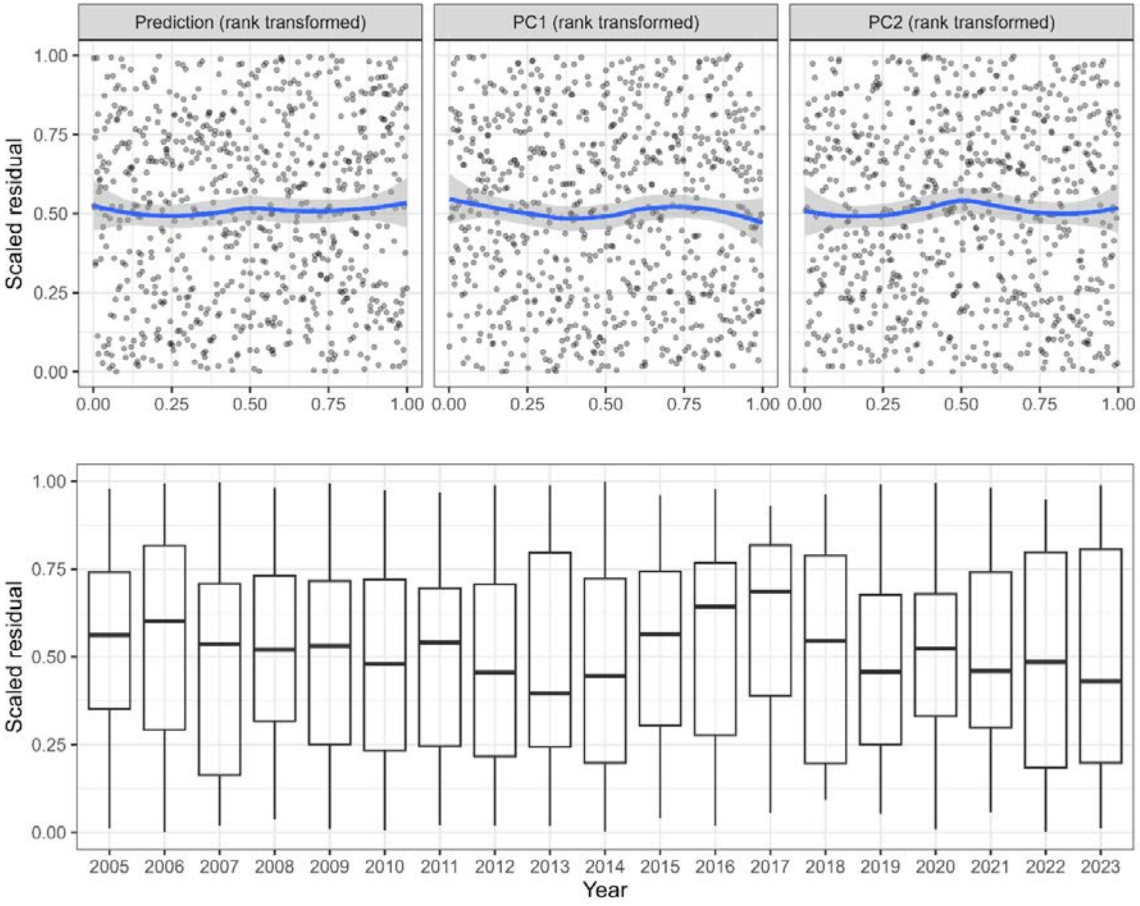
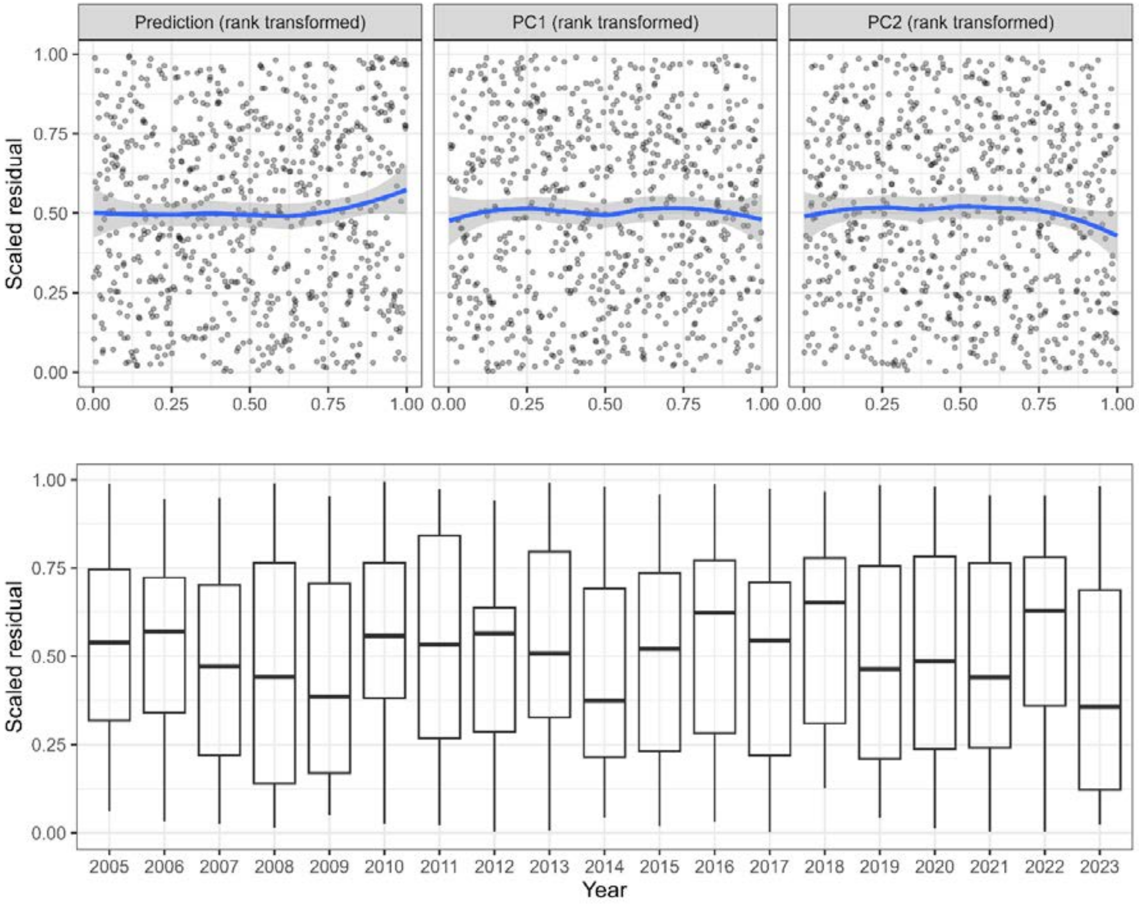


Fig. 6B: Age 1



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. 7A: Age 0

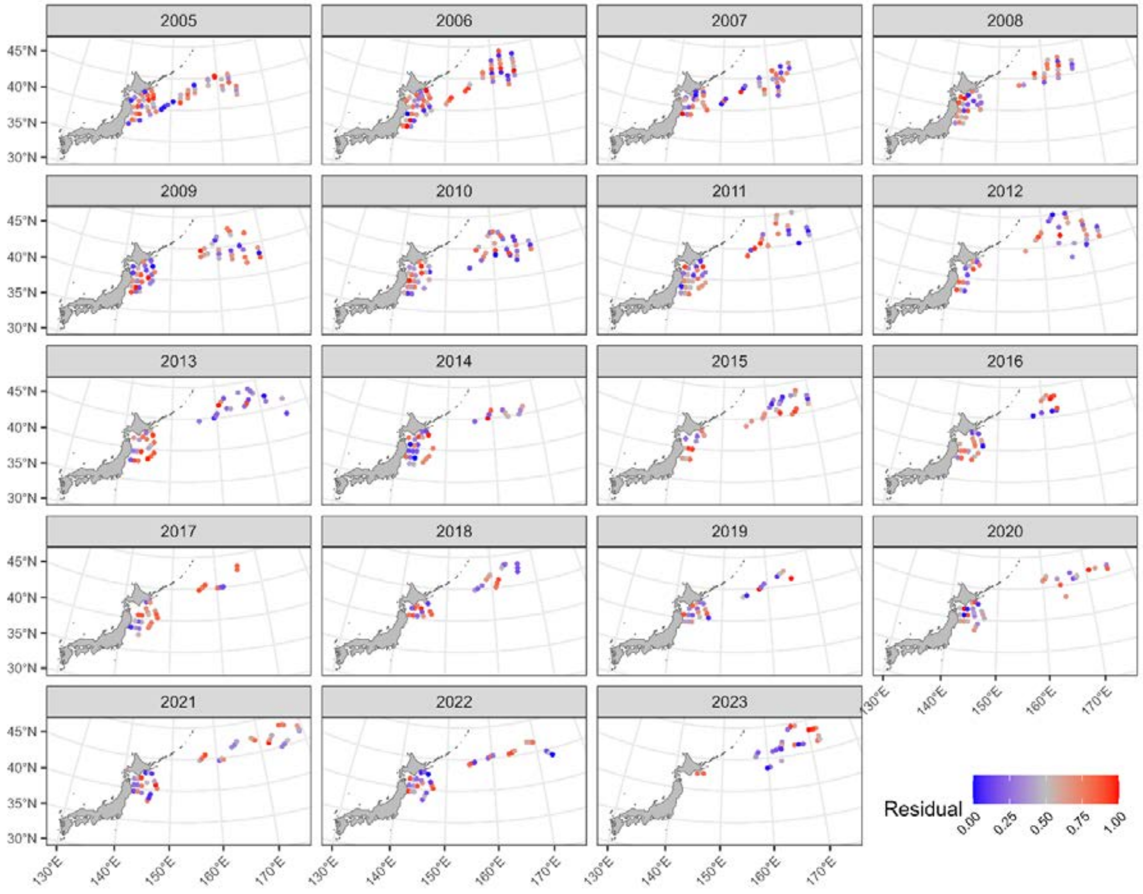
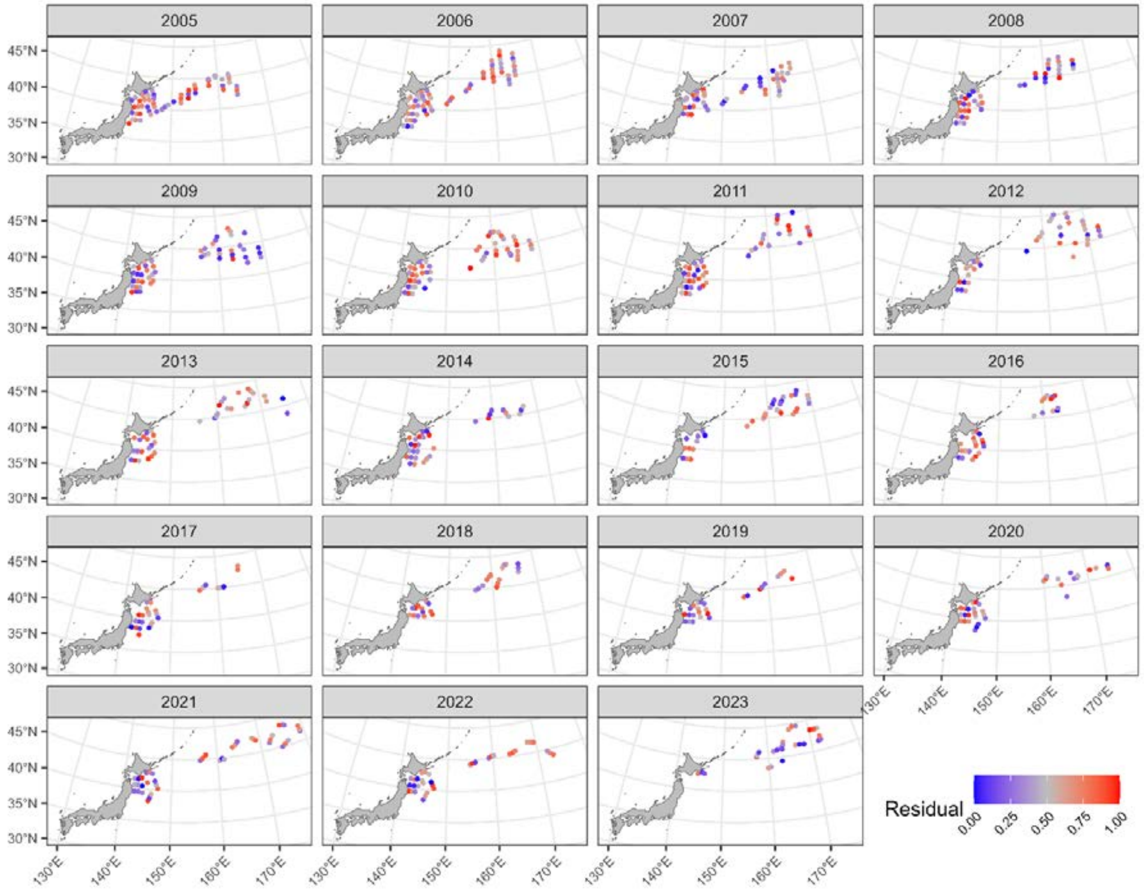


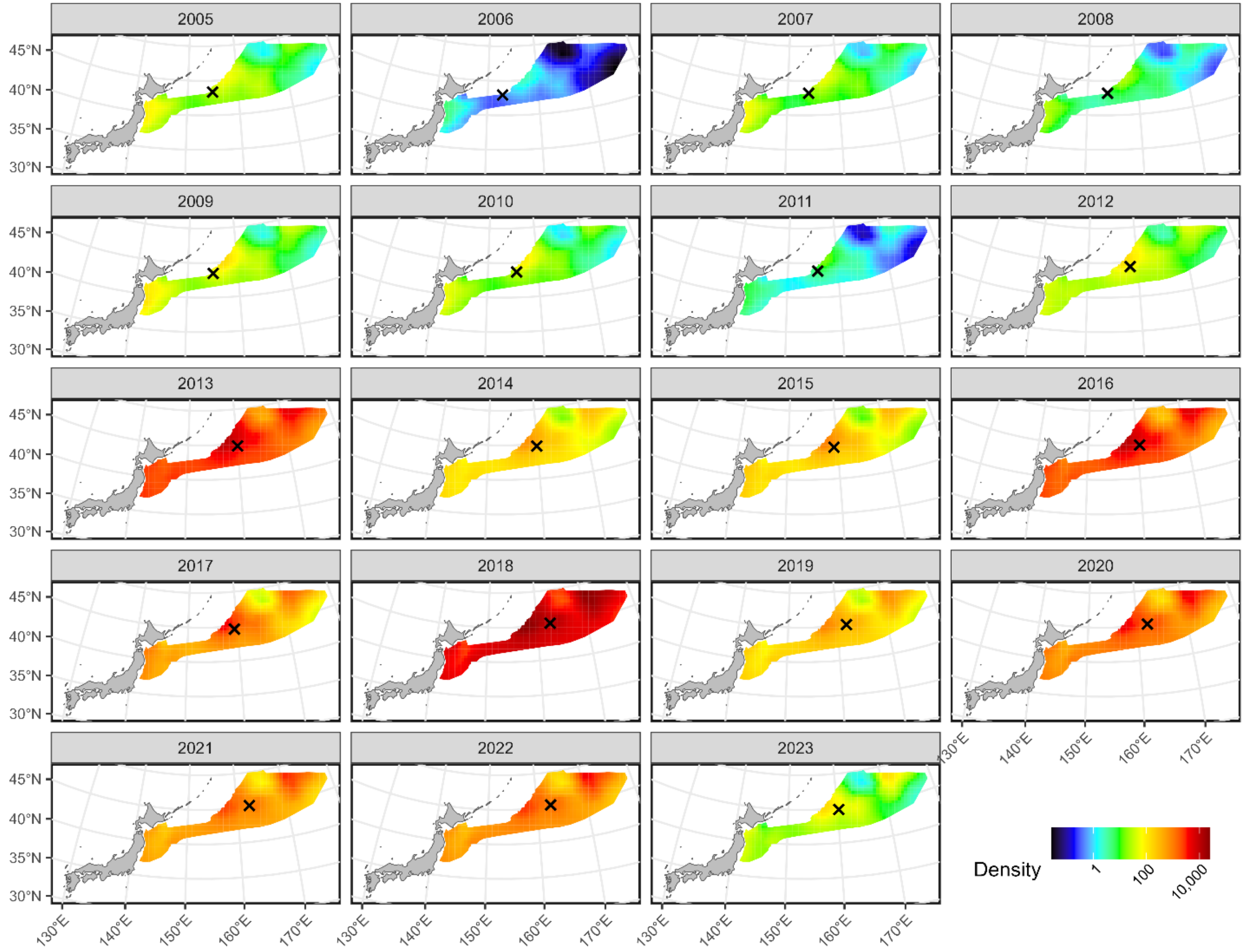
Fig. 7B: Age 1



No systematic spatial patterns in scaled residuals

Estimated spatio-temporal distributions of age 0

Fig. 8A



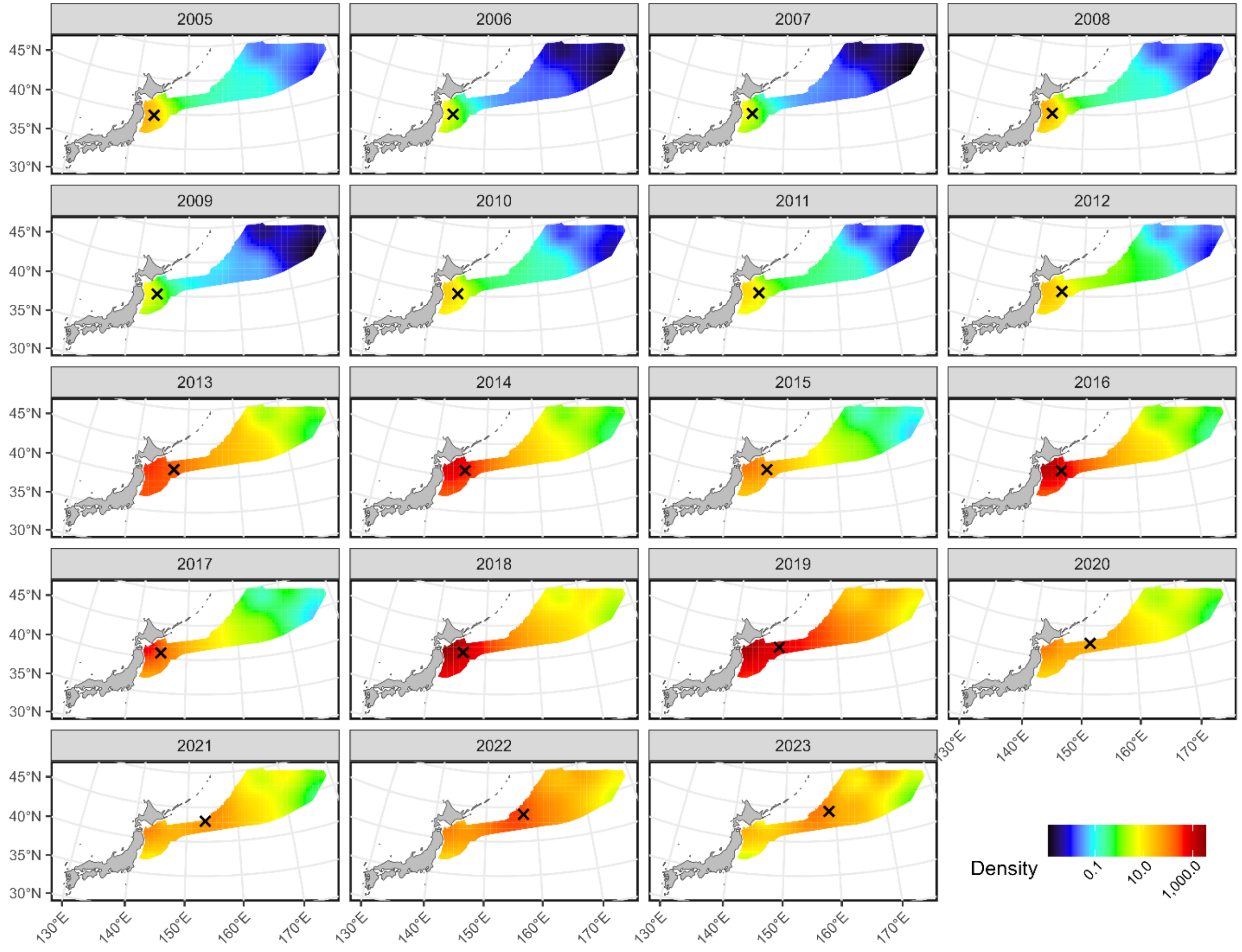
- Local densities were estimated from the product of encounter probability and positive catch rate when encountered

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

- The terms of catchability covariates were dropped off (assuming λ = 0)
- Estimated densities of YOY fish were low until 2012, but increased thereafter
- The distribution centroid of age 0 fish distributions has shifted to offshore to east longitude 159 degrees and north latitude 44.5 degrees or higher since 2013.

Estimated spatio-temporal distributions of age 1

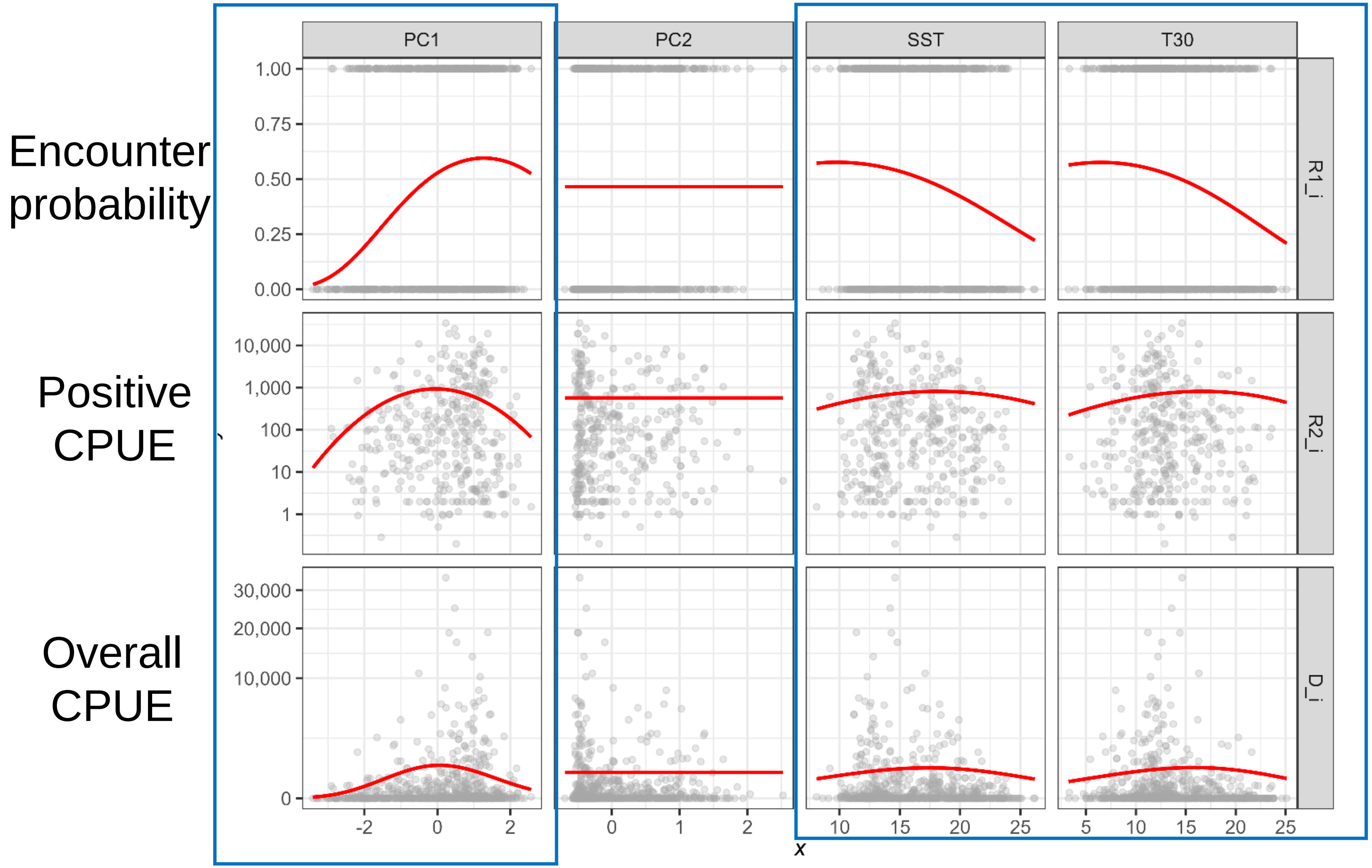
Fig. 8B



- Estimated densities of age 1 fish were low until 2012, but increased thereafter
- The distribution of 1-year-old fish has more clearly shifted offshore
- Over the 19-year period from 2005 to 2023, the centroid of the distribution has increased by approximately 15 degrees in longitude and about 5 degrees in latitude

Relationships between covariates and CPUE for age 0

Fig. 9A: Partial dependence plots

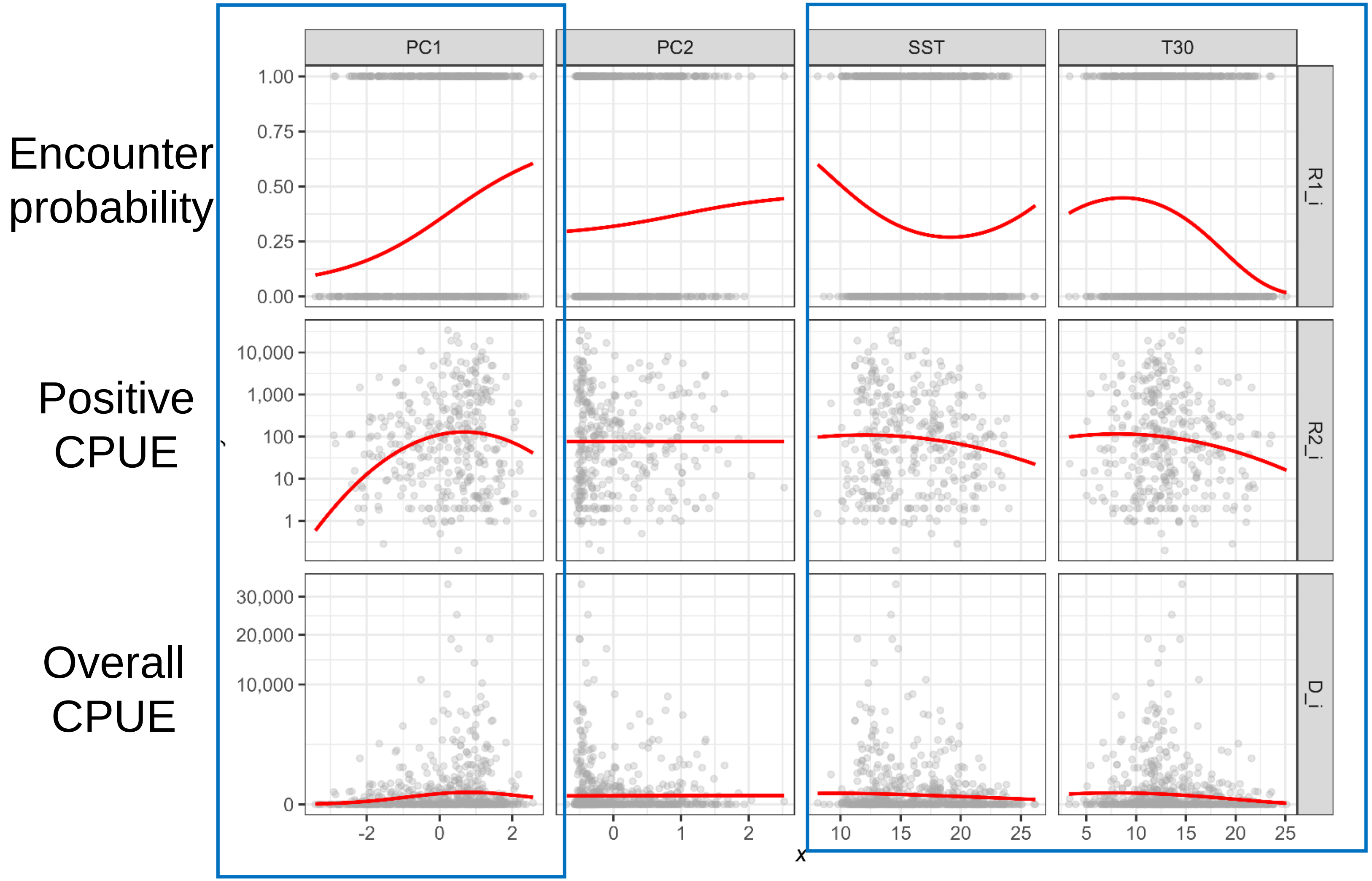


- The encounter probability and the positive CPUE when encountered for age 0 fish exhibited concave-down responses to PC1

- The expected CPUE was the highest when SST was 17.4° C and T30 was 15.8° C.

Relationships between covariates and CPUE for age 1

Fig. 9B: Partial dependence plots



- The encounter probability of age-1 fish responded negatively to increased PC1 and PC2
- The positive CPUE when encountered showed a concave-down response to PC1 and no response to PC2 (not selected in the best model)
- The expected CPUE was the highest when SST was 9.4° C and T30 was 7.8° C.

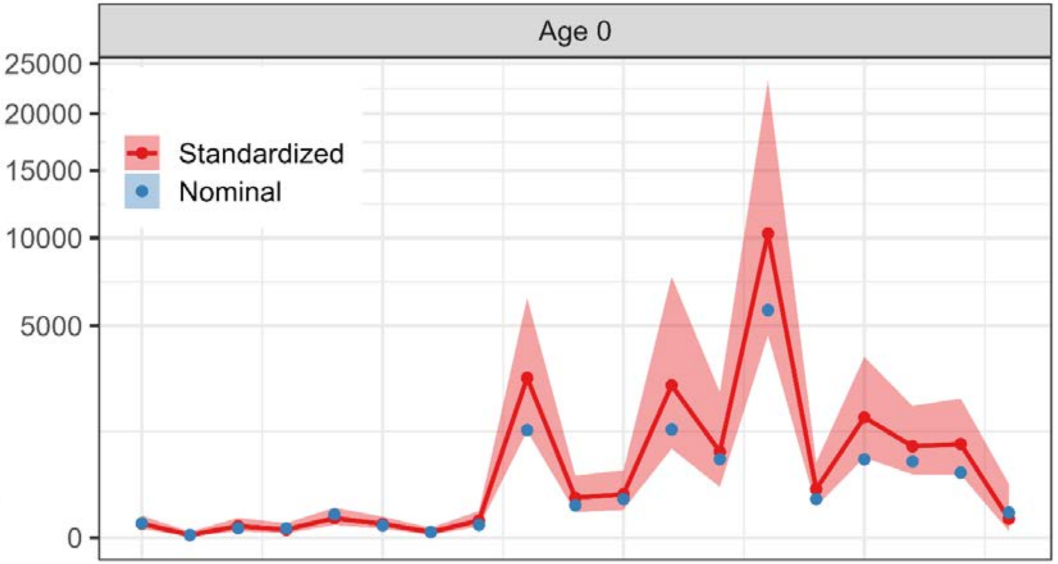
Yearly trends of nominal and standardized CPUE for age 0

Average density (CPUE)

$$I(t) = \frac{\sum_{s=1}^{n_s} \left(\overbrace{a(s)}^{\text{area}} \times \overbrace{d(s,t)}^{\text{density}} \right)}{\sum_{s=1}^{n_S} a(s)}$$

$$\frac{\text{Abundance}}{\text{Total area}}$$

Fig. 10



- Standardized CPUE of age 0 remained low until 2012, but high values were frequently observed since 2013.
- Especially in 2013, 2016, and 2018, the values were high
- The value of latest year (2023) was the lowest since 2013.
- This yearly trend of the standardized CPUE was not greatly different from that of nominal CPUE
- .

Yearly trends of nominal and standardized CPUE for age 1

Average density (CPUE)

$$I(t) = \frac{\overbrace{\textstyle\sum_{s=1}^{n_s}}^{\text{area}} \left(a(s) \times \overbrace{d(s,t)}^{\text{density}}\right)}{\sum_{s=1}^{n_s} a(s)}$$

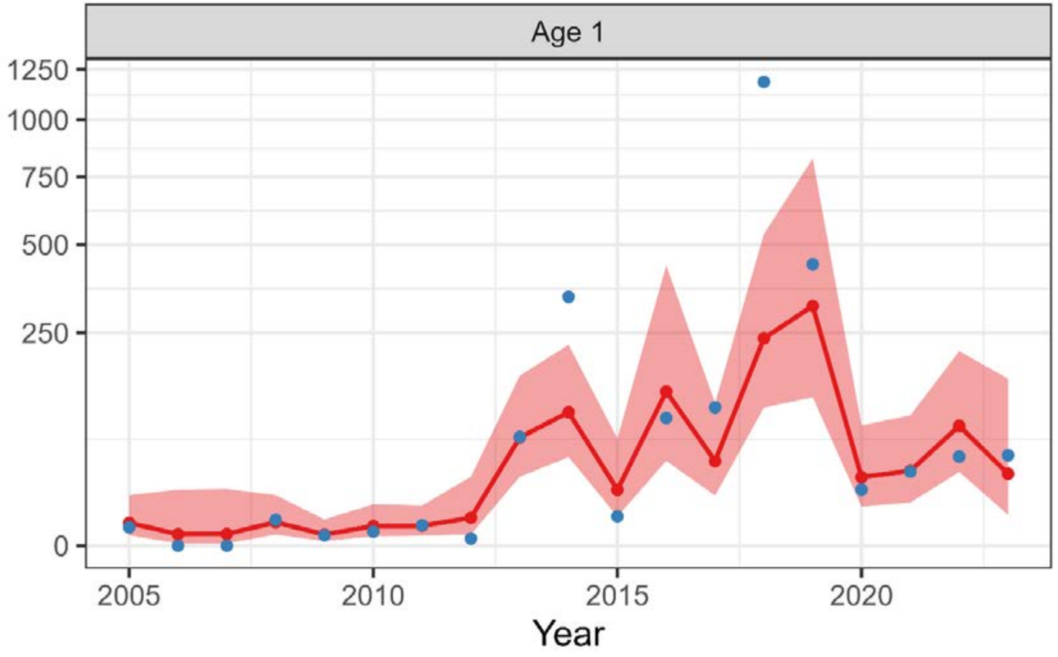
$\dfrac{\text{Abundance}}{\text{Total area}}$

Average density (CPUE)

$$I(t) = \frac{\overbrace{\textstyle\sum_{s=1}^{n_s}}^{\text{area}} \left(a(s) \times \overbrace{d(s,t)}^{\text{density}}\right)}{\sum_{s=1}^{n_s} a(s)}$$

$\dfrac{\text{Abundance}}{\text{Total area}}$

Fig. 10



- Standardized CPUE of age 1 also remained low until 2012, and thereafter gradually increased with a fluctuation until 2019
- The standardized CPUE remained stable at moderate levels in latest four years (2020-2023).
- The standardized values were apparently lower in 2014 and 2018 than nominal values
- This is because extremely high CPUE values over 4,500 individuals/hour were observed and smoothed by the temporal and spatio-temporal effects in these years.

Values and uncertainties of the nominal and standardized CPUE for age 0

Table 7

Year	Nominal (ind/h)	Standardized (ind/h)	CV	Lower 95%CI	Upper 95%CI
2005	23.24	21.63	0.44	8.54	54.79
2006	0.78	0.79	0.69	0.17	3.74
2007	9.98	14.58	0.50	4.85	43.82
2008	9.54	7.19	0.53	2.17	23.78
2009	60.76	42.41	0.39	17.73	101.40
2010	16.62	20.83	0.38	8.74	49.61
2011	3.48	3.46	0.48	1.12	10.73
2012	18.24	32.48	0.40	13.16	80.18
2013	1287.61	2840.92	0.36	1263.94	6385.44
2014	117.37	177.95	0.39	73.27	432.18
2015	166.33	209.74	0.38	86.80	506.80
2016	1303.30	2584.59	0.46	881.51	7578.00
2017	685.39	821.79	0.44	286.12	2360.30
2018	5765.05	10287.65	0.34	4547.86	23271.50
2019	165.91	262.77	0.36	109.32	631.57
2020	684.06	1611.04	0.33	713.31	3638.59
2021	646.41	929.35	0.30	447.15	1931.57
2022	471.63	976.33	0.32	441.74	2157.88
2023	70.30	39.63	0.79	4.88	322.03

The CV of the standardized age-0 CPUE were in the range of 0.30−0.53 except for 2006 and 2023, when the nominal and standardized CPUEs were the lowest (CV = 0.69 in 2006) or the number of stations was the lowest (CV = 0.79 in 2023)

Values and uncertainties of the nominal and standardized CPUE for age 1

Table 8

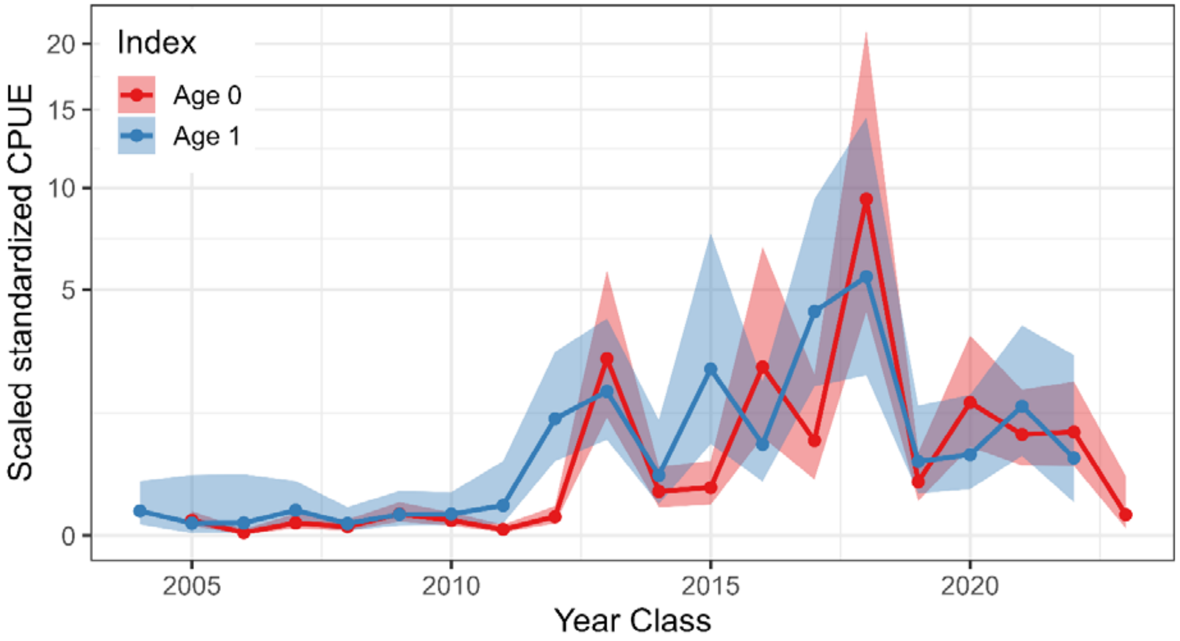
Year	Nominal (ind/h)	Standardized (ind/h)	CV	Lower 95%CI	Upper 95%CI
2005	1.85	2.87	0.52	0.59	14.08
2006	0.00	0.72	0.69	0.03	17.32
2007	0.00	0.75	0.67	0.03	17.72
2008	3.66	3.05	0.44	0.66	14.10
2009	0.60	0.68	0.44	0.12	3.82
2010	1.07	2.12	0.42	0.47	9.47
2011	2.32	2.19	0.39	0.54	8.89
2012	0.27	4.30	0.45	0.71	26.26
2013	65.17	64.57	0.28	26.16	159.40
2014	341.64	98.23	0.27	43.35	222.58
2015	4.75	17.19	0.37	4.67	63.32
2016	90.05	131.17	0.37	39.74	432.95
2017	105.49	39.43	0.33	13.86	112.15
2018	1186.44	237.14	0.28	105.07	535.20
2019	436.80	316.84	0.31	121.42	826.82
2020	17.36	25.92	0.33	8.42	79.81
2021	30.17	30.95	0.32	10.22	93.72
2022	43.74	79.15	0.29	30.01	208.72
2023	45.12	28.48	0.43	5.27	153.85

The CV of the age-1 standardized CPUE were in the range of 0.28−0.52 except for 2006 and 2007, when no individuals of age 1 fish were captured in the survey (CV = 0.69 and 0.67 in 2006 and 2007, respectively)

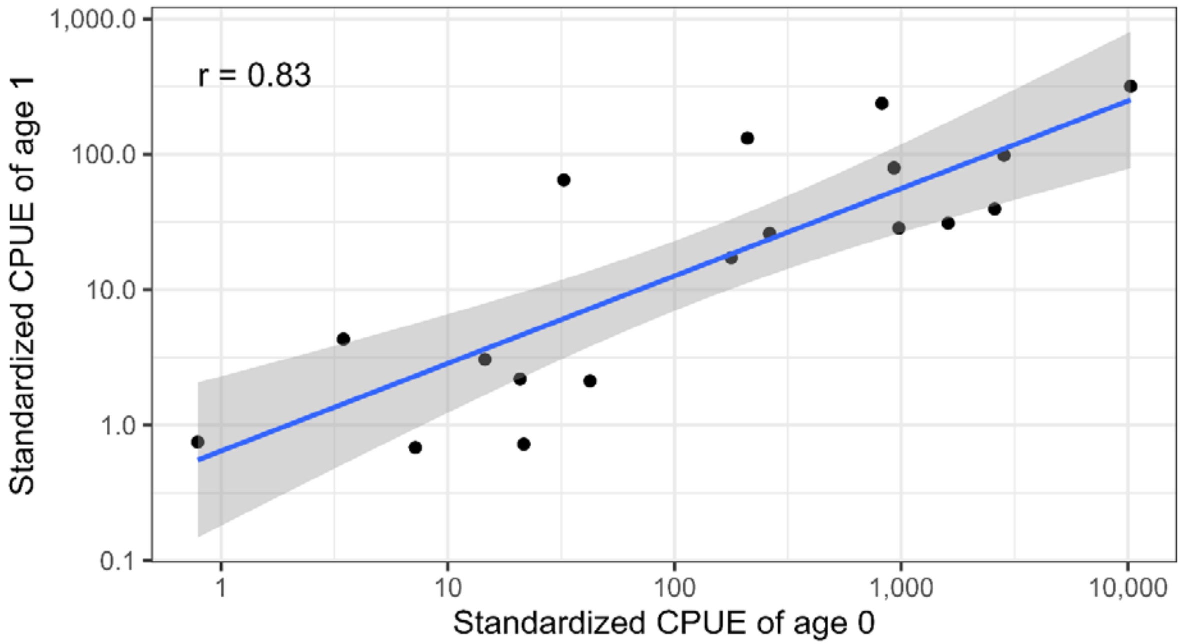
Association between the age-0 and age-1 indices

- The standardization of age-1 CPUE was newly conducted in TWG CMSA
- To assess the validity of the standardized age 1 index, we examined its association with the standardized age 0 index by matching year classes

Figure 11



The standardized index for 1 YO fish likely contain information about the abundance of each cohort



- A consistent pattern emerges where the 2013 and 2018 year-classes exhibit higher values in both indices
- For the 2012, 2015, and 2017 year-classes, differences are observed between the two indices.

- A high correlation and a significant relationship were detected between the two indices in log space

Recommendation

- The standardized indices obtained from this analysis cover a long time series from periods of poor chub mackerel recruitment in the Pacific to times of high recruitment
- The surveys covered a moderately broad area in the Northwestern Pacific Ocean
- The cutting-edge VAST model was used for CPUE standardization
- Model diagnostics showed favorable results
- Propose utilizing the standardized indices from the autumn survey as abundance indices of the numbers of age 0 fish and age 1 fish for the chub mackerel stock assessment in TWG CMSA