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Standardized CPUE of Japanese commercial dip-net fishery targeting spawners of chub mackerel in the Northwest Pacific up to 2024

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Summary

- We conducted CPUE standardization of Japanese commercial dip-net fishery for Pacific chub mackerel using a generalized linear mixed-effect model

- The analysis showed that the dip-net fishery CPUE was affected by month, area, sea surface temperature, and ship as well as year.

- The abundance index standardizing these influential variables except for year showed a great decline in 2022-2024 after a high-level decade from 2011 to 2021.

- We propose this standardized index to be used as an index of spawning stock biomass (SSB) in the Technical Working Group for the Chub Mackerel Stock Assessment (TWG CMSA) in NPFC.

Background

- The dip-net fishery operating around the Izu islands is a small-scale artisanal fishery targeting spawning chub mackerel during the spawning season
- The total catch amount of chub mackerel in this fishery contributes less than 1% of the overall catch by Japan (Table 1)
- It is the only fishery that targets spawning chub mackerel and operates in the main spawning ground around the Izu Islands during the spawning season
- Most mature fish are considered to migrate to this area for spawning (Watanabe and Yatsu 2006)
- The CPUE of the dip-net fishery is considered to represent the relative abundance of spawning stock biomass (SSB) for the Pacific chub mackerel
- The CPUE has long been used as a reliable abundance index of SSB in the Japanese domestic stock assessment.

Catch and effort information

Year	Number of observations[1]	% Coverage of CPUE FLEET (catch)[2]	% Coverage of CPUE FLEET (effort)[2]	Total Catch CPUE FLEET (mt)	Total Effort for CPUE FLEET (fishing days)[3]	Percentage of overall catch by member (%)[4]
2003	132	21.56	20.99	60.81	132	0.13
2004	168	25.96	27.57	41.68	166	0.06
2005	117	26.64	25.16	34.97	117	0.02
2006	117	46.38	49.16	143.86	117	0.06
2007	198	14.91	43.14	350.95	198	0.14
2008	104	28.46	13.22	124.77	103	0.07
2009	112	31.22	31.73	137.79	112	0.08
2010	118	36.34	39.33	124.15	118	0.10
2011	105	22.57	43.15	177.01	104	0.14
2012	76	10.05	44.44	49.99	76	0.05
2013	98	21.01	26.98	495.18	58	0.39
2014	117	25.06	30.93	723.53	73	0.33
2015	84	36.59	32.70	851.09	52	0.30
2016	129	31.37	26.81	1492.43	85	0.45
2017	124	55.52	38.30	537.62	72	0.16
2018	113	33.38	26.84	1194.23	73	0.36
2019	120	45.37	32.43	1436.21	84	0.48
2020	178	47.64	37.06	1980.79	106	0.74
2021	179	44.69	33.44	1467.18	104	0.53
2022	72	36.31	22.61	549.65	52	0.29
2023	88	41.25	24.66	253.88	73	0.27
2024	81	49.04	26.86	145.66	65	0.20

Table 1

- The data of dip-net fishery from 2003 to 2024 was obtained from the logbooks from eight sampling ships in Kanagawa and Shizuoka Prefectures
- The coverage of catch from the sampling ships against the total catch of the dip-net fishery is 10 to 56%
- The data was recorded by operation by ship, along with the information on locations (longitude/latitude or area name), *in-situ* sea surface temperatures (SST), the number of fishermen (nets), and fishing time

Filtering rule

Table 2

Filter Applied	Number of Records Remaining	Number Removed	Number of Records with Chub Mackerel Catch >0
Initial Data set	2,630	-	2,042
Remove data with no spatial information (area or long/lat)	2,620	10	2,038
Remove data with no effort (time and person)	2,515	105	1,960
Remove data with SST = NA or 0 (not recorded)	2,497	18	1,950
Select data between January and June	2,323	174	1,880

- The number of samples in the original data was 2,630
- We removed data with no spatial information, data with no effort information (fishing time and the number of fishermen), and no SST information from the analysis
- We exclusively focused on the data from January to June, the main spawning season of chub mackerel, and removed the data obtained during the other months.
- The sample size of the final dataset was 2,323 and that having positive catch was 1,880 (80.9%)

Area division, and relationship between area and effort

Fig. 1

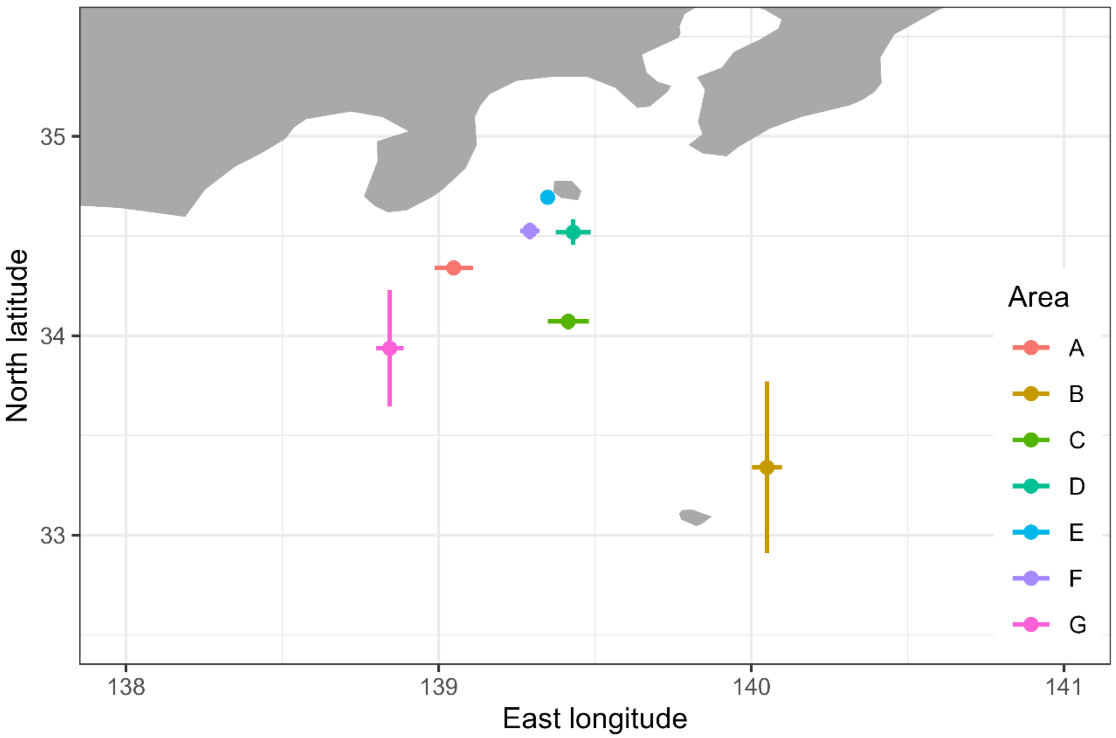


Fig. 2B

- The dip-net fisheries are conducting in the area approximately from 138º–140.5º E and 32.5º–35º N
- There are many samples that had either longitude/latitude or area name
- We assigned the area whose center was closest, to each sample that had only longitude and latitude, and then used area as a categorical variable in CPUE standardization.

Catch and CPUE by area by month in each year

Fig. 2A

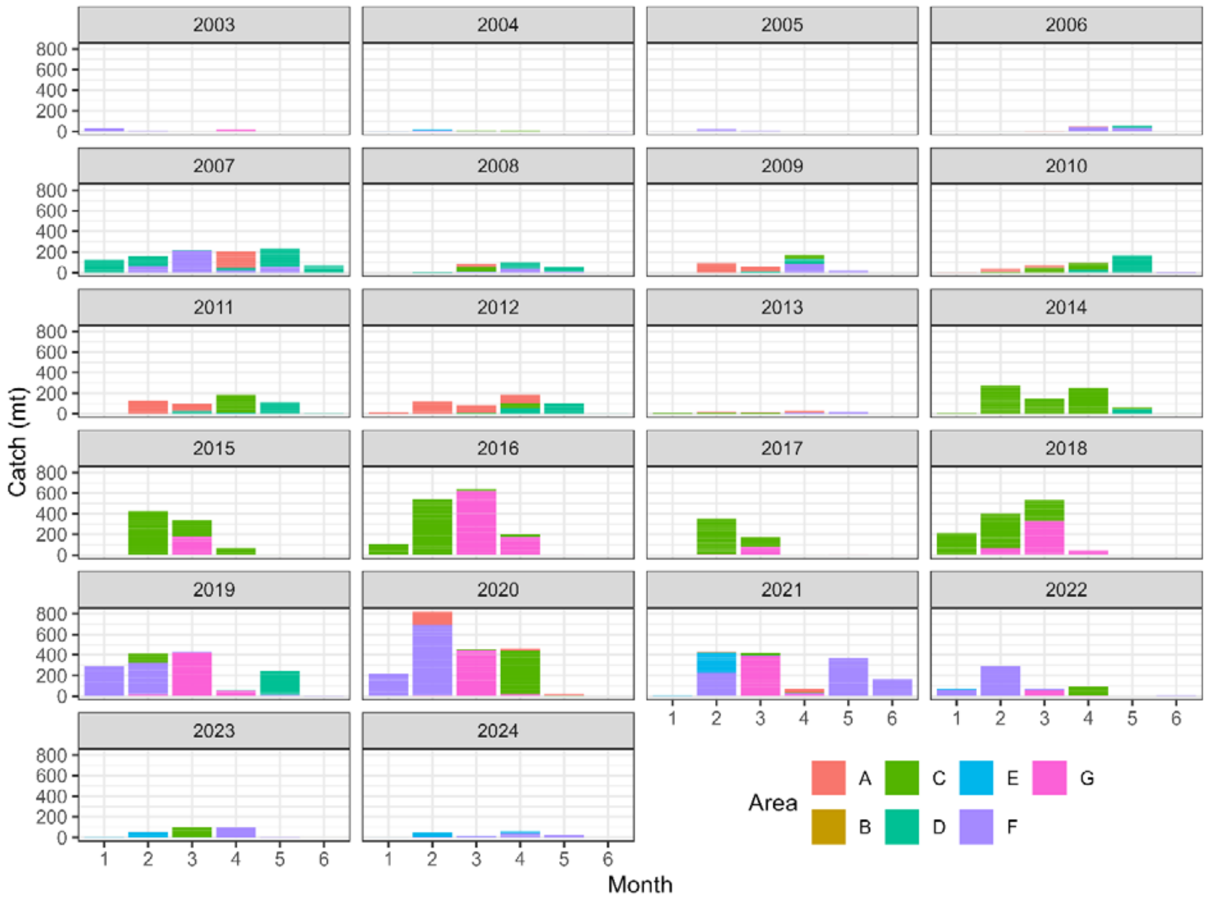
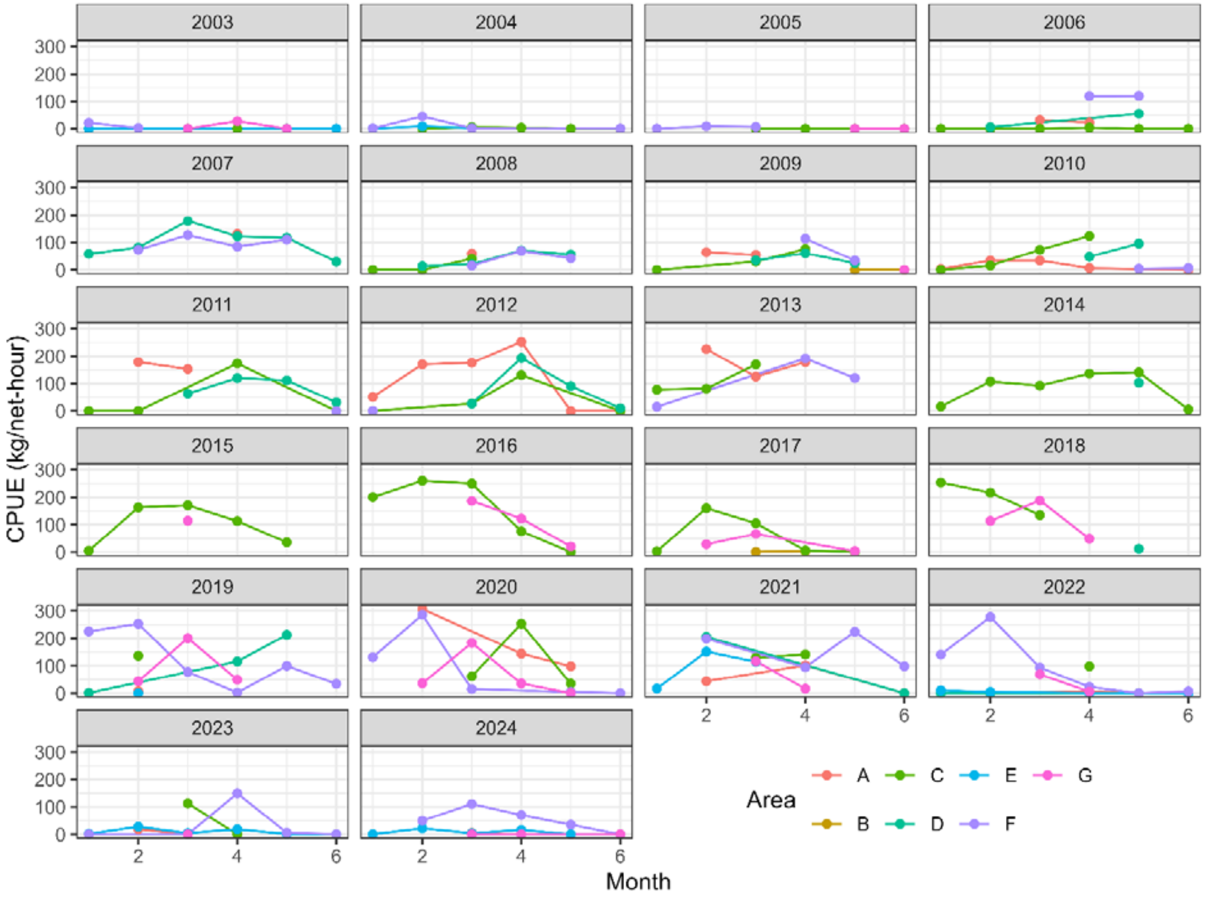


Fig. 2C



- Catch and CPUE have greatly decreases in most recent two years (2023-2024)
- Catch and CPUE tended to be high from February to April

Spatial maps of catch and effort

Plotted spatial maps of catch and effort only for data having information on longitude and latitude

Fig. 3A

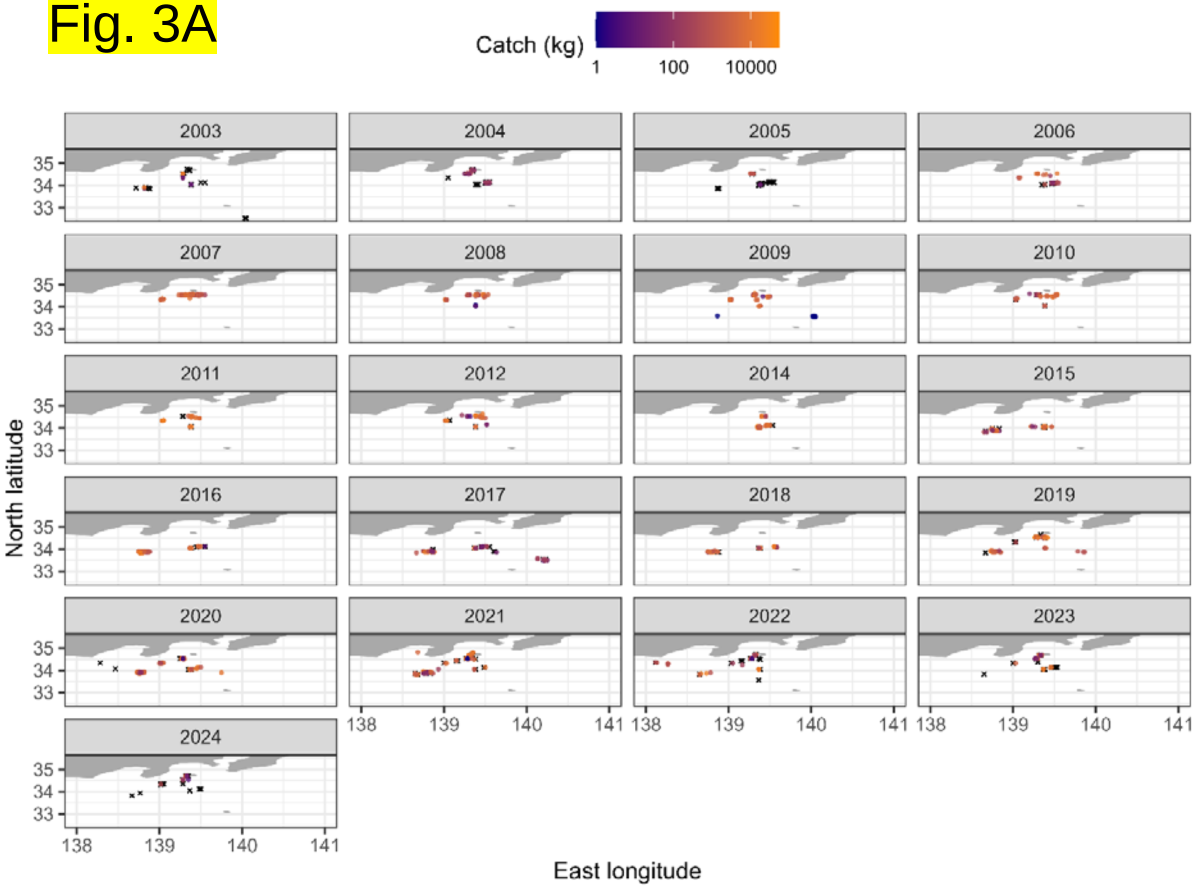
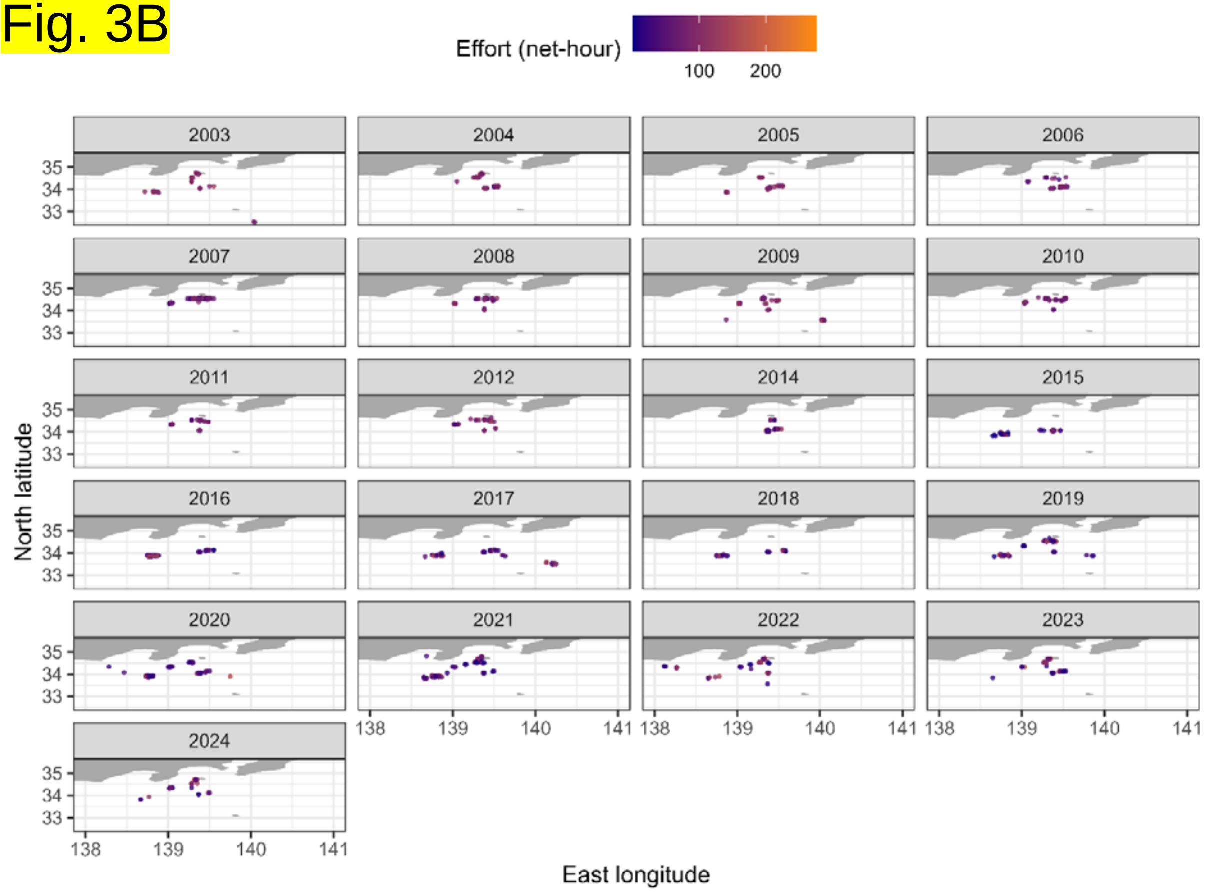


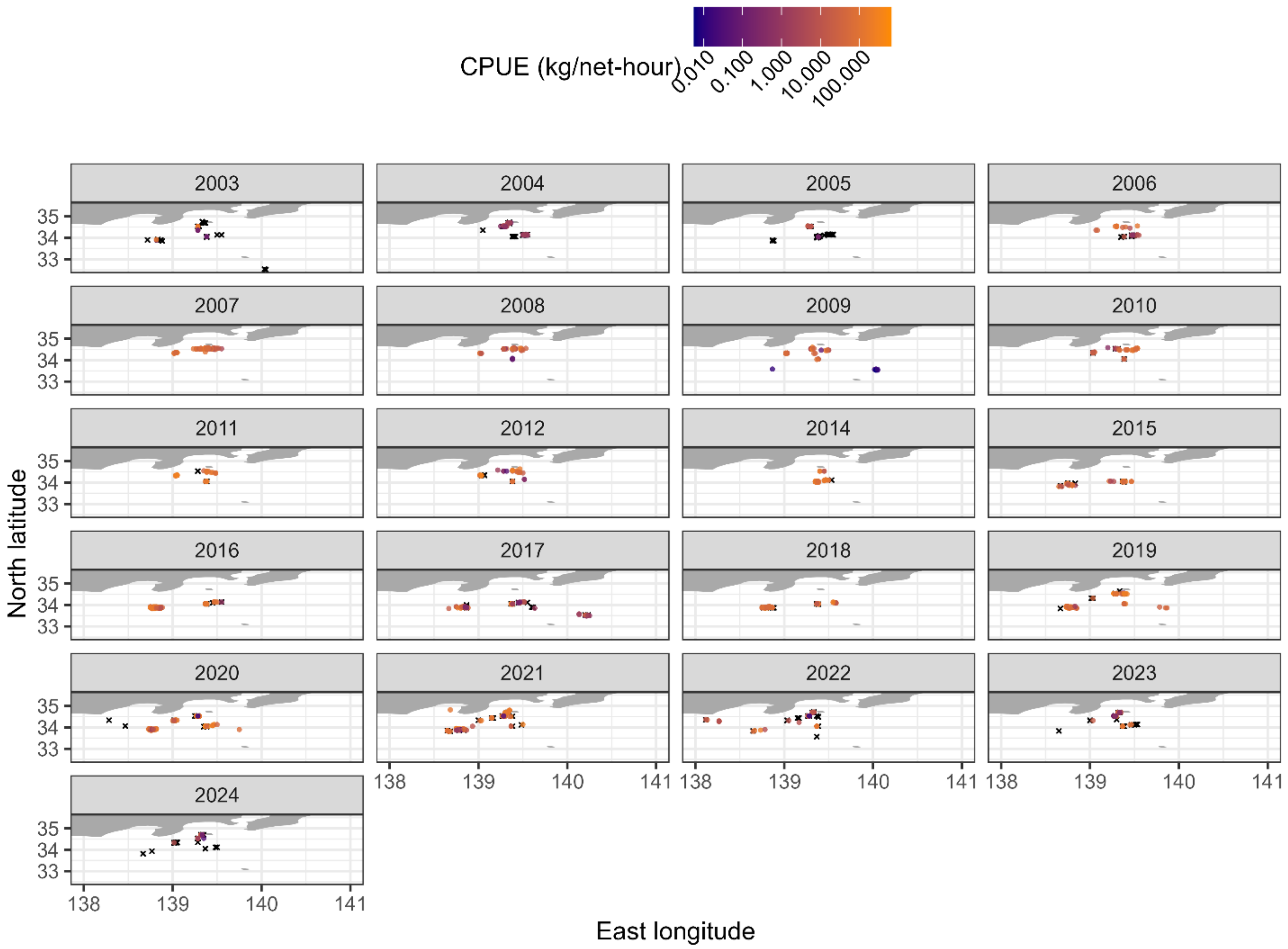
Fig. 3B



Spatial map of CPUE

Plotted spatial map of CPUE (kg/net-hour) only for data having information on longitude and latitude

Fig. 3C



Explanatory variables used

Table 3

Variable	Abbreviation	Number of categories	Detail	Note
Year	year	22	2003-2024	Treated as fixed effect for Tweedie and as random effect for the binomial distribution
Month	month	6	January-June	Categorical variable with fixed effect
Area	area	7	A-G	Categorical variable with fixed effect
Sea surface temperature	SST	-	13.2-28.2	Continuous variable scaled by mean and SD
SST squared	I(SST^2)	-	Squared SST	Squared values of the scaled SST
Prefecture	pref	2	Belonging of ship (Kanagawa or Shizuoka)	Categorical variable with fixed effect
Ship	ship	8	Sampling ship	Categorical variable with fixed effect

- All variables except for SST and its squared term were categorical variables
- The effect of year was treated as fixed effect for Tweedie distribution and as random effect for binomial distribution assuming AR(1) process
- This is because several years have only positive catch samples

Associations of year, month, ship, and prefecture

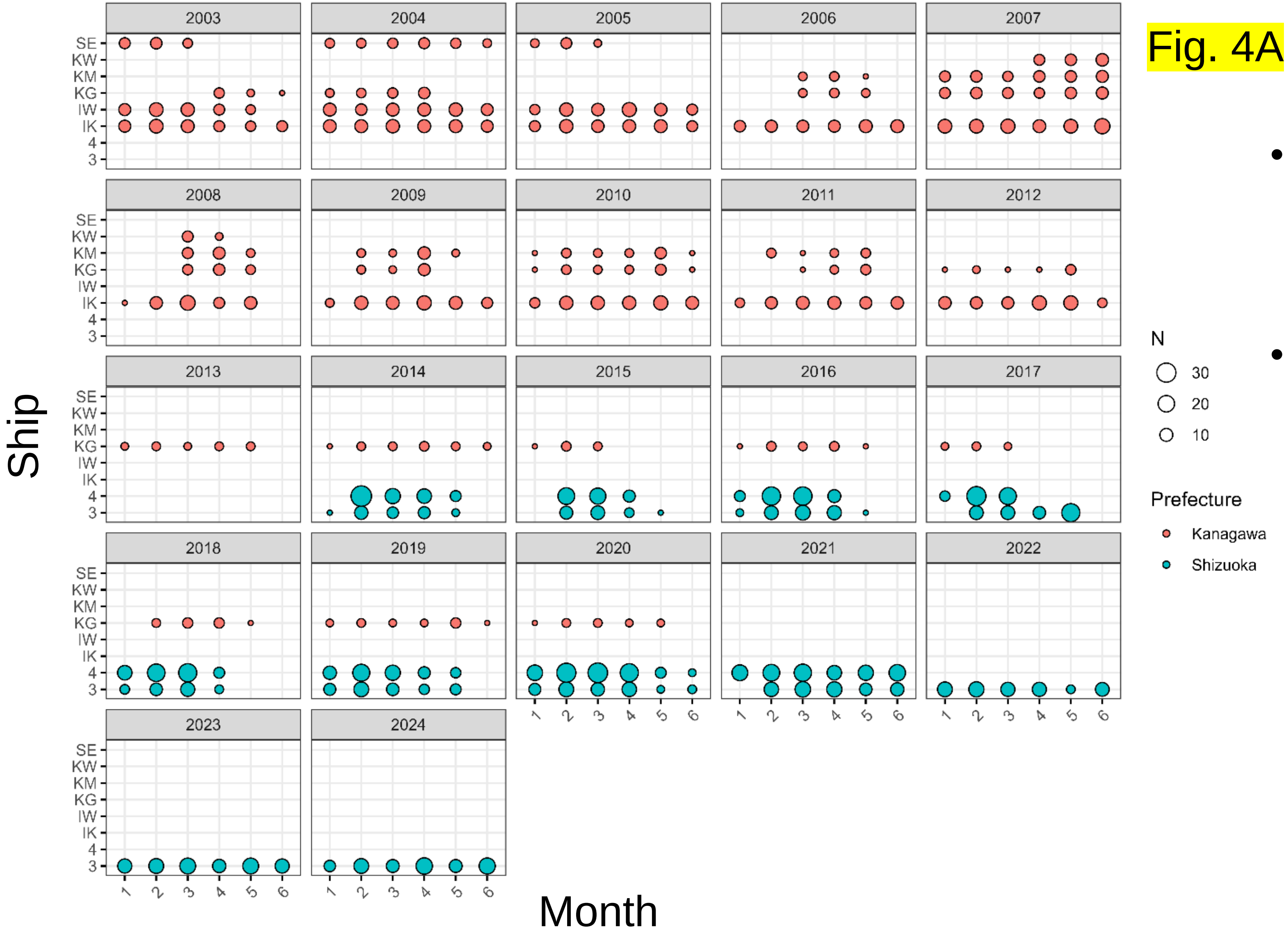


Fig. 4A

- The variables of ship and prefecture have a nested structure and year with operations strongly depended on prefectures
- There are many missing categories

Associations of year, month, and area

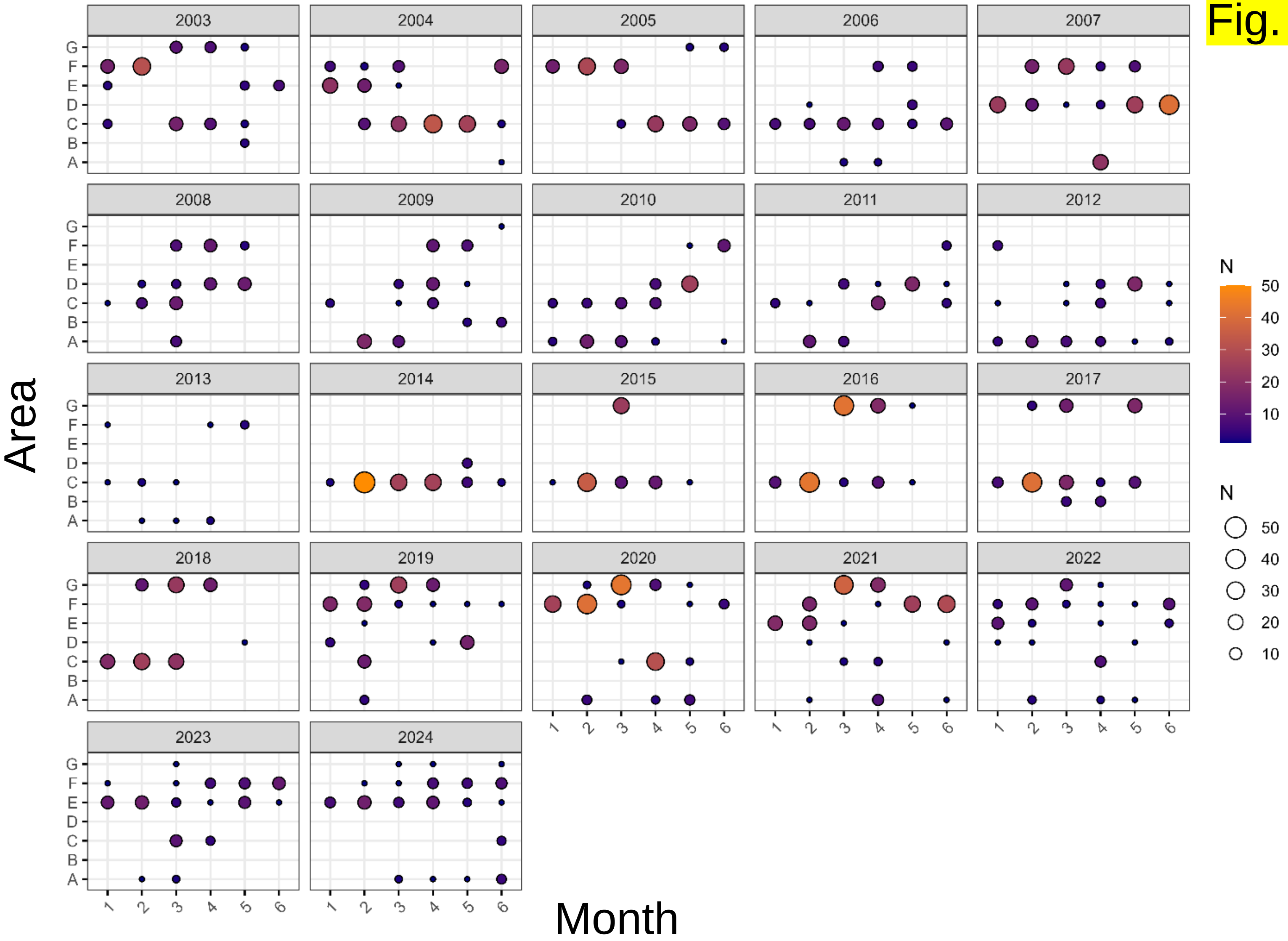
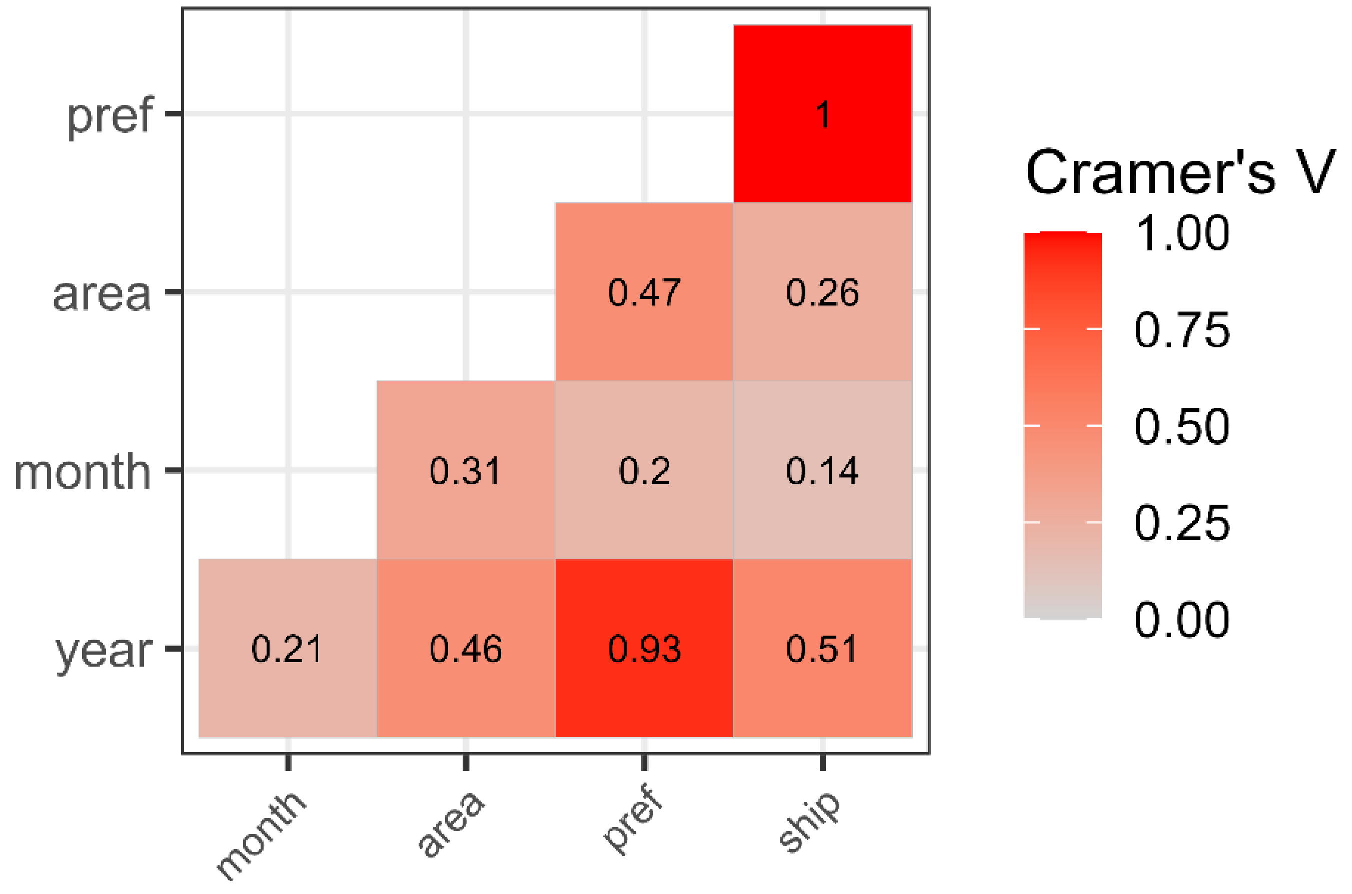


Fig. 4B

Allocations of efforts to each area depended on the years

Correlation among the categorical variables

Fig. 4C



Cramer’s V (like correlation coefficient for categorical variables) was

- High between prefecture and ship and between prefecture and year (>0.9)
- Moderately high between year and area, between year and ship, and between area and prefecture (0.4~0.5)

Relationships between SST and categorical variables

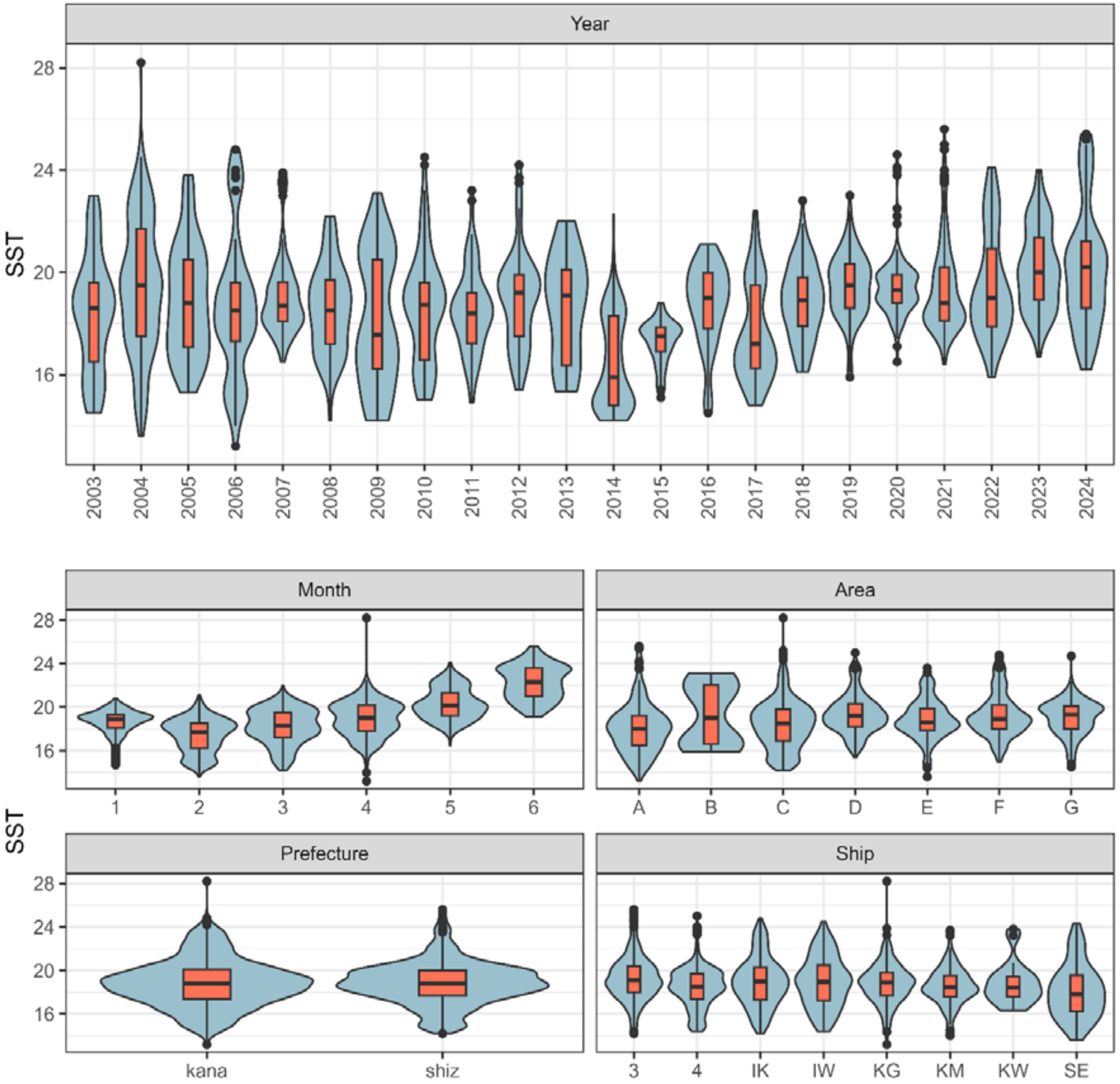


Fig. 4D

- SST was strongly correlated with month
- There was no apparent correlation of SST to the other categorical variable

Relationships between CPUE and categorical variables

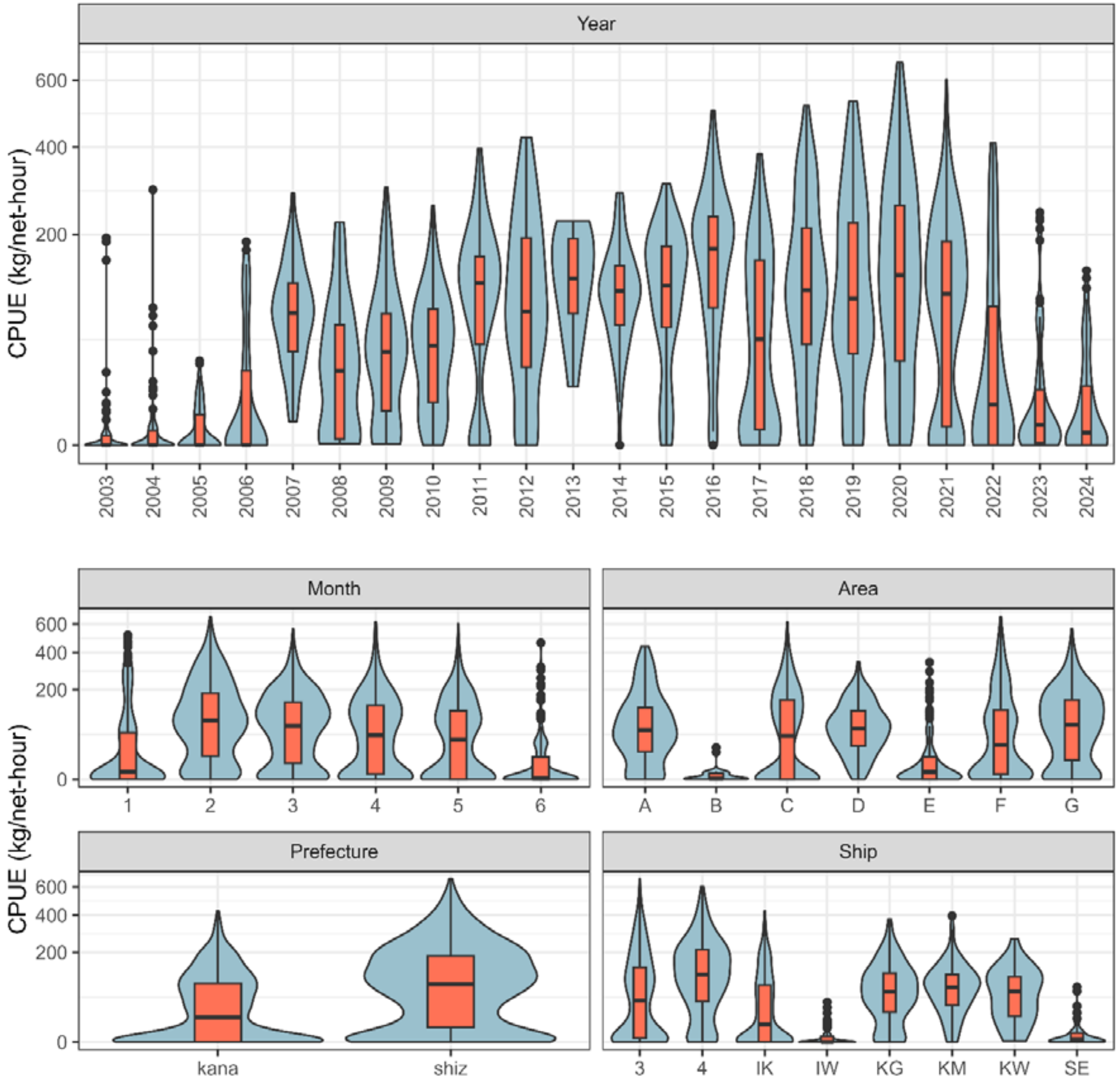


Fig. 4E

CPUE was seemingly correlated by all the categorical variables

Full model description and model selection method

- The dependent variable CPUE (kg/net-hour) was a continuous value more than or equal to zero
- Used a generalized linear mixed-effects model (GLMM) with a zero-inflated Tweedie distribution via the R package ‘glmmTMB’ (Brooks et al. 2017).
- The zero-inflated Tweedie distribution in this study is a mixture of binomial distribution (with logit link) and Tweedie distribution (with log link).
- The full model involved all the five categorical variables (year, month, area, prefecture, and ship)
- Considered the squared term of SST in the full model because CPUE seemed to be the highest at an intermediate level of SST
- Not consider interactions between any combination of the independent variables because including interactions would cause many missing categories
- Estimated all parameters as fixed effect except for the year effect in the binomial model
- Conducted the brute-force model selection approach except that the year effect was always selected and models with both prefecture and ship were not considered because of their nested structure and the strongest correlation (Fig. 4A, C),
- Based on AICc useing the R package ‘MuMIn’ (Bartoń 2022)

Model selection results

Table 4

Rank	(T)area	(T)month	(T)pref	(T)ship	(T)SST	(T)I(SST^2)	(T)year	(B)area	(B)month	(B)pref	(B)ship	(B)SST	(B)I(SST^2)	df	logLik	AICc	ΔAICc
1	+	+		+	0.116	-0.117	+	+	+			0.7314	0.1914	59	-10137.14	20395.53	0
2	+	+		+	0.115	-0.117	+	+	+	+		0.7202	0.1900	60	-10136.78	20396.91	1.38
3	+	+		+	0.116	-0.122	+	+	+			0.7741		58	-10140	20399.13	3.6
4	+	+		+	0.115	-0.122	+	+	+	+		0.7557		59	-10139.68	20400.6	5.07
5	+	+		+	0.115	-0.117	+	+	+		+	0.6903	0.1898	66	-10135.04	20406.15	10.62
6	+	+		+	0.115	-0.121	+	+	+		+	0.7291		65	-10137.98	20409.9	14.37
7	+	+	+		0.139	-0.113	+	+	+			0.7415	0.1966	53	-10152.3	20413.23	17.7
8	+	+	+		0.139	-0.113	+	+	+	+		0.7277	0.1954	54	-10151.98	20414.68	19.15
9	+	+		+	0.156		+	+	+			0.7269	0.2108	58	-10148.18	20415.5	19.97
10	+	+		+	0.156		+	+	+	+		0.7185	0.2083	59	-10147.78	20416.8	21.27
11	+	+	+		0.139	-0.118	+	+	+			0.7754		52	-10155.27	20417.07	21.54
12	+	+	+		0.139	-0.118	+	+	+	+		0.7619		53	-10154.99	20418.6	23.07
13	+	+		+	0.159		+	+	+			0.7700		57	-10151.92	20420.87	25.34
14	+	+		+	0.158		+	+	+	+		0.7514		58	-10151.51	20422.15	26.62
15	+	+		+	0.101	-0.125	+	+	+					57	-10153.36	20423.74	28.21
16	+	+	+		0.139	-0.112	+	+	+		+	0.7026	0.1964	60	-10150.3	20423.95	28.42
17	+	+		+	0.101	-0.125	+	+	+	+				58	-10152.82	20424.78	29.25
18	+	+			0.129	-0.112	+	+	+			0.7575	0.1964	52	-10159.57	20425.67	30.14
19	+	+		+	0.155		+	+	+		+	0.6884	0.2076	65	-10146.05	20426.04	30.51
20	+	+			0.129	-0.112	+	+	+	+		0.7439	0.1954	53	-10159.36	20427.34	31.81

- The effects of area, month, and SST were always selected in both Tweedie and binomial parts in the top 20 models
- Squared SST was also selected for both distributions in the top model with minimum AICc.
- Ship was selected only in binomial distribution in the top model.
- Selected the model with minimum AICc as the base model.

- The same model was selected as the best as in the previous year
- The estimated parameters values were also very similar

Analysis of deviance table

Table 5

Analysis of deviance table for the best model.

Variable	Chisq	Df	Pr(>Chisq)	signif.code	%deviance explained
Tweedie					
area	331.75	7	9.90E-68	***	8.90%
month	170.66	5	5.28E-35	***	
ship	45.91	7	9.11E-08	***	
SST	8.27	1	4.04E-03	**	
I(SST^2)	22.24	1	2.40E-06	***	
year	350.56	21	1.45E-61	***	
Binomial					
area	84.45	6	4.28E-16	***	
month	47.51	5	4.46E-09	***	
SST	25.45	1	4.53E-07	***	
I(SST^2)	6.67	1	9.79E-03	**	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

- The effects of area, month, and SST had significant influences on CPUE in both Tweedie and binomial parts in the base model, according to the likelihood ratio test using the chi-square statistic
- The percent deviance explained of the base model was low (8.90%)

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. 5A

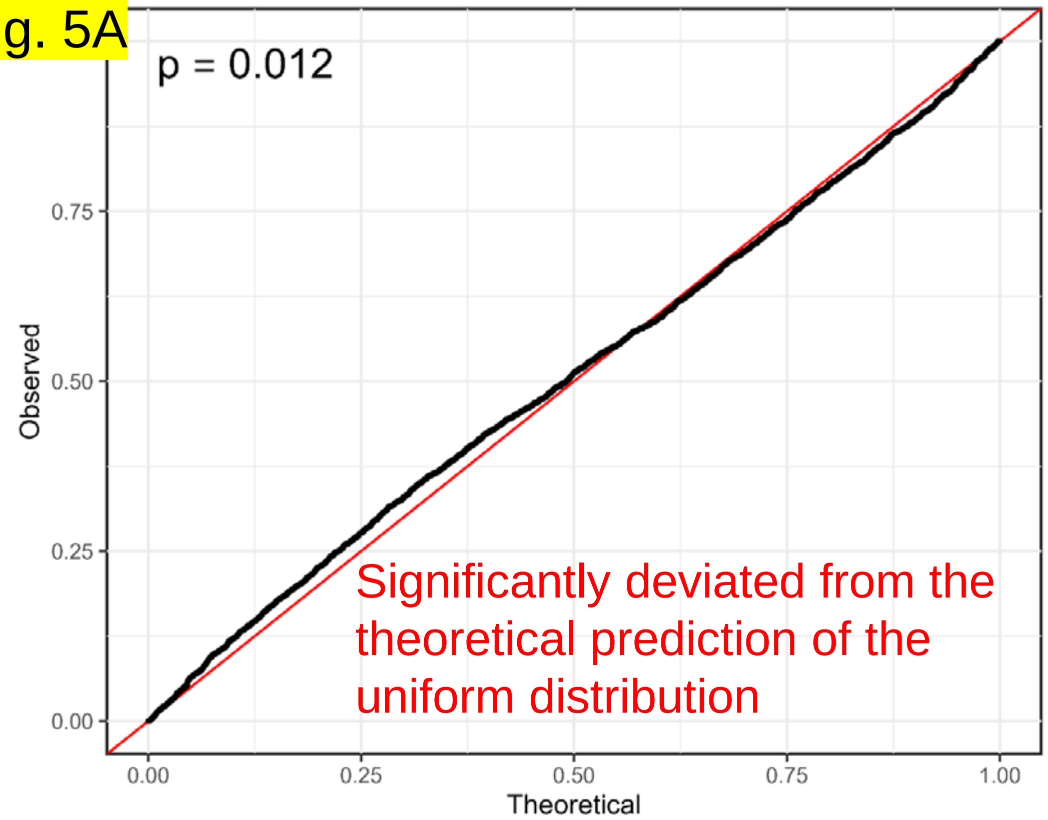
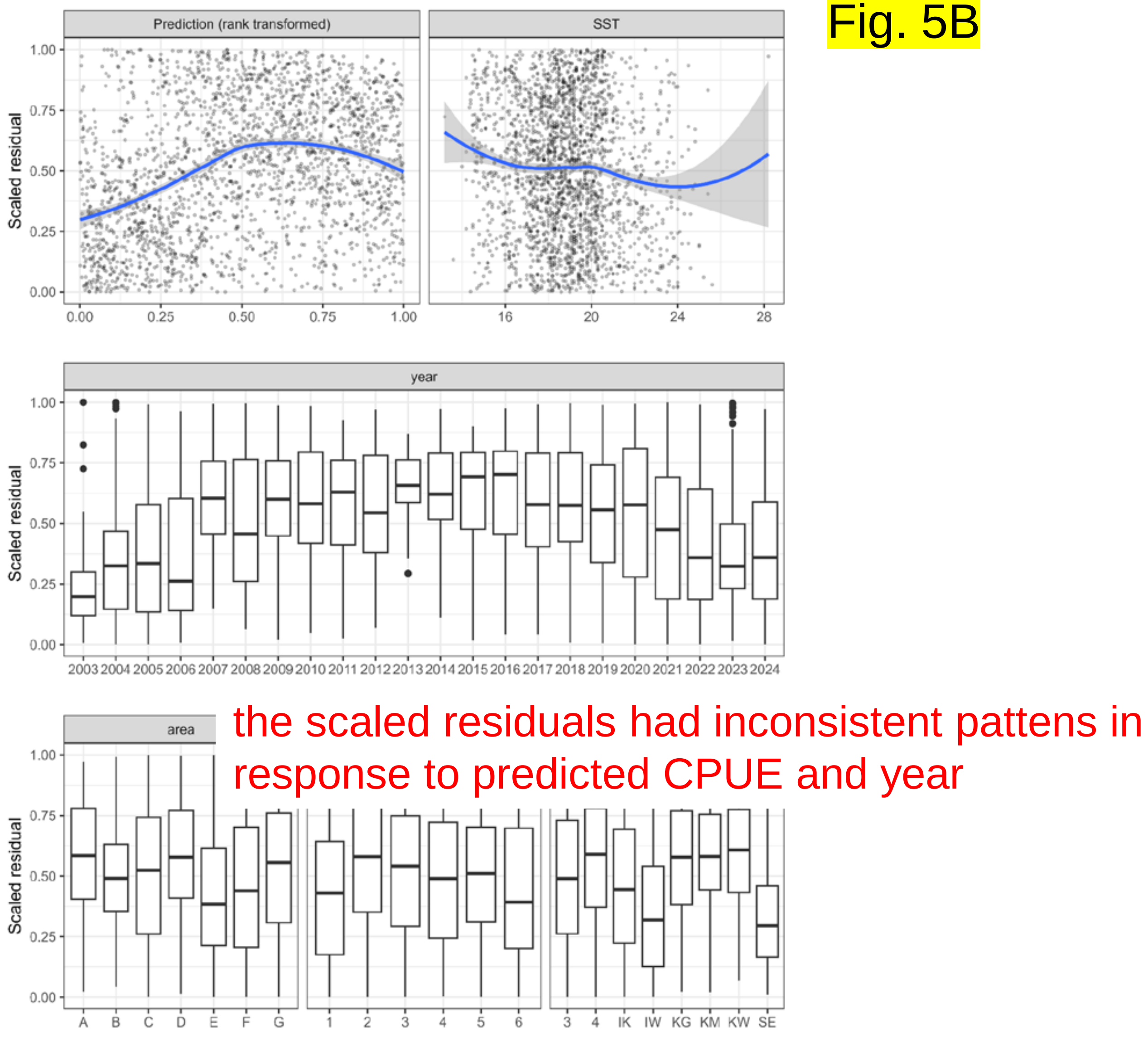
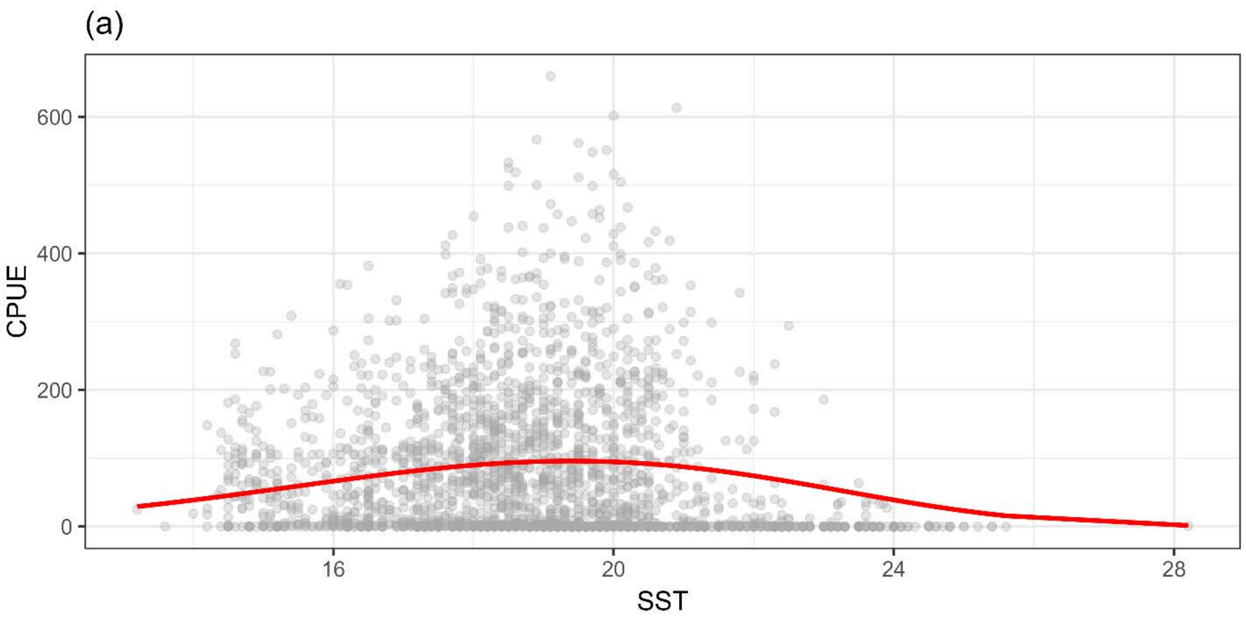


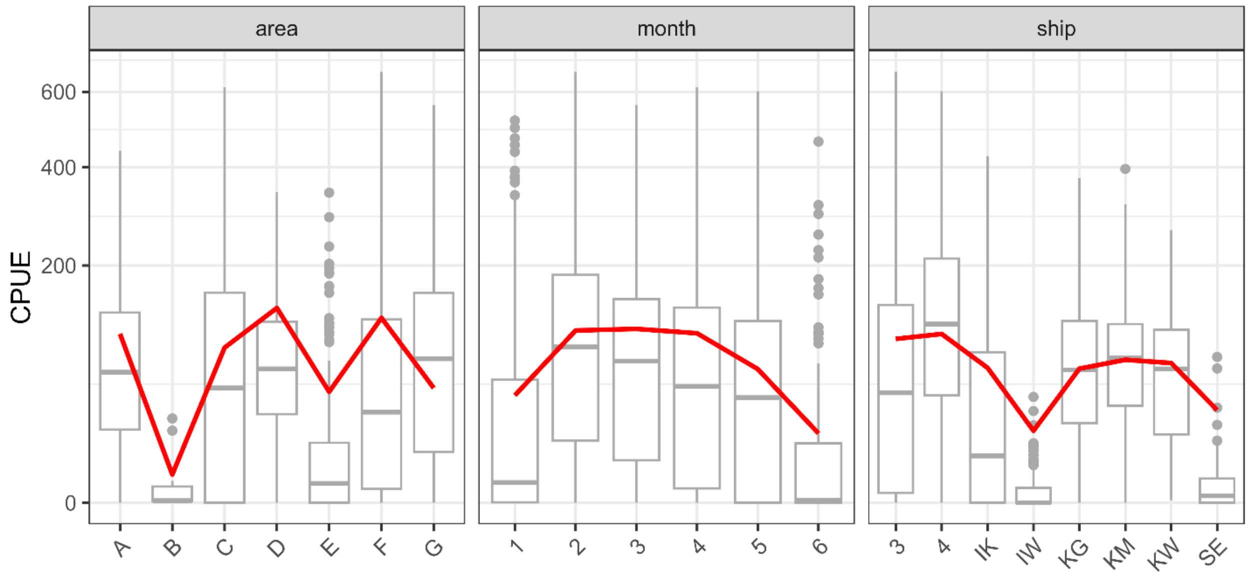
Fig. 5B



Relationship between explanatory variables and predicted CPUE

Fig. 6: Partial dependence plot



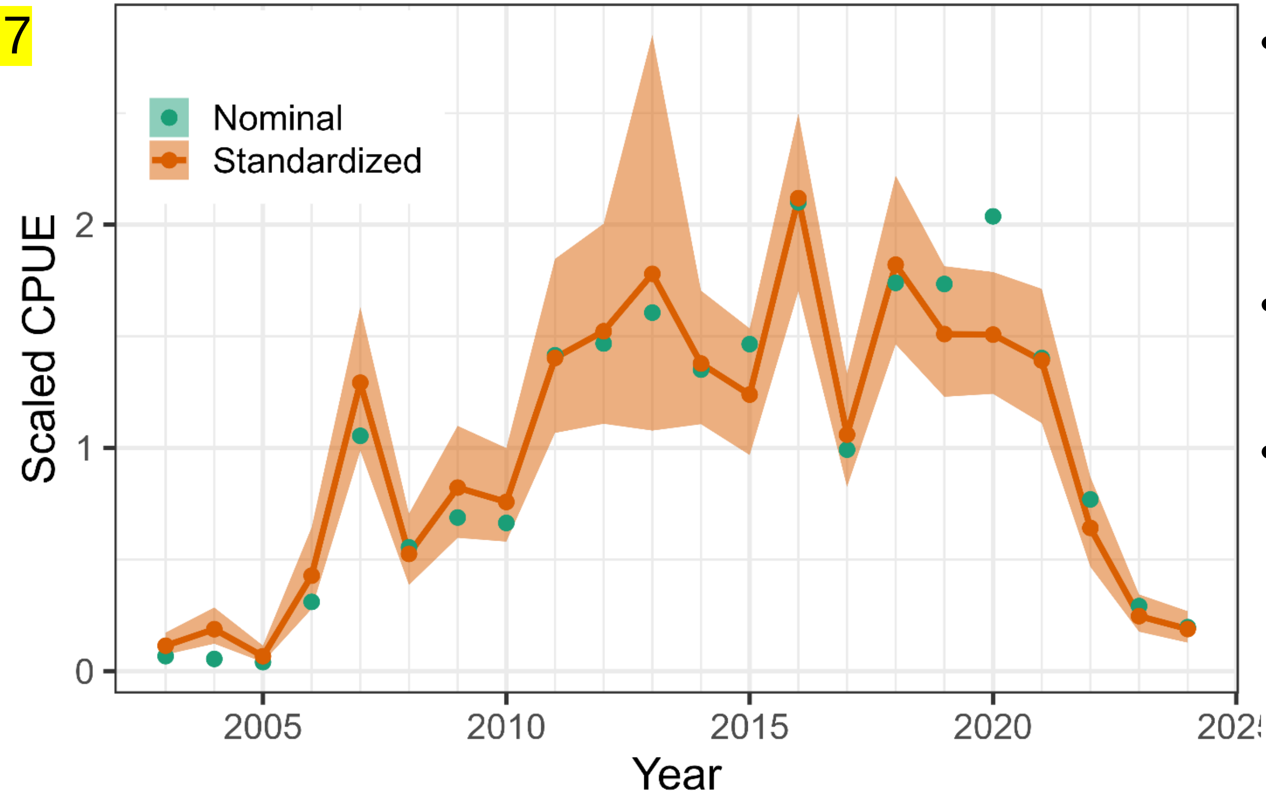


- CPUE was expected be the highest at 19.4℃
- CPUE was higher in February to April than in the other months.

Yearly trends of nominal and standardized CPUE

- To derive the standardized CPUE values, we calculated predicted CPUE values per each category (for the continuous variables, we divided their range at small regular intervals) of selected variables (e.g., Area = A, B, C…, Year = 2003, 2003, 2004…, SST = 10.0, 11.0, 12.0…) using the *expand.grid* function in R
- Then calculated the arithmetic mean of each year.
- Not implement an area-weighting approach because the size of each area was unknown.

Fig. 7

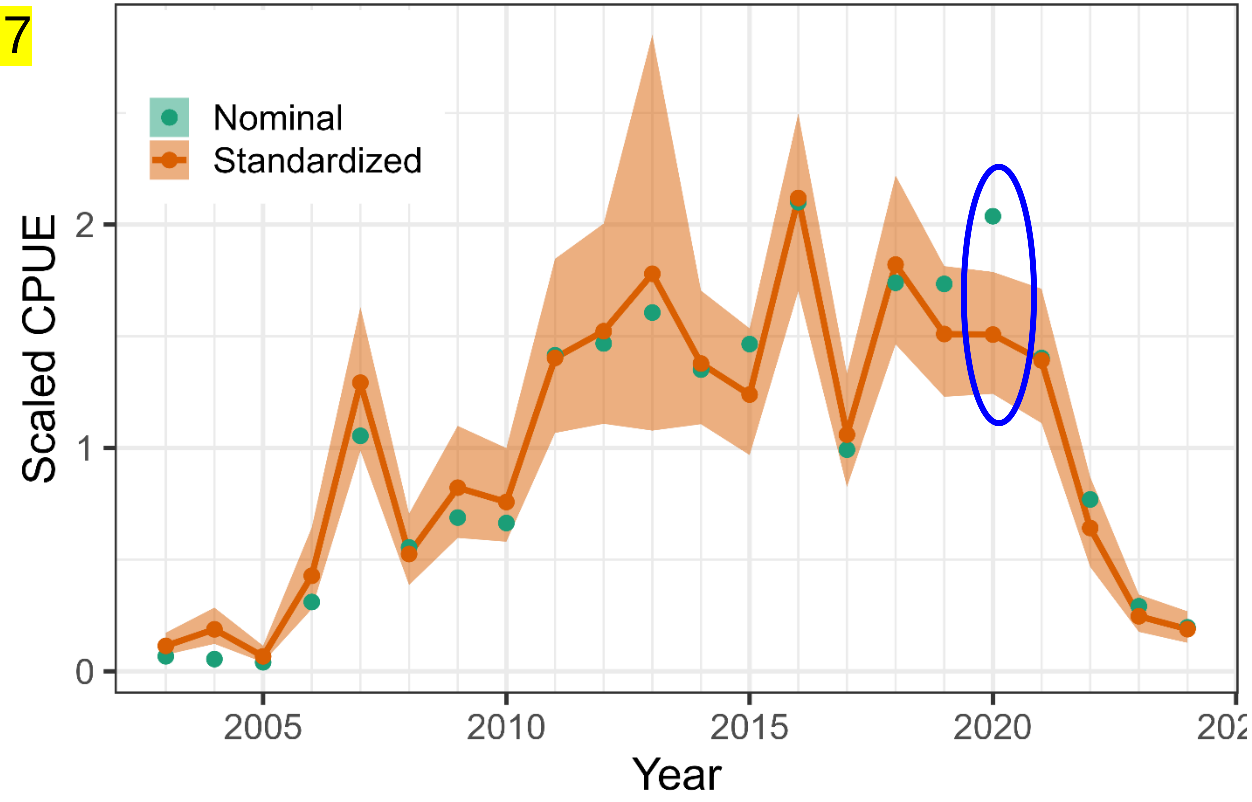


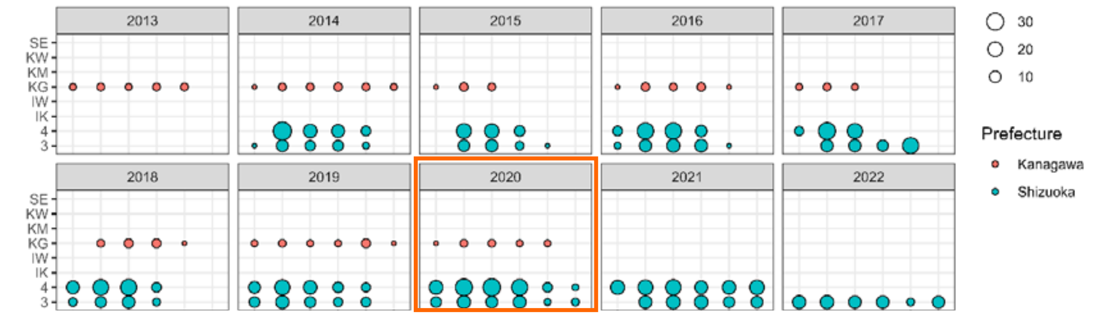
- Standardized CPUE has been relatively low until 2005, increased since then, and remained relatively stable at a high level from 2011 to 2021
- However, it declined significantly thereafter and was at its lowest in 2024 since 2006.
- This yearly trend of the standardized CPUE was not largely different from that of nominal CPUE except that the scaled standardized CPUE was much lower in 2020 than the scaled nominal value

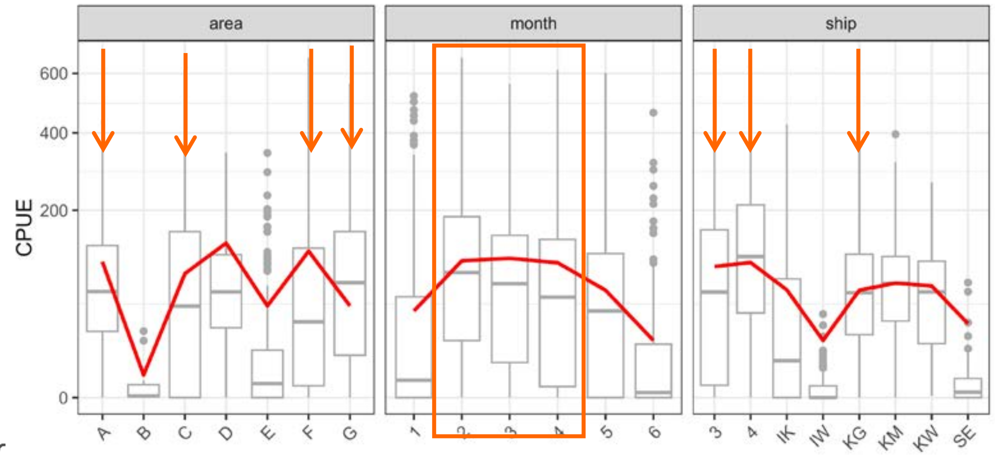
Why nominal and standardized values were much different in 2020?

- The samples in 2020 had a large proportion of February to April and ship IDs of 3 and 4, when CPUE tends to be higher,
- There were no operations in areas B and D, when CPUE tends to be lower, which elevated the nominal CPUE

Fig. 7







Values and uncertainties of the nominal and standardized CPUE

Table 7

Year	Nominal (kg/man-hour)	Standardized (kg/man-hour)	CV	Lower 95% CI	Upper 95% CI
2003	5.49	3.34	0.22	2.23	5.26
2004	4.46	5.53	0.2	3.88	8.34
2005	3.29	1.96	0.26	1.26	3.31
2006	25.46	12.6	0.22	8.4	19.77
2007	86.56	38.08	0.12	30.33	49.41
2008	45.53	15.47	0.14	12.17	21.15
2009	56.51	24.23	0.15	18.76	33.41
2010	54.51	22.33	0.15	17.11	30.13
2011	116.21	41.35	0.15	31.63	56.1
2012	120.54	44.87	0.16	33.22	61.84
2013	131.91	52.45	0.28	31.43	90.78
2014	110.94	40.61	0.16	30.54	56.03
2015	120.32	36.51	0.17	26.91	52.41
2016	172.48	62.46	0.15	48.05	84.6
2017	81.48	31.22	0.17	23.22	44.56
2018	142.86	53.66	0.16	40.93	75.33
2019	142.44	44.5	0.13	35.34	58.88
2020	167.34	44.43	0.14	34.64	60.14
2021	115.21	41.02	0.16	31.37	57.76
2022	63.17	18.9	0.18	13.76	26.67
2023	23.91	7.25	0.19	5.11	10.72
2024	16.15	5.55	0.21	3.74	8.48

The coefficients of variation (CV) of the estimates were 0.13−0.28

Discussion and recommendation

- The dip-net fishery CPUE was influenced by the factors of month, area, in-situ SST, and ship
- These factors were considered to have an impact independent of the stock abundance in each year, and hence, standardized to eliminate sampling biases
- The standardized index values showed a relatively stable trend at high levels from 2011 to 2021, followed by a sharp decline since 2022
- The index value in 2024 further declined from that in 2023, being the lowest since 2003
- In terms of model diagnostics, issues such as scaled residuals deviating from theoretical values were observed, and the % deviance explained was low.
- This might be attributed to the considerable variability in the original data, imperfect spatial information, and the possibility of overlooking other important variables such as interactions among explanatory variables
- There might be room for model improvement in the future
- It is believed that the majority of spawning chub mackerel migrates around the Izu Islands and, therefore, the CPUE of the dip-net fishery targeting the spawners represents valuable information based on the direct observations of spawning fish of chub mackerel.
- Propose to use the standardized CPUE values in this paper as an abundance index of SSB in CMSA.