



North Pacific Fisheries Commission

NPFC-2026-TWG CMSA12-WP01

Standardized CPUE of Chub mackerel (*Scomber japonicas*) caught by the China's lighting purse seine fishery up to 2025

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Summary

Catch per unit fishing effort (CPUE) standardization is an important approach to obtaining accurate indices of stock abundance by removing the influence of external factors. Chub mackerel (*Scomber japonicas*) is an economically important small pelagic fish inhabiting the Northwest Pacific Ocean. Most of the Chub mackerel catch is harvested by the lighting purse seine fishery in China. In this paper, we standardized CPUE of Chub mackerel using generalized linear model (GLM) and generalized additive model (GAM). Four groups of independent variables were considered in the CPUE standardization: spatial variables (latitude and longitude), temporal variables (year and month), fishery variables (vessel length) and environmental variables (SST and Chla). The model selections of GLM and GAM were based on the Bayesian information criterion (BIC). From the results, Higher Spearman's correlation and lower mean squared error (MSE) were observed by GAM. Therefore, we prefer to choose the best GAM model to estimate standardized CPUE of Chub mackerel fishery.

1. Background of the Chub mackerel fishery

Chub mackerel (*Scomber japonicas*) is a highly migratory fish, widely distributed in the high seas of the Northwest Pacific Ocean (Yatsu et al., 2005). Now, about 100 Chub mackerel vessels from China operate in the Northwest Pacific Ocean. The distribution of Chub mackerel fishing grounds shows large variation during the fishing period (April–November) each year (Yatsu et al., 2002), therefore, temporal variables (year and month), spatial variables (longitude and latitude) were included in the analysis. The fishing ground of the Chub mackerel is tightly associated with the marine environment (Zhang et al., 2009). Thus, Sea surface temperature (SST) and Chlorophyll-a concentration (Chla) were included in the analysis. In addition, the vessel length may affect the quantity of the catch, which were also included in this study.

2. Method

2.1. The Data

Full-commercial fishery data (logbook) were from 2014 to 2025, which were derived from Technical Group for Chub mackerel Fishery, Distant-water Fishery Society of China. The catch and effort of CPUE Fleet were aggregated by monthly at $1^{\circ} \times 1^{\circ}$ grid, with good representativeness of the whole fishery (Table 1). The Table 2 represents the filter "rules" used on data for CPUE standardization and the effect on the overall sample size. Annual spatial distribution patterns of catch, effort and nominal CPUE were presented in the Figure 1.

Summary of explanatory variables used for CPUE standardization were listed in the Table 3. *Year* is a categorical variable of 12 years (2014—2025). *Month* is a categorical variable including the 10 calendar months from March to December. *Longitude* and *latitude* are categorical variables, which divided at intervals of 1° . We attempted two cases (categorical and splined variable) for *SST* and investigated splined variable for *Chla*. *Vessellength* is a categorical variable of 44—61 m, which will affect the catchability (Table 3).

SST and Chla data were derived from the Copernicus Marine Service products (<http://marine.copernicus.eu>). The spatial-temporal resolution of the SST and Chla data are monthly at $0.25^{\circ} \times 0.25^{\circ}$ grid. The environmental data was matched with the fishery data for the further analysis. The environmental factors such as SST, Chla have been recognized as important drivers of chub mackerel distribution (Torrejon-Magallanes et al., 2021). SST influences fish physiology, metabolism, production rates, and migration patterns, and Chla reflects primary productivity (Lee et al., 2018; Okunishi et al., 2020). These factors play crucial roles in shaping the distribution and abundance of fishery resources. Therefore, they should be considered in

CPUE standardization.

The scatter plots/ box plots of explanatory variables were presented in Figure 2, and the correlation matrix of explanatory variables used in the analysis was shown in Figure 3.

2.2 Full model description and model selection

Both generalized linear model (GLM) and generalized additive model (GAM) were used to estimate standardized CPUE.

The full GLM model was:

$$\log(\text{CPUE}+1) = \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst} + \text{Chla} + \text{Vessellength} + \text{interaction} + \varepsilon$$

The full GAM model was:

$$\log(\text{CPUE}+1) = \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + s(\text{Sst}) + s(\text{Chla}) + s(\text{Vessellength}) + \text{interaction} + \varepsilon$$

where ε is the residual, which is assumed to have a normal distribution. *interaction* is an interaction term representing the interactive effect of spatial and temporal factors for the Chub mackerel. Full model interaction includes all the possible combination of Year, Month, Longitude and Latitude.

The optimal model was selected using the Bayesian information criterion (BIC) based on forward selection. Spearman's correlation and mean squared errors (MSE) between the predicted and observed CPUEs were calculated by 5 fold cross-validation with repeated 5 times to select well-performance model between two optimal models. All the model construction and data analysis were used the R(4.0.3) software (packages mgcv and nlme).

2.3 Yearly trend extraction

Time series of standardized CPUE was estimated using the well-performance model. Expanded grid function in R was used to generate a series of spatial homogeneous explanatory variables and the area of each $1^\circ \times 1^\circ$ grid cell was considered the same. Then, annual values of $\ln(\text{CPUE})$ for each area ($1^\circ \times 1^\circ$) were predicted. Finally annual standardized CPUE were calculated as the mean of CPUE_y :

$$\overline{\text{CPUE}}_y = \frac{1}{n_y} \times \sum_{k=1}^{n_y} \text{CPUE}_k^{\text{fitted}}$$

where, $\overline{\text{CPUE}}_y$ is CPUE indices in y th year, n_y is the spatial homogeneous explanatory variables number in y th year, $\text{CPUE}_k^{\text{fitted}}$ is the k th fitted CPUE data in y th year.

The fitted CPUE and 95% confidence intervals of optimal model were calculated by

bootstrap resampled residuals with 1000 replications.

3 Result and Discussion

In this study, we used two models to standardize the CPUEs. The result of the best GLM and GAM model selections were shown in Table 4 and Table 5, respectively. Comparing the results of cross validation tests in GLM and GAM analyses (Table 6), higher Spearman's correlation and lower MSE between observed and predicted of test data were observed by GAM, so we prefer to choose the best GAM model to estimate standardized CPUE of Chub mackerel. The summary of fitting a GAM for the optimal model is shown in Table 7. All explanatory variables are highly significant ($p < 0.01$). Residuals from the best GAM model showed an approximately normal distribution around 0, which indicated that the model assumptions were satisfied (Figure 4). The estimated relationship between response and explanatory variables were shown in the Figure 5, and the estimated values of main parameters and uncertainty in the parameters were presented in Table 8.

Table 9 and Figure 6 shows the annual changes of nominal CPUE and standardized CPUE by the optimal GAM model. There is similar trend between nominal CPUE and standardized CPUE by GAM. In conclusion, we prefer to choose the best GAM model to estimate standardized CPUE of Chub mackerel fishery.

We standardized CPUE in accordance with the standardization protocol. The checklist is shown in Appendix 1.

References

- Lee, D., Son, S., Kim, W., Park, J.M., Joo, H., Lee, S.H., 2018. Spatio-temporal variability of the habitat suitability index for chub mackerel (*Scomber japonicus*) in the east/Japan sea and the south sea of South Korea. *Remote Sens.* 10 (6), 938.
- Okunishi, T., Yokouchi, K., Hasegawa, D., Tanaka, T., Setou, T., Yukami, R., Takasuka, A., 2020. Relationship between sea temperature variation and fishing ground formations of chub mackerel in the Pacific Ocean off Tohoku. *Jpn. Soc. Fish. Oceanogr.* 84 (4), 271–284.
- Torrejon-Magallanes, J., Angeles-Gonzalez, L.E., Csirke, J., Bouchon, M., Morales- Bojorquez, E., Arreguin-Sanchez, F., 2021. Modeling the Pacific chub mackerel (*Scomber japonicus*) ecological niche and future scenarios in the northern Peruvian current system. *Prog. Oceanogr.* 197, 10.
- Yatsu A, Mitani T, Watanabe C, *et al.*, 2002. Current stock status and management of Chub mackerel *Scomber japonicus* along the Pacific coast of Japan. *Fisheries science*, 68(supl):93-96.
- Yatsu, A. Watanabe, T. Ishida, M. Sugisaki, H. Jacobson, L.D., 2005. Environmental effects on recruitment and productivity of Japanese sardine *Sardinops melanostictus* and Chub

mackerel *Scomber japonicus* with recommendations for management. *Fish. Oceanogr.* 14, 263–278.

Zhang G W, Chen X J, Li G, 2009. Bio-economic model and its application of Chub mackerel in the East China Sea and Yellow Sea. *Journal of Shanghai Ocean University*, 18(4):447-452.

Tables:

Table 1. Catch and effort information by CPUE FLEET

Year	Number of observations	% Coverage of CPUE FLEET(catch)	% Coverage of CPUE FLEET(effort)	Total Catch of CPUE FLEET (MT)	Total Effort for CPUE FLEET and unit	Percentage of overall catch by member (across all fleets/gears)
2014	1477	80%	75%	30030	1477 vessel days	71%
2015	5605	74%	85%	93884	5605 vessel days	67%
2016	6644	82%	89%	98132	6644 vessel days	69%
2017	9578	92%	95%	133632	9578 vessel days	86%
2018	6617	81%	90%	98142	6617 vessel days	75%
2019	2504	81%	90%	43364	2504 vessel days	67%
2020	5158	82%	94%	69543	5158 vessel days	75%
2021	14239	93%	96%	88550	14239 vessel days	82%
2022	13723	70%	90%	75341	13723 vessel days	68%
2023	14075	98%	95%	46133	14075 vessel days	94%
2024	13830	98%	95%	67835	13830 vessel days	93%
2025	15939	93%	100%	37609	15939 vessel days	95%

Table 2. Filter "Rules" used on data for CPUE standardization and the effect on the overall sample size.

Filter Applied	Number of Records Remaining	Number Removed	Number of Records with Chub Mackerel Catch >0
Initial Data set	109389	-	100489
Remove records <2°C & >26°C	109389	4320	105069
Final Data Set	109389	4320	105069

Table 3. Summary of explanatory variables used for GLM and GAM analysis.

Variables		Categorical or continuous	Details	Note
Year	<i>Year</i>	12 categories	12 years from 2014 to 2025	
Month	<i>Month</i>	10 categories	10 months from March to December	
Longitude	<i>Longitude</i>	22 categories	$145^{\circ} \leq \text{Longitude} < 146^{\circ}$; $146^{\circ} \leq \text{Longitude} < 147^{\circ}$; $147^{\circ} \leq \text{Longitude} < 148^{\circ}$; ..., $166^{\circ} \leq \text{Longitude} < 167^{\circ}$	at intervals of 1°
Latitude	<i>Latitude</i>	15 categories	$34^{\circ} \leq \text{Latitude} < 36^{\circ}$; $36^{\circ} \leq \text{Latitude} < 37^{\circ}$; ..., $48^{\circ} \leq \text{Latitude} < 49^{\circ}$	at intervals of 1°
Sea surface temperature	<i>SST</i> <i>SST_c</i>	spline 20 categories	$3^{\circ}\text{C} \leq \text{SST} < 4^{\circ}\text{C}$; $4^{\circ}\text{C} \leq \text{SST} < 5^{\circ}\text{C}$; $5^{\circ}\text{C} \leq \text{SST} < 6^{\circ}\text{C}$; ..., $25^{\circ}\text{C} \leq \text{SST} < 26^{\circ}\text{C}$	at intervals of 1°C
Chlorophyll-a concentration	<i>Chla</i>	continues		
Vessel length	<i>Vessellength_c</i>	10 categories	$45\text{m} \leq \text{Vessellength} < 47\text{m}$; $47\text{m} \leq \text{Vessellength} < 49\text{m}$..., $61\text{m} \leq \text{Vessellength} < 63\text{m}$	at intervals of 2m

Table 4. Result of GLM model selection

No	GLM model	R ²	BIC	Explained deviance
1	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst_c} + \text{Chla} + \text{Vl_c}$	0.3977	61326.91	39.54%
2	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst_c} + \text{Chla} + \text{Vl_c} + \text{Year:Month}$	0.4422	60387.13	43.80%
3	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst_c} + \text{Chla} + \text{Vl_c} + \text{Year:Month} + \text{Year:Longitude}$	0.4528	61462.06	44.52%
4	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst_c} + \text{Chla} + \text{Vl_c} + \text{Year:Month} + \text{Year:Latitude}$	0.4477	61200.06	44.11%
5	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst_c} + \text{Chla} + \text{Vl_c} + \text{Year:Month} + \text{Year:Longitude} + \text{Year:Latitude} + \text{Month:Longitude} + \text{Month:Latitude} + \text{Longitude:Latitude}$	0.4983	63599.72	48.21%

Table 5. Result of GAM model selection

No	GAM model	R ²	BIC	Explained deviance
1	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst} + \text{Chla} + \text{Vl_c}$	0.3960	61239.68	39.81%
2	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst} + \text{Chla} + \text{Vl_c} + \text{Year:Month}$	0.4387	60298.15	44.27%
3	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst} + \text{Chla} + \text{Vl_c} + \text{Year:Month} + \text{Year:Longitude}$	0.4457	61342.90	45.31%
4	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst} + \text{Chla} + \text{Vl_c} + \text{Year:Month} + \text{Year:Latitude}$	0.4423	61044.13	44.86%
5	$\ln(\text{CPUE}+1) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Longitude} + \text{Latitude} + \text{Sst} + \text{Chla} + \text{Vl_c} + \text{Year:Month} + \text{Year:Longitude} + \text{Year:Latitude} + \text{Month:Longitude} + \text{Month:Latitude} + \text{Longitude:Latitude}$	0.4826	63323.71	49.82%

Table 6. The Five-fold cross validation for the best GLM and GAM

case	cor_GLM_test	MSE_GLM_test	cor_GAM_test	MSE_GAM_test
1	0.6526	0.7146	0.6702	0.6903
2	0.6597	0.7285	0.6758	0.6856
3	0.6683	0.7292	0.6739	0.6947
4	0.6624	0.7317	0.6697	0.6935
5	0.6619	0.7394	0.6747	0.6979

The spearman's correlation coefficient is showed in the table.

Table 7. Anova test for best GAM model

Parametric Terms:

	df	<i>F</i>	P-value	
factor(Year)	10	269.51	< 2.2E-16	***
factor(Month)	9	9.16	5.53E-14	***
factor(Longitude)	21	19.09	< 2.2E-16	***
factor(Latitude)	14	12.41	< 2.2E-16	***
factor(VI_c)	9	9.08	7.87E-14	***
factor(Year):factor(Month)	96	61.91	< 2.2E-16	***

Approximate significance of smooth terms:

	Edf	Ref.df	<i>F</i>	P-value	
s(SST)	8.64	8.96	21.17	< 2.2E-16	***
s(Chla)	8.72	8.98	5.68	< 2.2E-16	***

Significant code: *** 0.001, **0.01, *0.05

Table 8. The estimated coefficients in the best GAM models for CPUE standardization

Explanatory variable	Coefficient	SE	Explanatory variable	Coefficient	SE
Year2015	-0.0934	0.0571	year2020:month5	-0.0285	0.2948
Year2016	-0.2085	0.0517	year2021:month5	-1.112	0.3423
Year2017	-1.8662	0.5148	year2022:month5	-1.1852	0.1383
Year2018	0.0323	0.7113	year2023:month5	-0.9009	0.2065
Year2019	0.8475	0.209	year2024:month5	-1.0166	0.1301
Year2020	-0.5739	0.2371	year2025:month5	-0.888	0.182
Year2021	-0.6642	0.2993	year2015:month6	0.2699	0.1219
Year2022	-1.3938	0.0561	year2016:month6	0.3898	0.1192
Year2023	-1.4568	0.0715	year2017:month6	1.5713	0.525
Year2024	-1.4512	0.0514	year2018:month6	0.0314	0.7224
Year2025	-1.8204	0.0698	year2019:month6	-0.6326	0.2441
Month4	0.1467	0.1845	year2020:month6	-0.1029	0.2714
Month5	0.7826	0.2181	year2021:month6	-0.763	0.3231
Month6	0.198	0.2089	year2022:month6	-0.5233	0.1207
Month7	-0.0437	0.2201	year2023:month6	-0.3546	0.1783
Month8	-0.2754	0.2353	year2024:month6	-0.6029	0.1084
Month9	0.6819	0.2392	year2025:month6	-0.4763	0.1733
Month10	0.6415	0.2153	year2015:month7	0.2152	0.1274
Month11	0.6691	0.2394	year2016:month7	0.1366	0.1258
Month12	0.2905	0.1552	year2017:month7	1.6852	0.5267
factor(lon)146	0.2269	0.2012	year2018:month7	-0.0448	0.724
factor(lon)147	0.2634	0.2082	year2019:month7	-0.5823	0.2513
factor(lon)148	0.1309	0.2103	year2020:month7	-0.2475	0.2761
factor(lon)149	0.162	0.2115	year2021:month7	-0.7731	0.3284
factor(lon)150	0.1912	0.2121	year2022:month7	-0.6092	0.136
factor(lon)151	0.1626	0.2124	year2023:month7	-0.2394	0.1698
factor(lon)152	0.1872	0.2127	year2024:month7	0.2855	0.1171
factor(lon)153	0.266	0.213	year2025:month7	0.7125	0.1793
factor(lon)154	0.4065	0.2133	year2015:month8	0.2441	0.1491
factor(lon)155	0.4154	0.2139	year2016:month8	-0.0747	0.1438
factor(lon)156	0.3533	0.2153	year2017:month8	1.807	0.5315
factor(lon)157	-0.0162	0.2157	year2018:month8	0.0486	0.7313
factor(lon)158	0.1135	0.2154	year2019:month8	-0.6004	0.2577
factor(lon)159	0.2169	0.2158	year2020:month8	0.5094	0.2881
factor(lon)160	0.2091	0.2163	year2021:month8	-0.0144	0.335
factor(lon)161	0.1442	0.2173	year2022:month8	0.428	0.1544
factor(lon)162	-0.0333	0.2187	year2023:month8	0.3422	0.1917
factor(lon)163	0.1525	0.2181	year2024:month8	0.5106	0.1364
factor(lon)164	-0.312	0.221	year2025:month8	0.444	0.1887
factor(lon)165	-0.7116	0.231	year2015:month9	-0.3561	0.1582
factor(lon)166	-1.1935	0.6276	year2016:month9	-0.984	0.154
factor(lat)35	-1.1935	0.6276	year2017:month9	0.8461	0.5338
factor(lat)36	-0.043	0.8666	year2018:month9	-1.1065	0.7322
factor(lat)37	0.173	0.8543	year2019:month9	-1.2525	0.2757
factor(lat)38	0.1308	0.8502	year2020:month9	-0.4243	0.2853
factor(lat)39	0.2439	0.8494	year2021:month9	-0.6943	0.3389
factor(lat)40	0.4209	0.8487	year2022:month9	-0.0546	0.1641
factor(lat)41	0.5569	0.8484	year2023:month9	0.0362	0.1956
factor(lat)42	0.6351	0.8487	year2024:month9	-0.3806	0.1472

factor(lat)43	0.7339	0.8492	year2025:month9	-0.5618	0.2211
factor(lat)44	0.8016	0.8495	year2015:month10	0.224	0.1381
factor(lat)45	0.734	0.8502	year2016:month10	-0.3027	0.119
factor(lat)46	0.8919	0.8507	year2017:month10	1.45	0.526
factor(lat)47	0.7826	0.8512	year2018:month10	-0.224	0.7285
factor(lat)48	0.473	0.8522	year2019:month10	-1.0267	0.267
factor(vl_c)50	-0.176	0.0608	year2020:month10	0.5369	0.2879
factor(vl_c)51	-0.0199	0.02	year2021:month10	-0.2807	0.3288
factor(vl_c)52	0.0266	0.0191	year2022:month10	0.6694	0.1318
factor(vl_c)53	-0.2019	0.0556	year2023:month10	-0.2249	0.1829
factor(vl_c)54	-0.2163	0.052	year2024:month10	-0.5147	0.1115
factor(vl_c)55	-0.0196	0.0285	year2025:month10	-0.5248	0.1845
factor(vl_c)57	0.0764	0.024	year2015:month11	0.5446	0.1889
factor(vl_c)59	0.016	0.0182	year2016:month11	0.2248	0.1658
factor(vl_c)61	0.1027	0.0312	year2017:month11	1.4391	0.5379
year2015:month4	-0.4546	0.1709	year2018:month11	0.2161	0.7434
year2016:month4	0.3917	0.1091	year2019:month11	-1.1335	0.2742
year2017:month4	1.424	0.5268	year2020:month11	0.4131	0.3
year2018:month4	0.3809	0.7164	year2021:month11	-0.6264	0.344
year2019:month4	-0.279	0.2249	year2022:month11	0.3152	0.1702
year2020:month4	0.0192	0.2736	year2023:month11	0.1526	0.2123
year2021:month4	-0.1095	0.3138	year2024:month11	-0.0068	0.1573
year2022:month4	-0.5955	0.1366	year2025:month11	-0.2627	0.2112
year2023:month4	-0.345	0.2399	year2017:month12	1.0197	0.5024
year2024:month4	-0.3985	0.0633	year2019:month12	-0.5034	0.2284
year2025:month4	0.1131	0.1443	year2020:month12	0.3345	0.2438
year2015:month5	-0.7805	0.145	year2021:month12	-1.0948	0.3201
year2016:month5	0.01	0.1422	year2022:month12	0.1613	0.1527
year2017:month5	0.8481	0.5277	year2023:month12	0.0768	0.2028
year2018:month5	-0.5804	0.7255	year2024:month12	0.6728	0.0989
year2019:month5	-1.0132	0.2533	year2025:month12	-0.3764	0.2537

Table 9. Nominal and standardized CPUEs of CPUE FLEET from 2014 to 2025

Year	Nominal CPUE	Standardized CPUE by GAM	CV (%)	95% CI by GAM	
2014	22.33	16.82	6.57	[16.13	17.26]
2015	16.75	13.50	5.21	[12.70	13.82]
2016	14.77	11.90	5.98	[11.06	12.63]
2017	13.92	9.61	3.87	[9.06	10.23]
2018	14.83	12.49	5.25	[11.82	13.10]
2019	17.32	15.16	6.19	[14.22	15.86]
2020	13.48	9.78	6.68	[8.96	10.20]
2021	6.22	4.17	4.97	[3.59	4.72]
2022	5.49	3.82	4.73	[3.12	4.30]
2023	4.61	3.33	5.89	[2.92	3.86]
2024	4.90	3.47	6.41	[2.78	4.10]
2025	2.41	1.25	4.86	[1.03	2.08]

Figures:

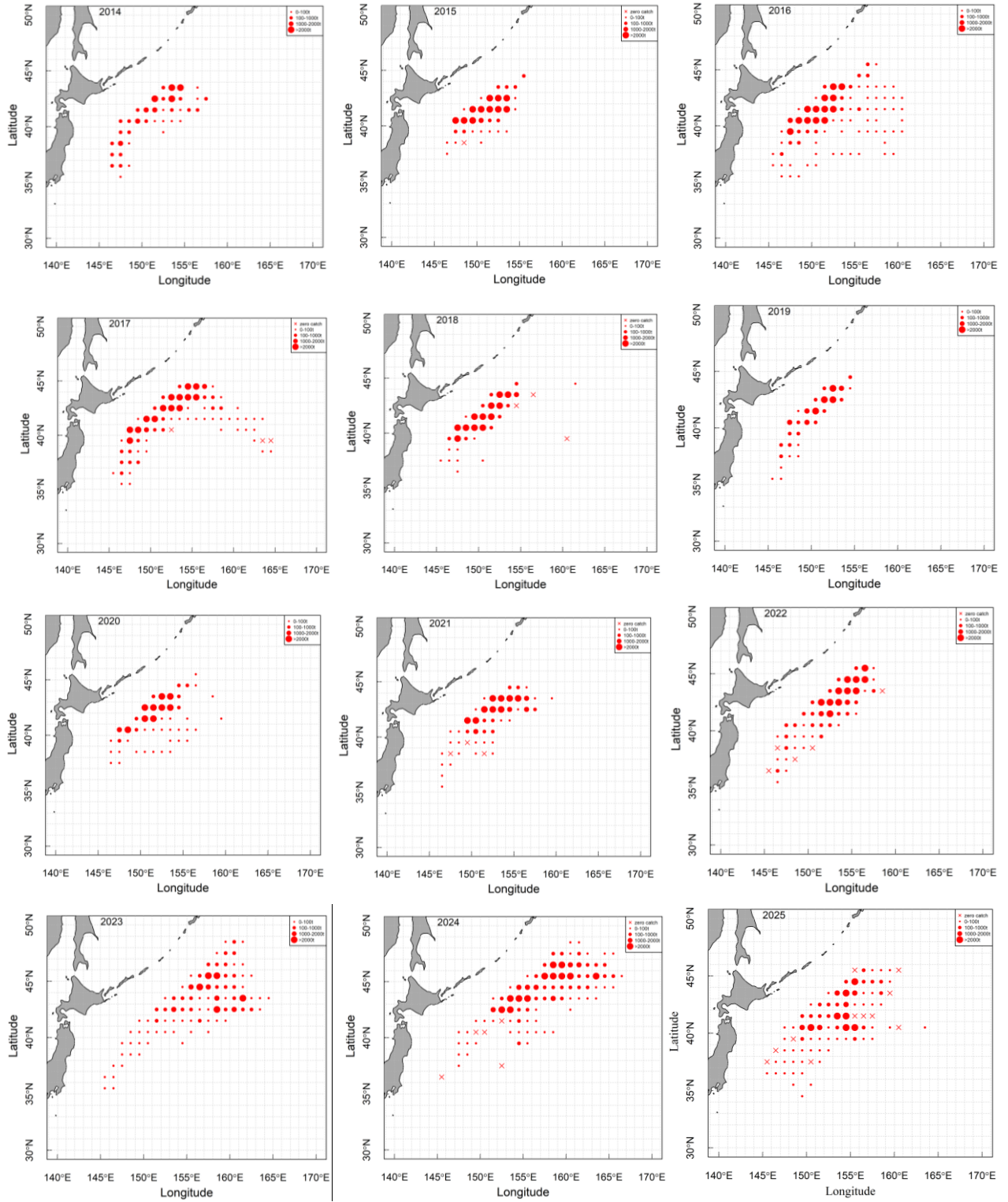


Fig. 1a. Spatio-temporal distribution of the total catch of CPUE fleet (metric tons).

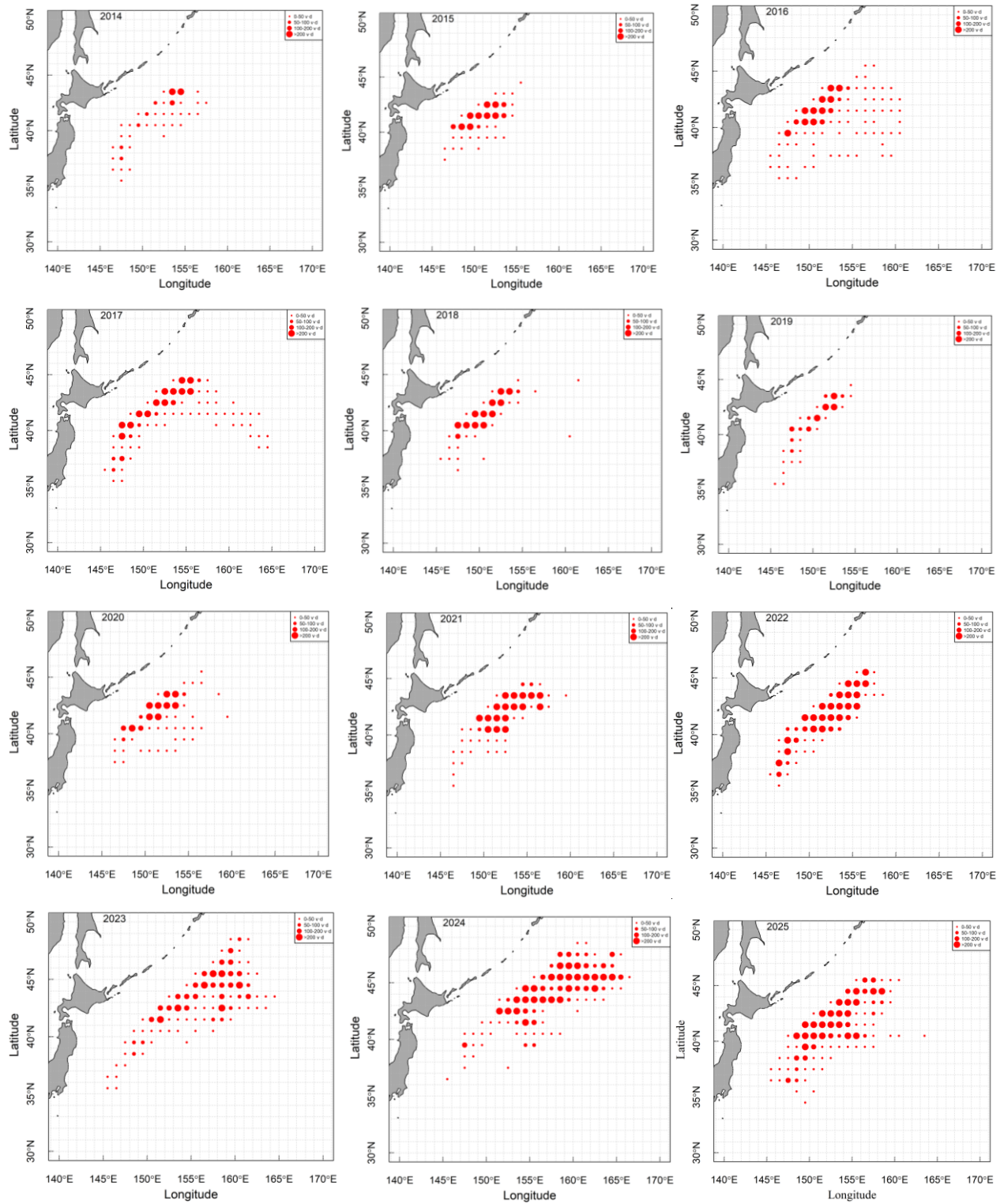


Fig. 1b. Spatio-temporal distribution of efforts by CPUE FLEET (vessel·day).

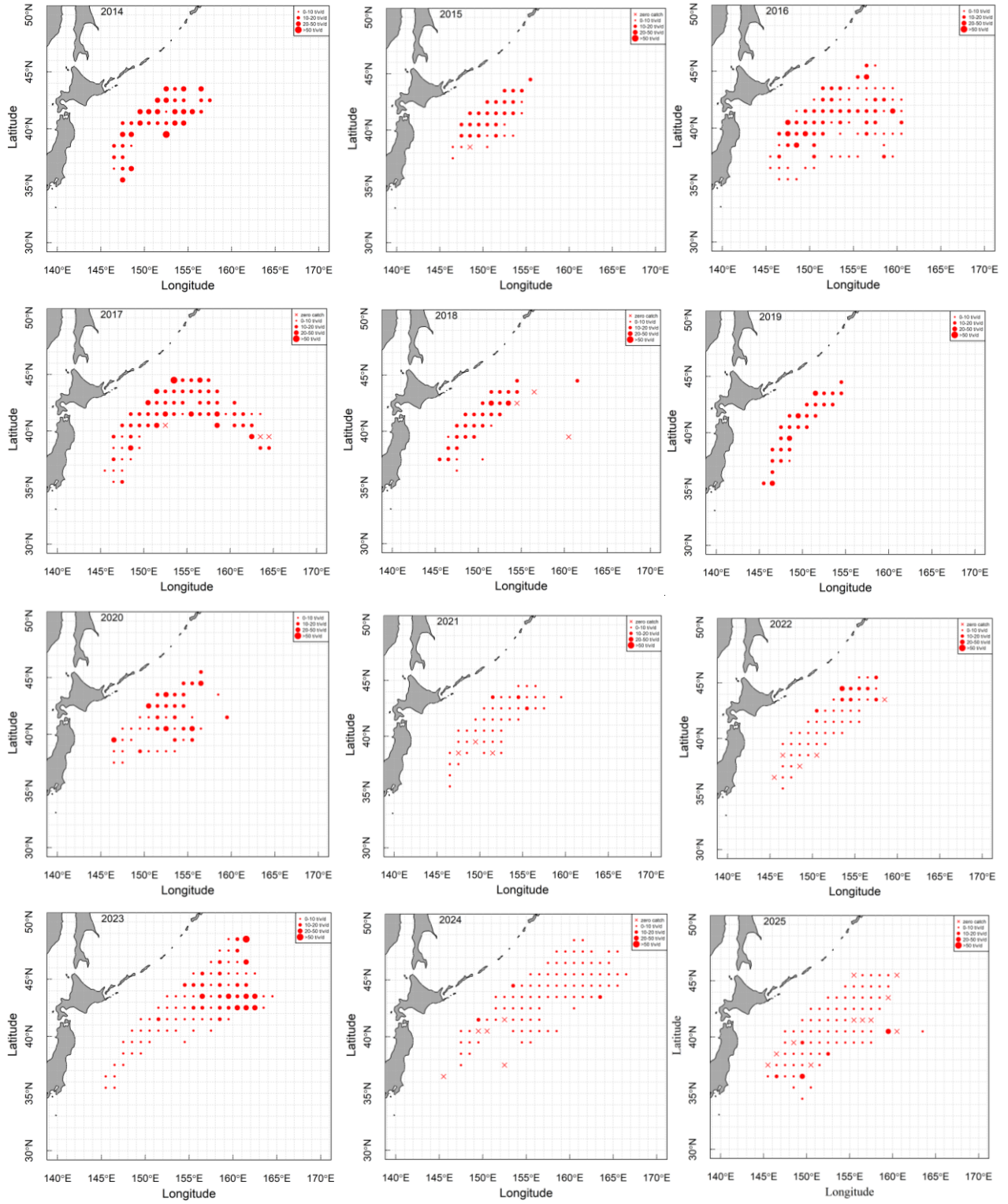


Fig. 1c. Spatio-temporal distribution of nominal CPUE of CPUE Fleet (t/v/d).

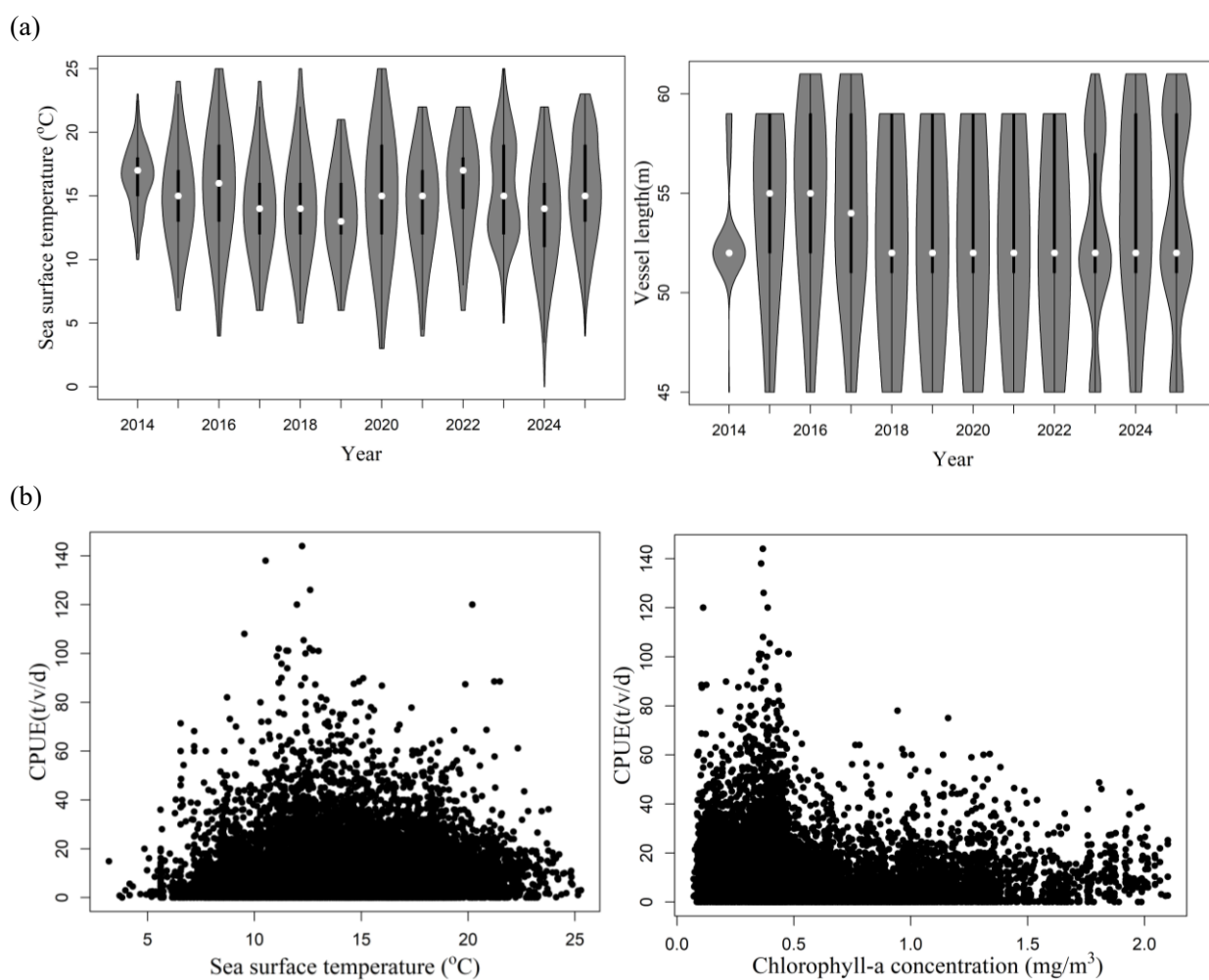


Fig. 2. Plots of explanatory variables of sea surface temperature (SST) and Vessel length by year (a) and scatter plots between CPUE and SST, Chla (b).

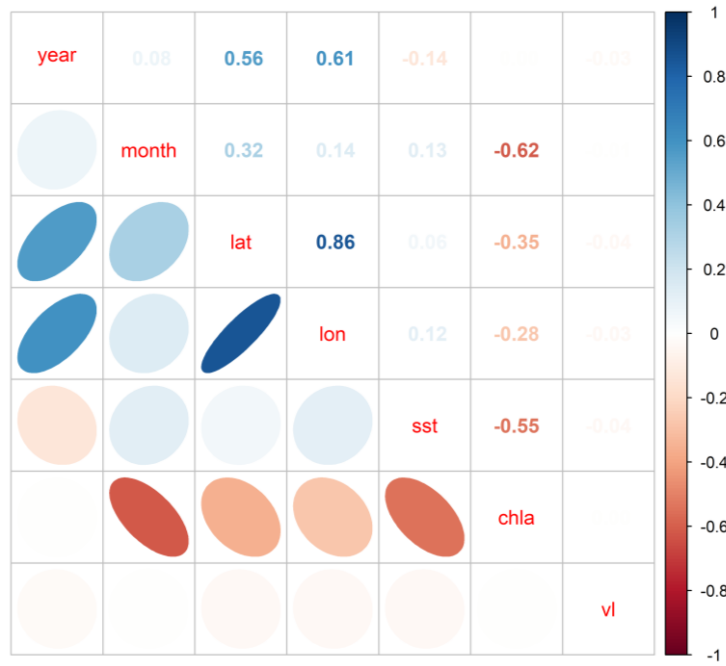


Fig. 3. Correlation matrix of explanatory variables used in the analysis

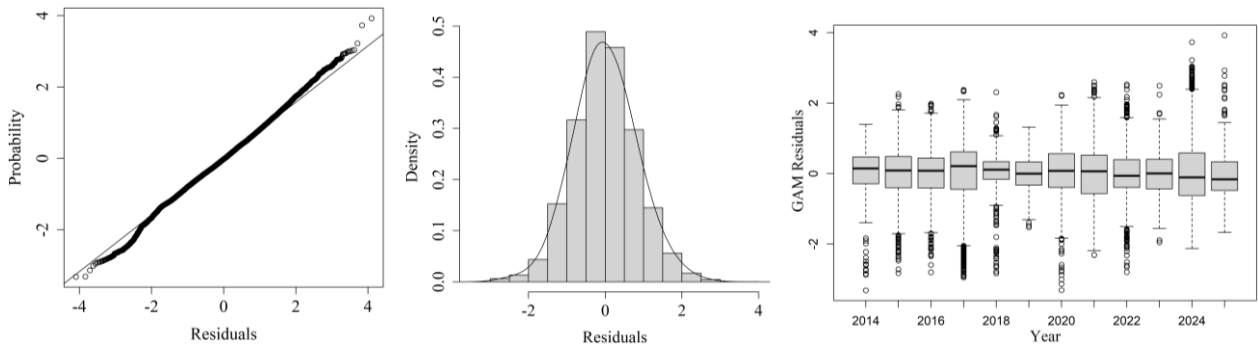
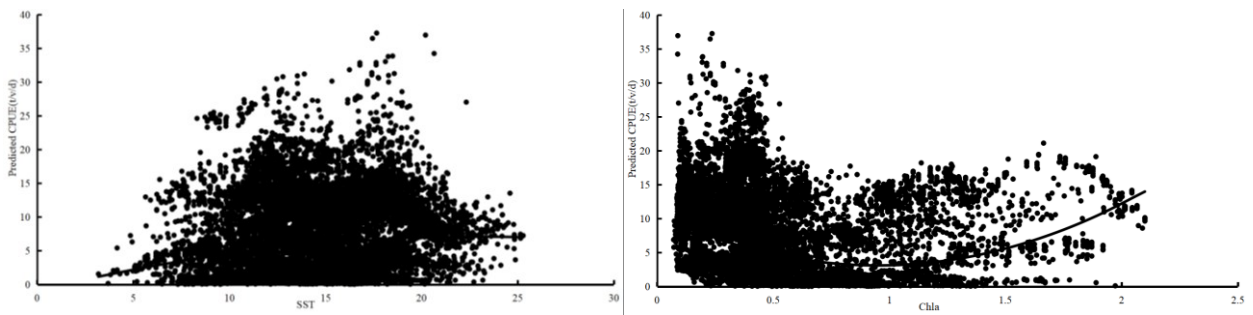


Fig. 4. Q-Q plot, histogram of residuals and residual plots across years for the best GAM.



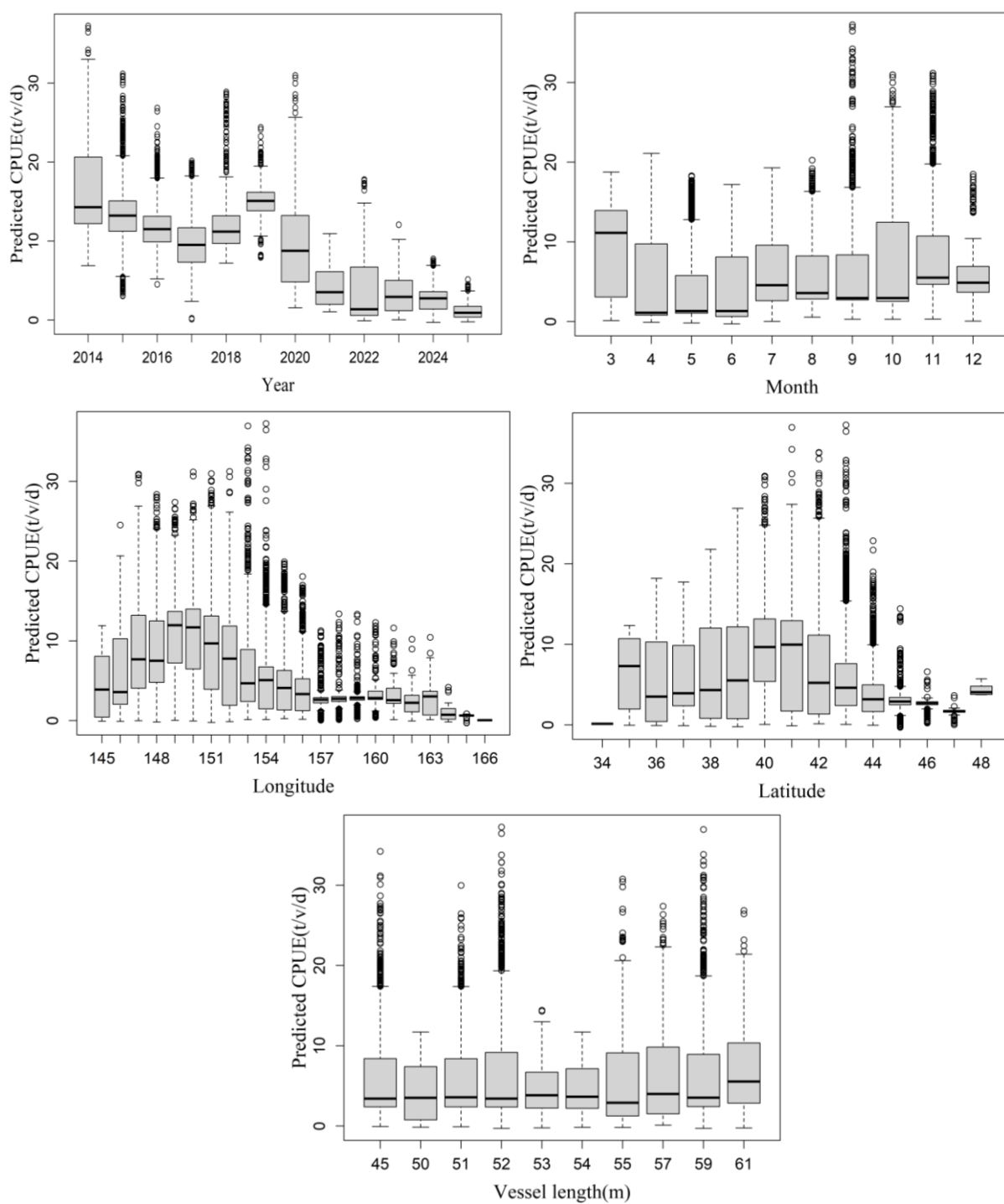


Fig. 5. Estimated relationships between response and explanatory variables.

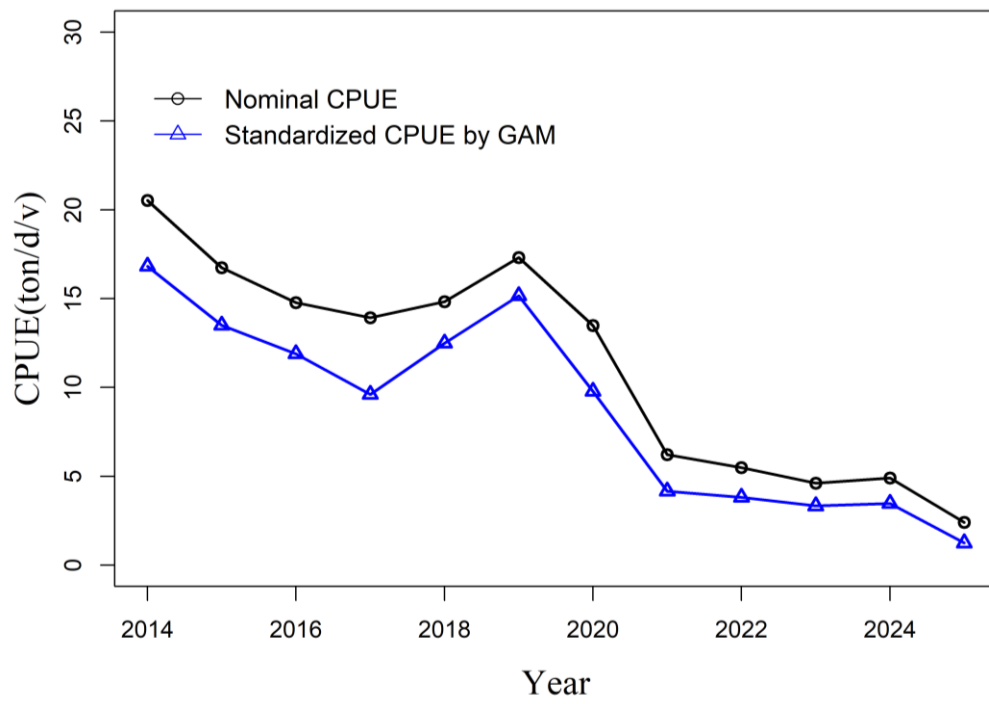


Fig.6. The nominal CPUE and standardized CPUE of Chub mackerel by best GAM up to 2024.

APPENDICES

Appendix 1. Checklist for the CPUE standardization protocol

No.	Step-by-step protocols	yes/no	Note
1	Provide a description of the type of data (logbook, observer, survey, etc.), and the "resolution" of the data (aggregated, set-by-set etc..). This description should also include the representativeness of the data in two tables: (1st table) Number of observations, % Coverage of CPUE fleet (catch), % Coverage of CPUE fleet (effort), Total Catch CPUE fleet (mt), Total Effort CPUE fleet, Percentage of overall catch by member (across all fleets/gears); and (2nd table) Number of records remaining, Number removed, Number of records with chub mackerel catch >0;	Yes	See section 2.1 ([page 2-3]) and Tables 1, [page 6] and 2, [page 6]
2	Conduct a thorough literature review to identify potential explanatory variables (i.e., spatial, temporal, environmental, and fisheries variables) that may influence CPUE values;	Yes	See sections 1 and 2.1 ([page 2-3])
3	Plot annual/monthly spatial catch, effort and nominal CPUE distributions and determine temporal and spatial resolution for CPUE standardization	Yes	See Fig. 1, [page 12-14]
4	Make scatter plots (for continuous variables) and/or box plots (for categorical variables) and present correlation matrix if possible to evaluate correlations between each pair of those variables;	Yes	See Figs 2, [page 15] and 3 [16]
5	Describe selected explanatory variables based on (2)-(4) to develop full model for the CPUE standardization;	Yes	See section 2.2. ([page 3]) and Table 3, [page 7]
6	Specify model type and software (packages) and fit the data to the assumed statistical models (i.e., GLM, GAM, Delta-lognormal GLM, Neural Networks, Regression Trees, Habitat based models, and Statistical habitat based models);	Yes	See section 2.2. ([page 3])
7	Evaluate and select the best model(s) using methods such as likelihood ratio test, information criterions, cross validation etc.;	Yes	See Table 4, [page 8] and Table 5, [page 8] and section 3
8	Provide diagnostic plots to support the chosen model is appropriate and assumption are met (QQ plot and residual plots along with predicted values and important explanatory variables, etc.);	Yes	See Table 7, [page 9] and Fig. 4, [page 16]
9	Present estimated values of parameters and	yes	See Table 8, [page 10-11]

	uncertainty in the parameters in table;		
10	Present the relationship between dependent variable and independent variables. Check whether it is interpretable.	Yes	See Fig. 5, [page 17-18]
11	Extract yearly standardized CPUE and standard error by a method that is able to account for spatial heterogeneity of effort, such as least squares mean or expanded grid. If the model includes area and the size of spatial strata differs or the model includes interactions between time and area, then standardized CPUE should be calculated with area weighting for each time step. Model with interactions between area and season or month requires careful consideration on a case by case basis. Provide details on how the CPUE index was extracted.	Yes	See section 2.3. ([page 3-4])
12	Calculate uncertainty (SD, CV, CI) for standardized CPUE for each year. Provide detailed explanation on how the uncertainty was calculated;	Yes	See section 2.3 (page 3-4), Table 9, [page 11] and Fig. 6, [page 18]
13	Provide a table and a plot of nominal and standardized CPUEs over time. When the trends between nominal and standardized CPUE are largely different, explain the reasons (e.g. spatial shift of fishing efforts), whenever possible.	Yes	