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Standardizing abundance index for recruitment of chub mackerel in the Northwest Pacific

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Summary

In this document, we provide the summary of the CPUE standardization for Pacific chub mackerel following the "CPUE Standardization Protocol for Chub Mackerel". The year trends of the recruitment indices were derived from standardized CPUE, by applying the delta-GLM-tree models to the data from surface trawl surveys in summer (June and July) and autumn (September and October). Since we found no significant problems during the standardization, we recommend these indices to be utilized in the Technical Working Group for the Chub Mackerel Stock Assessment.

This document describes following the order of the bullets specified in the CPUE Standardization Protocol for Chub Mackerel.

(1) Literature review to identify the candidate explanatory variables

Based on the literature search and the documents in previous TWG, we identified two candidate variables that can affect the presence and abundance of chub mackerel recruitments. First, since the recruitment index of chub mackerel is known to be affected by water temperature (Nishijima et al. 2017, Hashimoto et al. 2019), we used available information about water temperature. For the summer recruitment CPUE standardization, we incorporated the temperature at sea surface (SST) and at the 50m depth (T50) into the explanatory variables, and, for the autumn recruitment CPUE standardization, we used the SST and the temperature at 30m depth (T30) as explanatory variables. The temperatures were measured at the same time as the surveys. Second, to account for the spatial autocorrelation of the recruitment distribution, we incorporated the area identity as a fixed effect in the model. Please refer to "(5) Model details" for the details in determining the area identity.

(2) The spatio-temporal distributions of catch, effort, and CPUE.

The surface trawl surveys have been conducted by FRA in summer (June and July) and autumn (September and October) in a broad range of the Northwestern Pacific (Figs. 1-4). The standardizations of these survey data are necessary because survey areas slightly changed due to varying climatic and environmental conditions during the surveys while there were no systematic temporal shifts in the survey effort (Figs. 1 and 2). The summer surveys were conducted yearly-basis from 2002 to 2020, and autumn surveys were from 2005 to 2020 in the area approximately from 141.5º–175º E and 37º–50º N (Figs. 1 and 2). The CPUE (Figs. 3 and 4) were calculated as the number of fish per hour of trawl survey.

Table 1. The summary of the survey (number of surveys, number of surveys with positive catches of chub mackerel, and the mean nominal CPUE) and the result of standardization (standardized CPUE and confidence interval) for the summer recruitment survey.

Year	Number of surveys (Number of stations * months)	Number of positive catches	Mean nominal CPUE (Catch/hour)	Standardized CPUE	Lower 95% CI	Upper 95% CI
2002	86	16	3.01	1.96	0.35	5.88
2003	128	15	31.75	5.71	0.87	19.17
2004	123	24	172.87	5.20	1.37	13.77
2005	115	16	20.77	2.76	0.52	8.20
2006	126	3	0.31	0.35	0.00	2.51
2007	123	24	296.27	13.78	3.54	37.78
2008	113	16	53.31	2.22	0.43	6.85
2009	128	25	43.49	2.58	0.70	7.22
2010	95	18	26.28	3.66	0.80	11.08
2011	67	12	5.43	0.90	0.13	2.98
2012	81	20	58.59	5.55	1.26	16.29
2013	87	17	2073.92	61.57	12.85	188.78
2014	85	5	20.13	4.16	0.12	20.37
2015	89	19	48.97	9.04	1.99	28.51
2016	91	32	889.41	13.05	4.57	30.82
2017	93	18	736.59	66.94	14.87	204.65
2018	76	23	3259.93	353.56	100.97	878.34
2019	108	26	92.58	7.94	2.37	19.60
2020	61	28	562.48	43.13	11.96	108.11

Table 2. The summary of the survey (number of surveys, number of positive catches, and the mean nominal CPUE) and the result of standardization (estimated density and confidence interval) for the autumn recruitment survey.

Year	**Number of surveys (Number of stations * months)**	**Number of positive catches**	**Mean nominal CPUE (Catch/hour)**	**Standardized CPUE**	**Lower 95% CI**	**Upper 95% CI**
2005	53	14	23.6	43.3	3.7	232.8
2006	56	5	0.8	6.0	0.2	34.8
2007	46	13	10.0	17.4	1.3	90.7
2008	40	9	9.7	22.2	1.4	103.4
2009	49	22	60.7	95.3	10.8	539.1
2010	49	19	16.9	49.1	3.9	273.5
2011	42	12	4.5	16.1	1.2	91.4
2012	37	16	18.2	121.0	7.3	806.5
2013	37	26	1419.4	5060.5	283.5	27975.6
2014	32	21	95.1	256.2	17.3	1468.1
2015	34	18	169.0	687.8	49.7	3701.4
2016	29	15	1339.5	6261.0	408.8	37347.1
2017	28	14	645.0	1096.3	83.6	5899.7
2018	28	26	6237.1	33579.4	1589.3	189218.7
2019	26	20	261.0	872.7	44.7	5340.0
2020	35	26	660.6	4775.6	286.5	28113.0

Figure 1. Spatio-temporal distribution of the summer survey efforts (hours of trawl surveys). Rectangles with bold black lines are the area stratification determined by the GLM-tree.

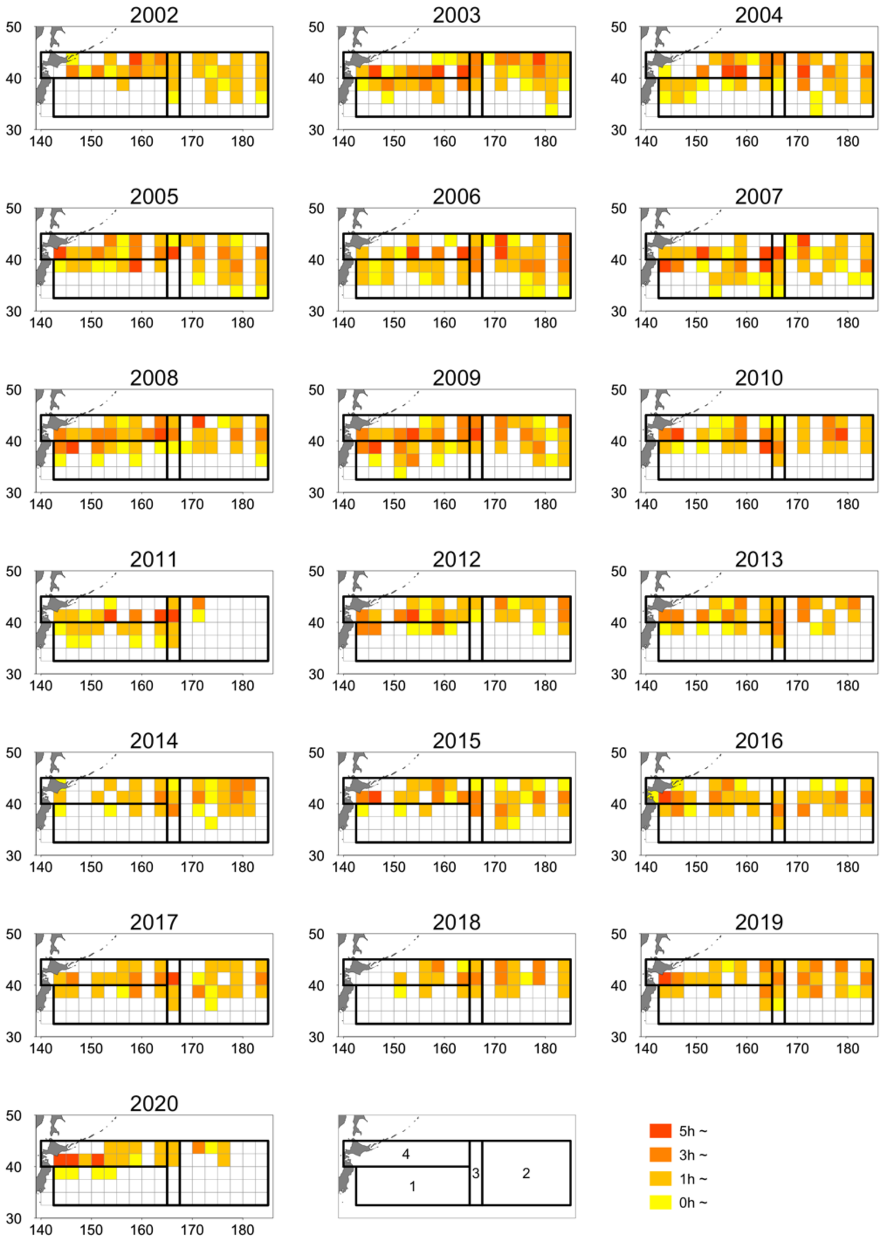


Figure 2. Spatio-temporal distribution of the autumn survey efforts (hours of trawl surveys). Rectangles with bold black lines are the area stratification determined by the GLM-tree.

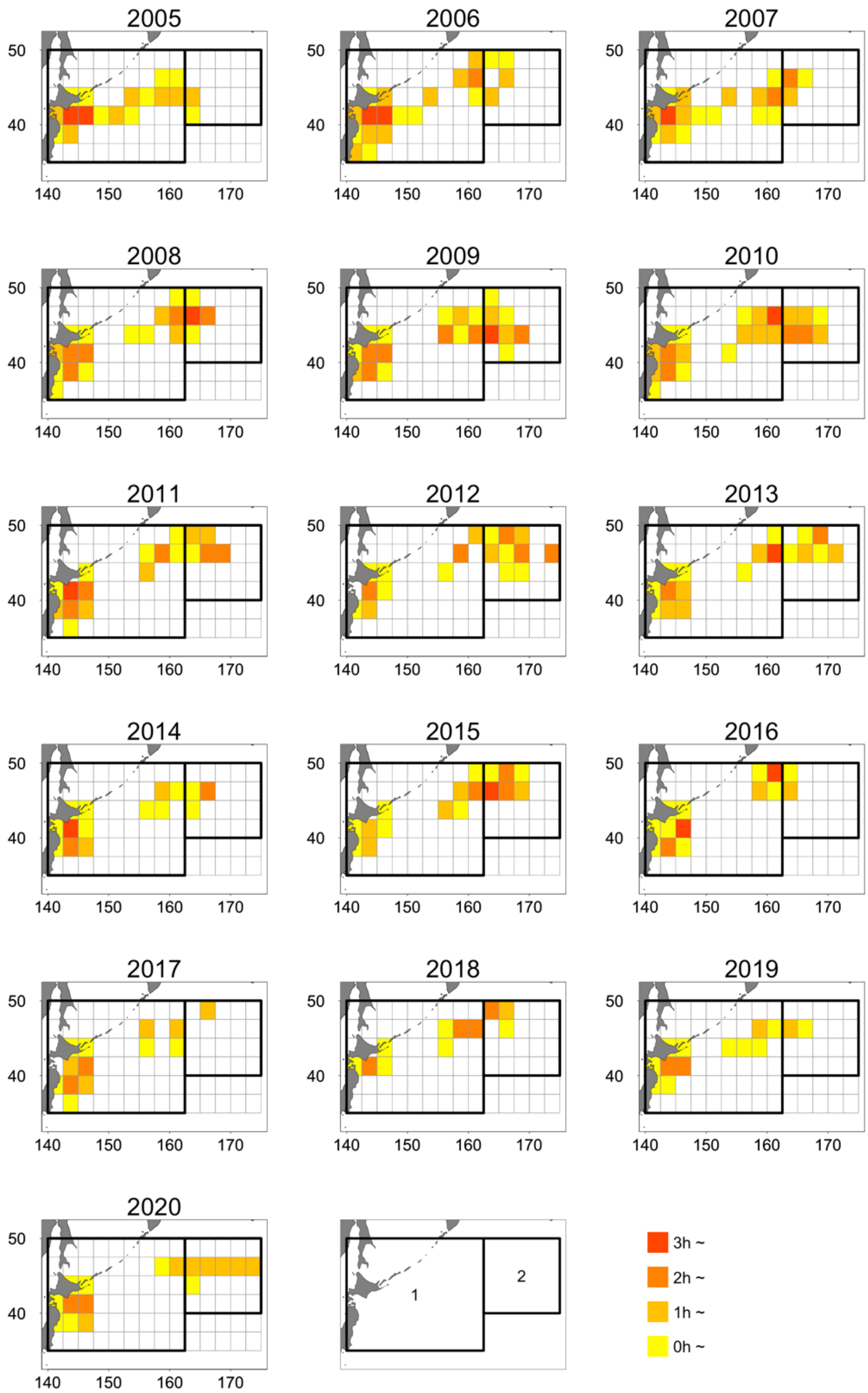


Figure 3. Spatio-temporal distribution of the summer survey CPUEs (number per hour). Rectangles with bold black lines are the area stratification determined by the GLM-tree.

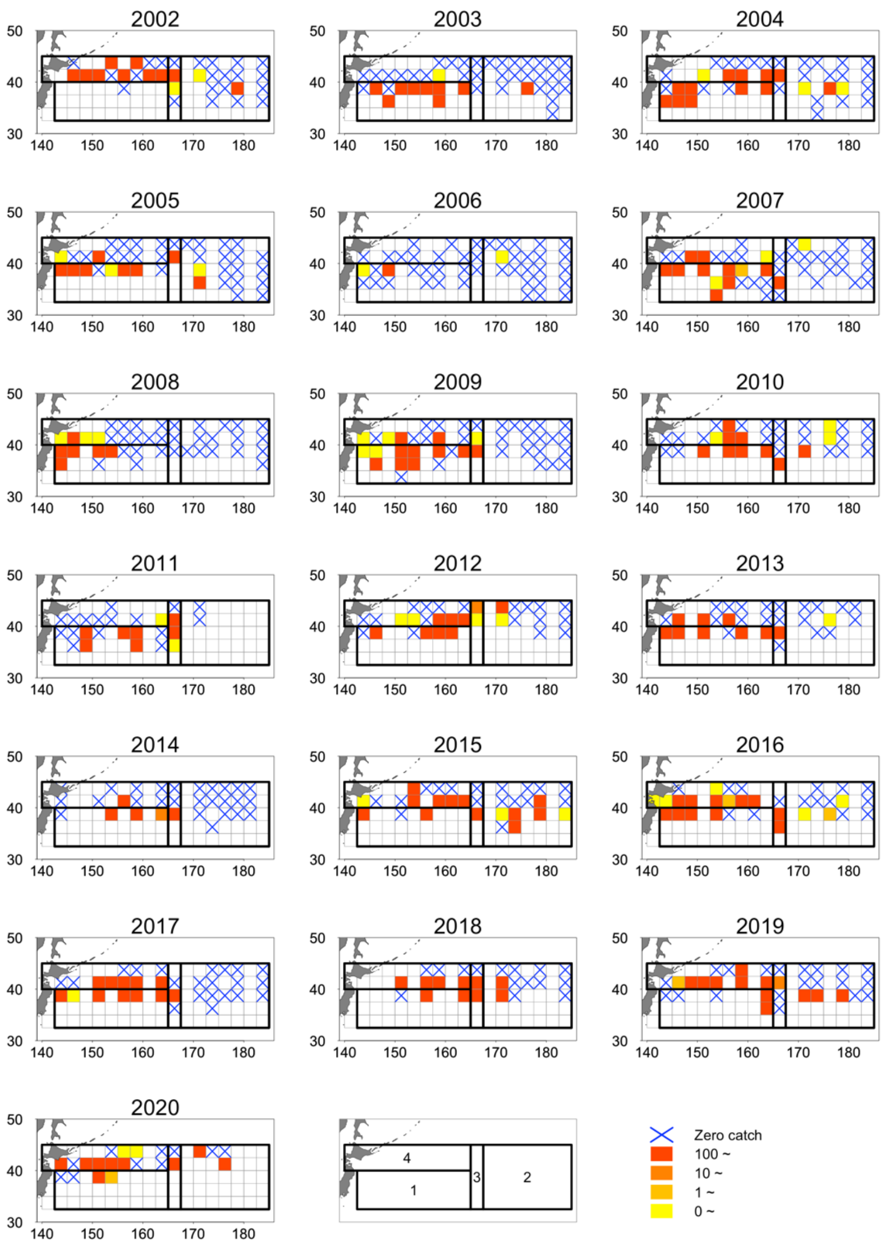
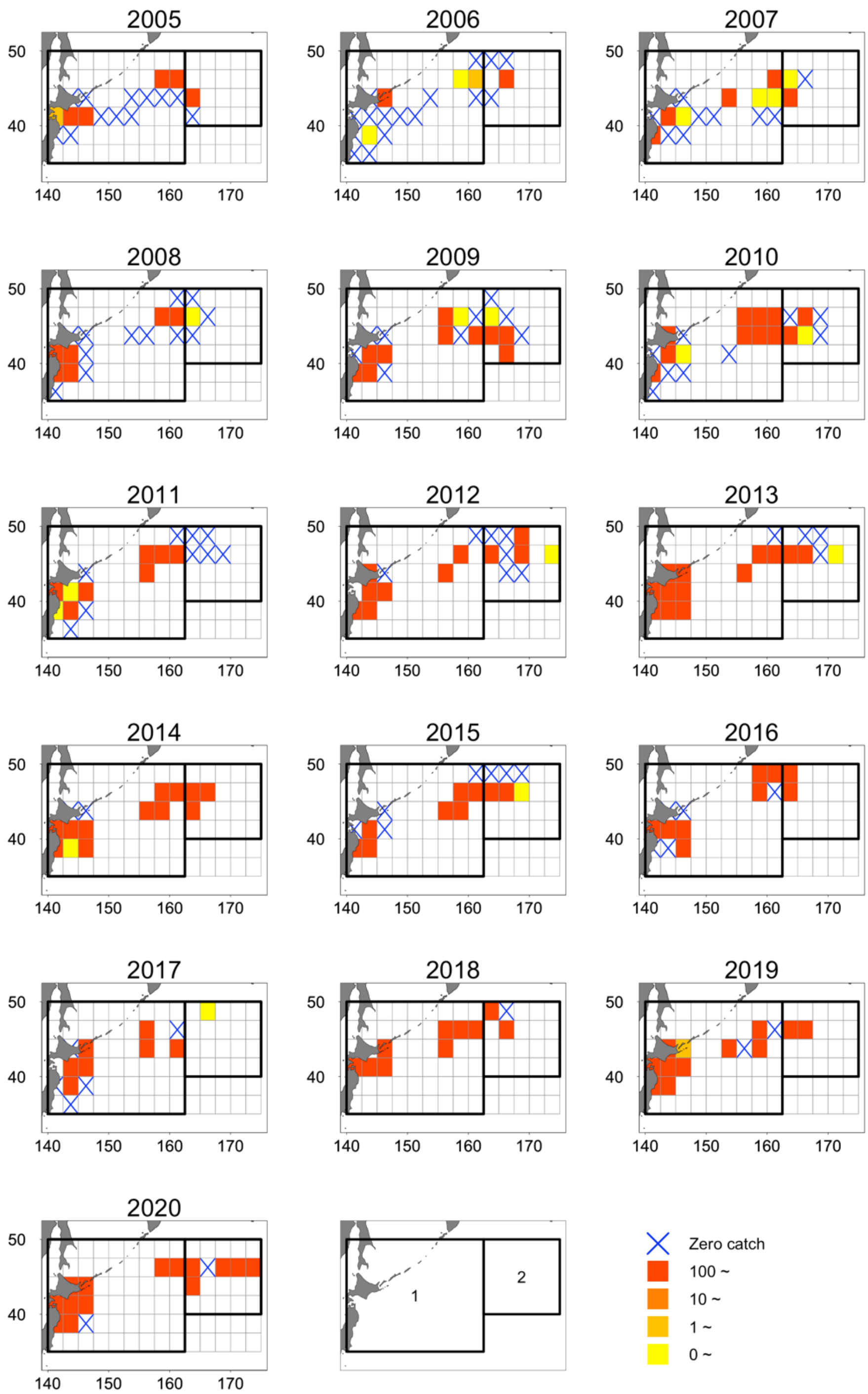


Figure 4. Spatio-temporal distribution of the autumn survey CPUEs (number per hour). Rectangles with bold black lines are the area stratification determined by the GLM-tree.



(3) Plots representing the correlation between the variables

In the following, we present (i) the yearly trends of scaled temperature (Fig. 5, Fig. 6), (ii) the yearly trends of the CPUE (Fig. 7, Fig. 8), and (iii) the relationship between temperature and CPUE (Fig. 9, Fig. 10), separately for the summer and autumn surveys. In addition, we present the correlation between SST and T50 of summer survey data (Fig. 11), and between SST and T30 of autumn survey data (Fig. 12).

Figure 5. Yearly trends of SST and T50 used in the summer CPUE standardization.

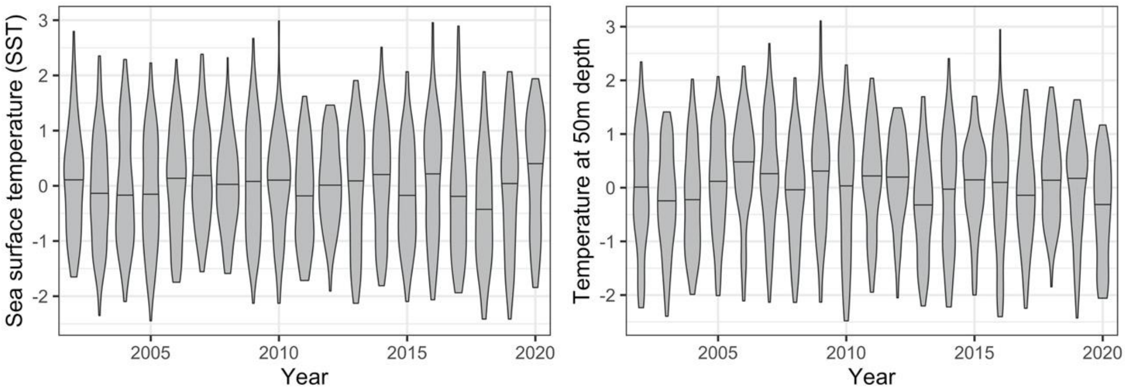


Figure 6. Yearly trends of SST and T30 used in the autumn CPUE standardization.

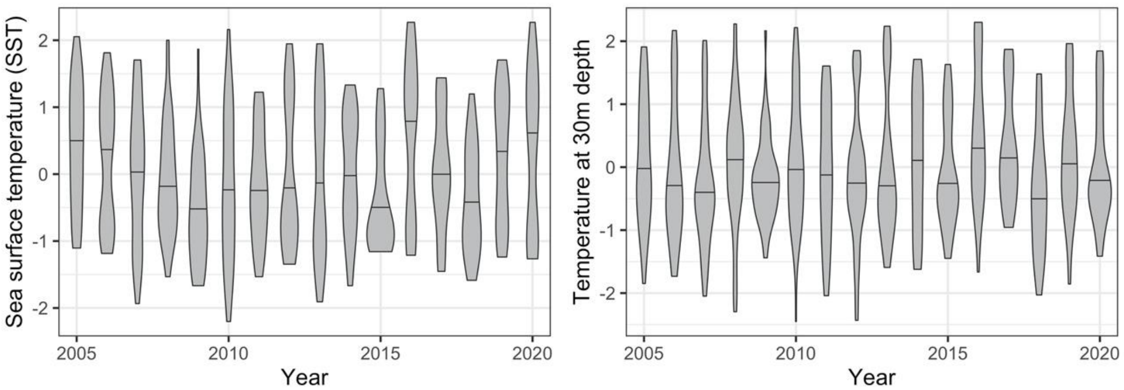


Figure 7. The yearly trend of the number of positive CPUE (left panel) and the average positive CPUE (right panel) of the summer recruitment survey. The y-axis of the right panel is log-scaled.

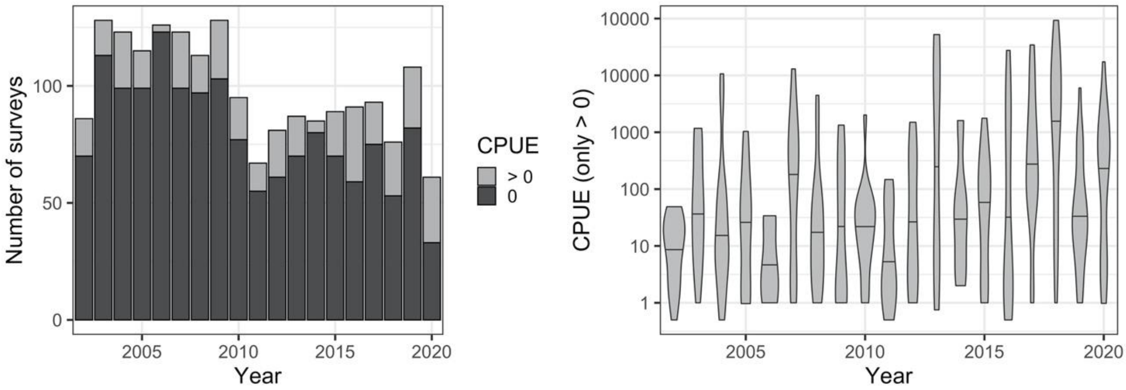


Figure 8. The yearly trend of the number of positive CPUE (left panel) and the average positive CPUE (right panel) of the autumn recruitment survey. The y-axis of the right panel is log-scaled.

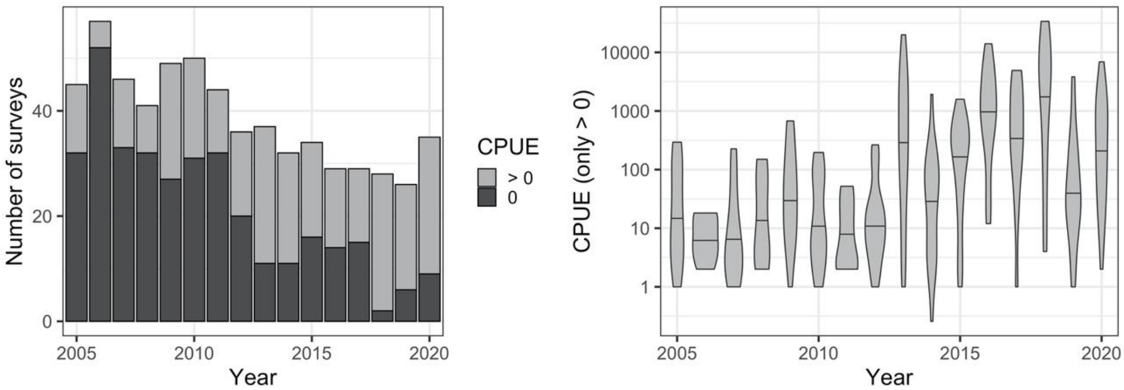


Figure 9. The relationships between CPUE and sea surface temperature (SST) (a: all CPUEs, b: only positive CPUEs in log scale), or temperature at 50m depth (c: all CPUEs, d: only positive CPUEs in log scale) of the summer recruitment data.

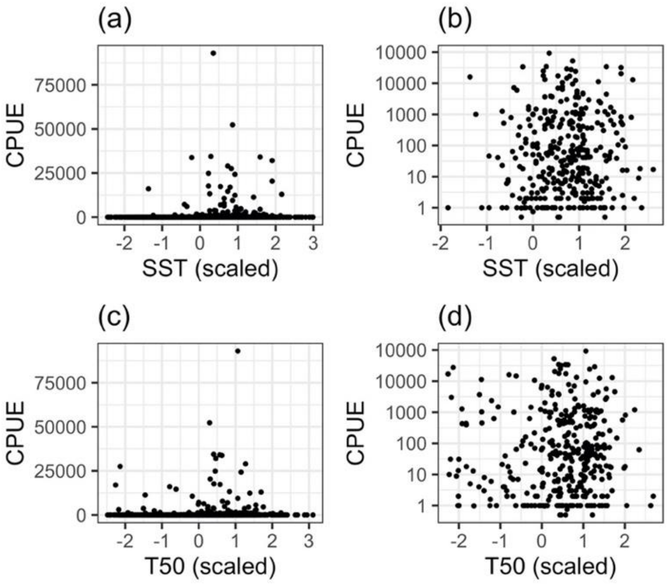


Figure 10. The relationships between CPUE and sea surface temperature (SST) (a: all CPUEs, b: only positive CPUEs in log scale), or temperature at 30m depth (T30) (c: all CPUEs, d: only positive CPUEs in log scale) of the autumn recruitment data.

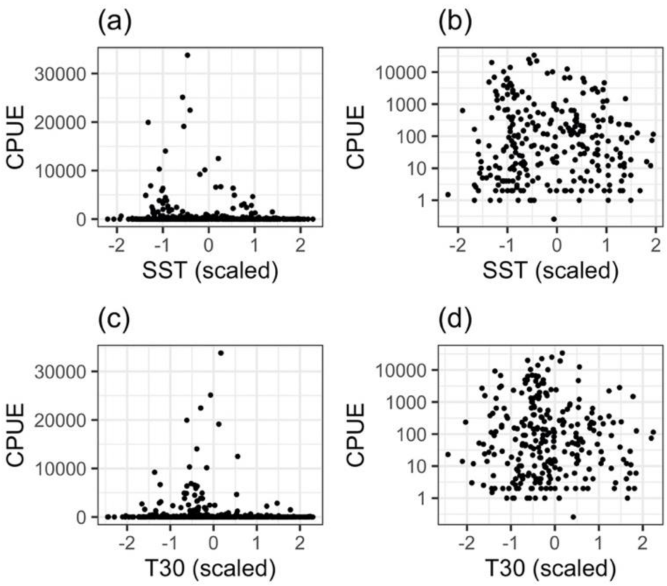


Figure 11. The correlation between SST and T50 of summer survey data. Pearson's correlation coefficient was 0.656.

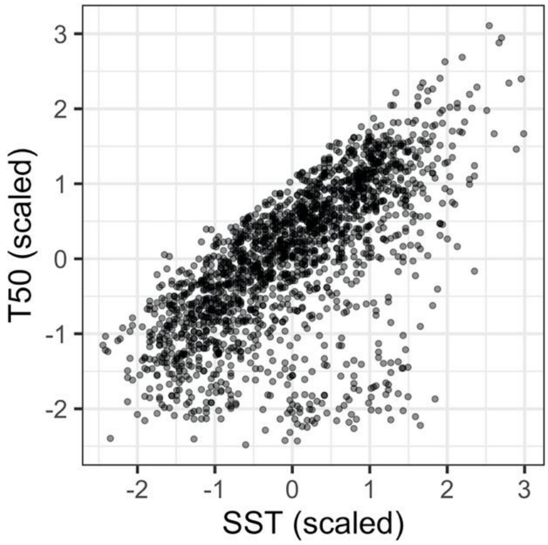
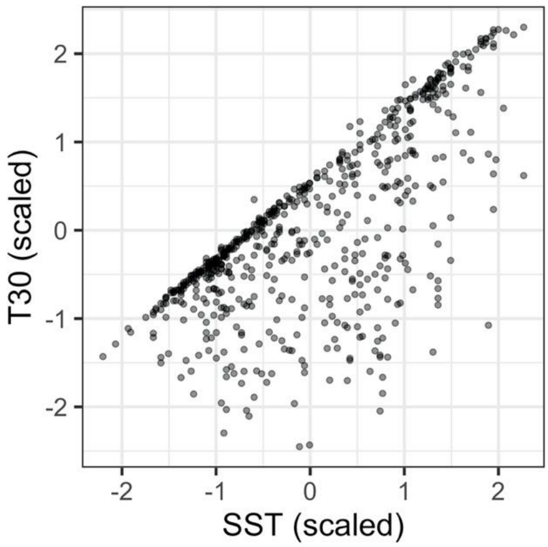


Figure 12. The correlation between SST and T30 of autumn survey data. Pearson's correlation coefficient was 0.691.



(4) Explanatory variables in the full model

For summer survey standardization, we incorporated (i) year (categorical), (ii) area (categorical, determined by delta-GLM-tree), (iii) year:area (interaction), (iv) sea surface temperature, or SST (continuous), (v) SST^2, (vi) water temperature at 50m depth, or T50 (continuous), (vii) $T50^2$, and (viii) SST:T50 (interaction) as fixed effects.

For autumn survey standardization, we incorporated (i) year (categorical), (ii) area (categorical, determined by delta-GLM-tree), (iii) year:area (interaction), (iv) sea surface temperature, or SST (continuous), (v) SST^2, (vi) water temperature at 30m depth, or T30 (continuous), (vii) $T30^2$, and (viii) SST:T30 (interaction) as fixed effects.

(5) Model details

We used delta-GLM-tree, a newly proposed derivative of delta GLM for the standardization of both summer and autumn data. Delta GLM is the two-step generalized linear model where the probability of occurrence and the density or CPUE when occurred were modelled separately. The delta-GLM-tree (Hashimoto et al. 2019) analysis allows one to perform the delta GLM with simultaneously conducting area (post-)stratification based on "GLM-tree" (Ichinokawa and Brodziak 2010), where areas were sequentially separated so that predictive error (BIC in this case) be the smallest.

We constructed the delta-GLM-tree models. While the probability of occurrence was modelled with binomial distribution (logit link), the CPUE when occurred was modelled with gamma distribution (log link) or lognormal distribution (identity). The distribution of the CPUE modelling was selected based on BIC. The results of the stratification are shown in Figs. 1 and 3 for the summer data, and Figs 2 and 4 for the autumn data.

(6) Best model

We performed the brute-force model selection approach and determined the best models based on BIC. The models where delta-BIC (difference of BIC with the best model) is less than two (Table 3, 5), and the estimated coefficients in the best models (Table 4, 6) are shown.

While the difference in AIC (ΔAIC) between the best and the second models was large (4.34) for summer recruitment CPUE standardization, it was small for autumn standardization (0.44, Table 5), suggesting that uncertainty exists in the variable selection. Therefore, we conducted a sensitivity analysis by investigating the second-best model for the autumn recruitment CPUE and comparing its standardized values with that of the best model. The standardized values slightly differed between the two models such that among-year variation in the positive CPUE values were small in the second model. The result of the comparison is shown in Figure. 20.

Table 3. Result of the model selection for the standardization of summer recruitment CPUE.

Occurrence model (binomial)			Positive CPUE model (gamma or lognormal)						
Explanatory variables	df	logLik	Explanatory variables	df	logLik	Distribution	Number of areas	BIC	Δ BIC
SST + SST^2 + T50 + Area + Year	25	-629.39	Year	20	-2237.12	lognormal	4	6072.17	0
SST + SST^2 + T50 + Area + Year	23	-643.93	Area + Year	21	-2228.53	lognormal	2	6076.51	4.34
SST + SST^2 + T50 + Area + Year	25	-629.39	SST + Year	21	-2235.66	lognormal	4	6076.78	4.61
SST + SST^2 + T50 + Area + Year	25	-629.39	T50 + Year	21	-2236.2	lognormal	4	6077.86	5.69
SST + SST^2 + T50 + SST:T50 + Area + Year	26	-629.13	Year	20	-2237.12	lognormal	4	6079.17	7
SST + SST^2 + Area + Year	23	-643.92	Area + Year	22	-2226.1	lognormal	3	6079.18	7.01
SST + SST^2 + T50 + $T50^2$ + Area + Year	26	-629.25	Year	20	-2237.12	lognormal	4	6079.42	7.25
SST + SST^2 + T50 + Area + Year	25	-629.39	SST + SST^2 + Year	22	-2233.77	lognormal	4	6080.54	8.37
SST + SST^2 + T50 + Area + Year	23	-643.93	Area + T50 + Year	22	-2226.95	lognormal	2	6080.89	8.72
SST + SST^2 + T50 + Area + Year	23	-643.93	Area + SST + Year	22	-2227.81	lognormal	2	6082.61	10.44

Table 4. The estimated coefficients in the best models for the standardization of summer recruitment CPUE.

Occurrence model (binomial)				Positive CPUE model (lognormal)	
Explanatory variable	Coefficient	Explanatory variable	Coefficient	Explanatory variable	Coefficient
SST	1.277	Year2002	0	Year2002	2.104
SST^2	-0.727	Year2003	-1.026	Year2003	3.857
T50	0.326	Year2004	0.117	Year2004	3.129
Area1	0.043	Year2005	-0.782	Year2005	2.935
Area2	-2.540	Year2006	-3.072	Year2006	1.638
Area3	-1.216	Year2007	-0.710	Year2007	4.632
Area4	-0.806	Year2008	-0.977	Year2008	2.928
		Year2009	-0.531	Year2009	2.839
		Year2010	-0.245	Year2010	2.932
		Year2011	-0.959	Year2011	1.916
		Year2012	-0.086	Year2012	3.258
		Year2013	-0.220	Year2013	5.69
		Year2014	-1.679	Year2014	3.527
		Year2015	0.227	Year2015	3.605
		Year2016	0.843	Year2016	3.731
		Year2017	0.118	Year2017	5.646
		Year2018	1.127	Year2018	6.862
		Year2019	0.069	Year2019	3.616
		Year2020	1.179	Year2020	4.761

Table 5. Model selection of the standardization of autumn recruitment CPUE.

Occurrence model (binomial)			Positive CPUE model (gamma or lognormal)						
Explanatory variables	df	logLik	Explanatory variables	df	logLik	Distribution	Number of areas	BIC	Δ BIC
T30 + T30^2 + Area + Year	19	-332.57	Area + SST + T30 + SST:T30 + Year	21	-1733.87	lognormal	2	4390.13	0
T30 + T30^2 + Area + Year	19	-332.57	Area + SST + SST^2 + Year	20	-1737.3	lognormal	2	4390.57	0.44
T30 + T30^2 + Area + Year	20	-327.57	SST + SST^2 + Year	19	-1743.22	lognormal	3	4392.41	2.28
T30 + T30^2 + Area + Year	20	-327.57	SST + T30 + SST:T30 + Year	20	-1740.94	lognormal	3	4394.27	4.14
T30 + T30^2 + Area + Year	19	-332.57	Area + SST + T30 + T30^2 + SST:T30 + Year	22	-1732.92	lognormal	2	4394.67	4.54
T30 + T30^2 + Area + Year	19	-332.57	Area + SST + SST^2 + + T30 + SST:T30 + Year	22	-1733.24	lognormal	2	4395.31	5.18
SST + SST^2 + Area + Year	19	-335.31	Area + SST + T30 + SST:T30 + Year	21	-1733.87	lognormal	2	4395.6	5.47
SST + T30 + T30^2 + Area + Year	20	-332.18	Area + SST + T30 + SST:T30 + Year	21	-1733.87	lognormal	2	4395.78	5.65
SST + SST^2 + Area + Year	19	-335.31	Area + SST + SST^2 + Year	20	-1737.3	lognormal	2	4396.04	5.91

Table 6. The estimated coefficients in the best models for the standardization of autumn recruitment CPUE.

Occurrence model (binomial)				Positive CPUE model (lognormal)			
Explanatory variable	Coefficient	Explanatory variable	Coefficient	Explanatory variable	Coefficient	Explanatory variable	Coefficient
T30	-0.486	Year2006	-1.458	Area1	3.512	Year2006	-0.945
$T30^2$	-0.354	Year2007	0.010	Area2	2.181	Year2007	-0.956
Area1	-0.615	Year2008	-0.103	SST	-0.757	Year2008	-0.613
Area2	-1.758	Year2009	0.792	T30	0.414	Year2009	0.214
		Year2010	0.774	SST:T30	-0.771	Year2010	-0.538
		Year2011	0.280			Year2011	-1.239
		Year2012	1.194			Year2012	-0.037
		Year2013	2.367			Year2013	2.908
		Year2014	1.956			Year2014	0.266
		Year2015	1.445			Year2015	1.628
		Year2016	1.581			Year2016	3.650
		Year2017	1.092			Year2017	2.323
		Year2018	3.755			Year2018	4.105
		Year2019	2.548			Year2019	1.015
		Year2020	2.470			Year2020	2.790

(7) Diagnostics of the model and the residuals

The best delta-GLM-tree model for summer recruitment CPUE standardization was diagnosed by evaluating the spatio-temporal distributions of deviance residuals of the binomial (Fig. 13) and lognormal models (Fig.14). It seems that there were no temporal trends in the residuals of the binomial (Fig. 13b) or lognormal (Fig. 14b) models, and no spatial biases for both model residuals (Fig. 13c, 14c). The binomial model was additionally diagnosed by the area under the ROC (receiver operating characteristic) curve (AUC), which quantifies the performance of the classification model and ranges from 0 to 1 where 0.5 suggests the random prediction and 1 suggests 100% correct prediction. Generally, 0.8 to 0.9 AUC value is considered as a good prediction ability. The AUC was 0.870 (Fig. 13d), suggesting its good prediction. The residuals of the lognormal distribution appear to follow normal distribution (Fig. 14a). Although the QQ-plot suggests some deviance from the expected distribution, one-sample Kolmogorov-Smirnov test indicates that the residual distribution did not deviate from the normal distribution ($p = 0.225$).

The best delta-GLM-tree model for autumn recruitment CPUE standardization was diagnosed in the same way (Fig. 15, 16). The residuals of the binomial and lognormal models did not show spatial biases (Fig. 15c, 16c). However, the residuals of the binomial model were larger in the later years (Fig. 15b), posing the possibility that the distribution of the stock have shifted toward Area 2 during the later years where the estimated probability of occurrence was lower (Table 6). The residuals of the lognormal model did not systematically change along with year, but it appears that the absolute values of the residuals were larger during the later years, suggesting the less reliability of the recent results. AUC suggests that the binomial model prediction was good (0.804, Fig. 15d). The residuals of the lognormal model did not deviate from the expected normal distribution (Fg. 16a, d, $p = 0.382$ in one-sample Kolmogorov-Smirnov test).

Figure 13. Diagnostics of the binomial (probability of occurrence) model in the delta-GLM-tree model for the standardization of summer CPUE. (a) Distribution of the deviance residuals, temporal (b) and spatial (c) trends of the deviance residuals, and (d) the receiver operating characteristic (ROC) curves and the area under the curve (AUC) value.

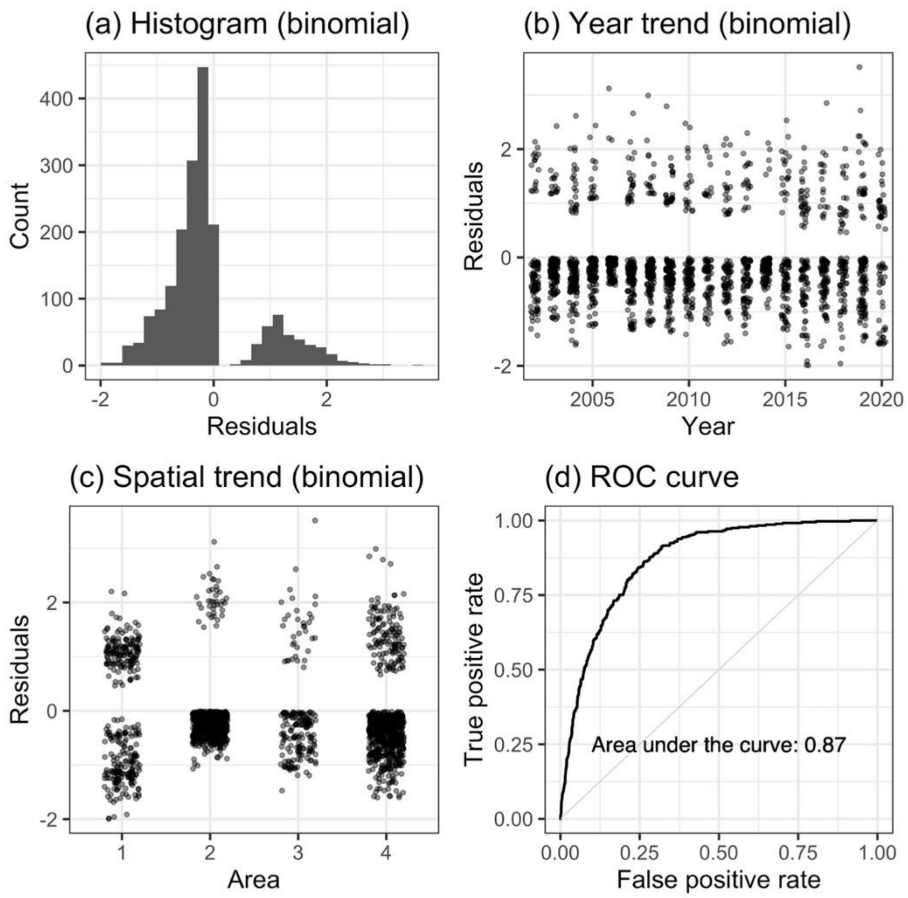


Figure 14. Diagnostics of the lognormal (positive CPUE) model in the delta-GLM-tree model for the standardization of summer CPUE. (a) Distribution of the deviance residuals, temporal (b) and spatial (c) trends of the deviance residuals, and (d) the QQ-plot.

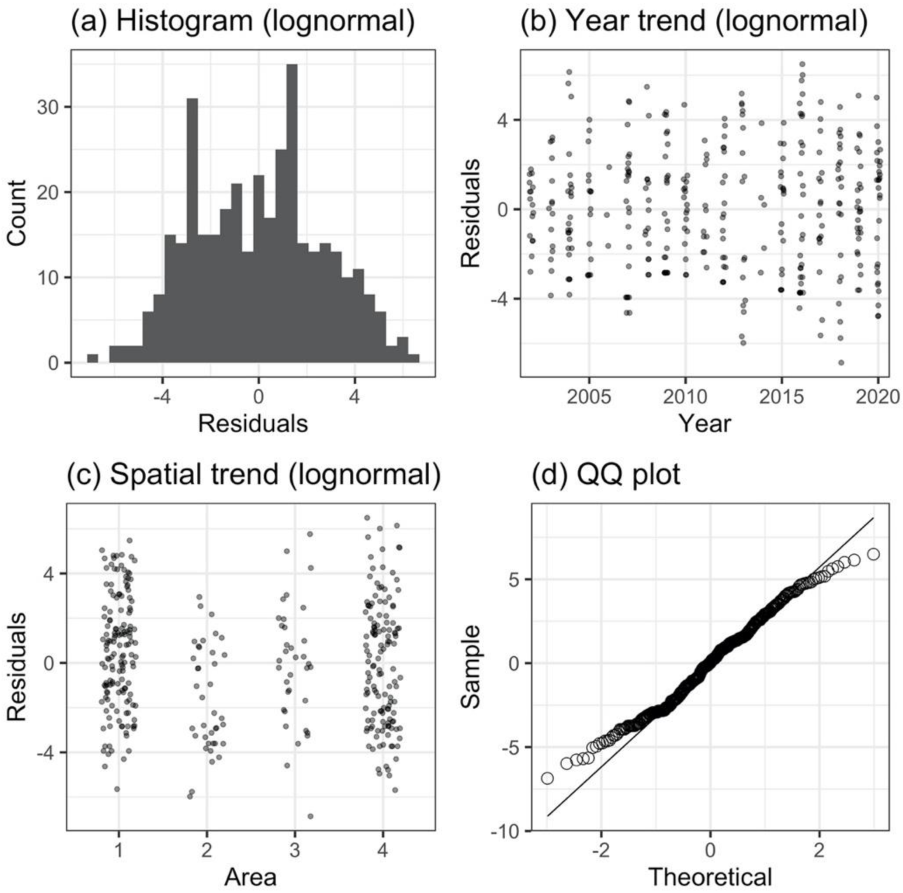


Figure 15. Diagnostics of the binomial (probability of occurrence) model in the delta-GLM-tree model for the standardization of autumn CPUE. (a) Distribution of the deviance residuals, temporal (b) and spatial (c) trends of the deviance residuals, and (d) the receiver operating characteristic (ROC) curves and the area under the curve (AUC) value.

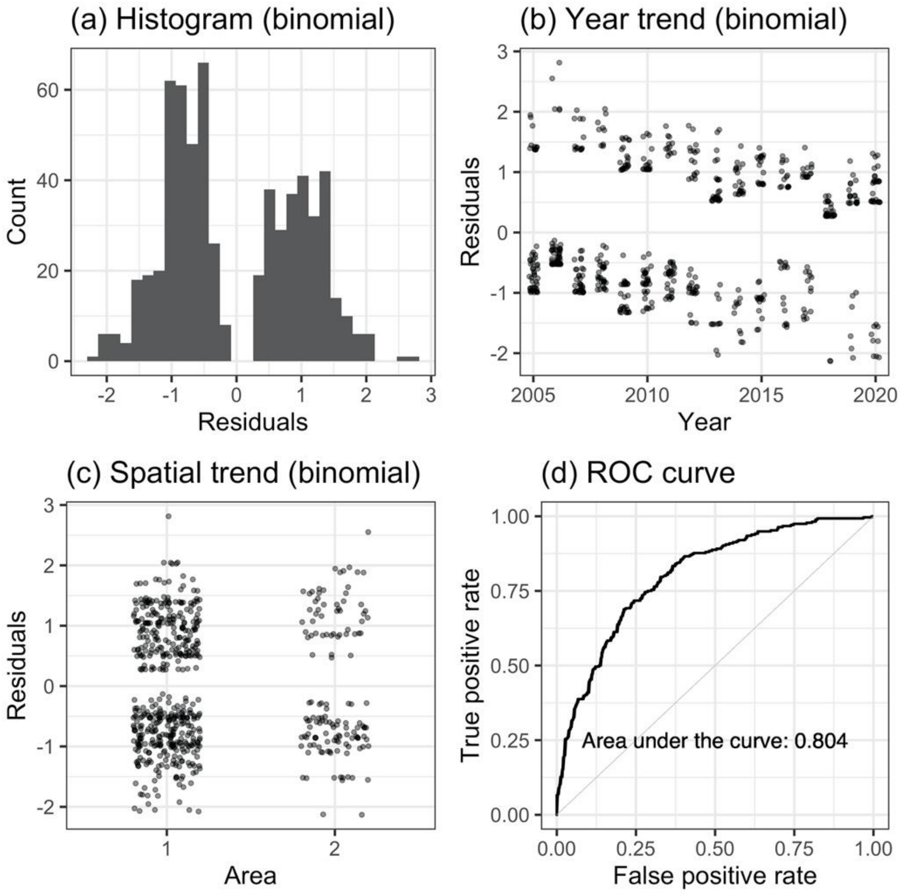
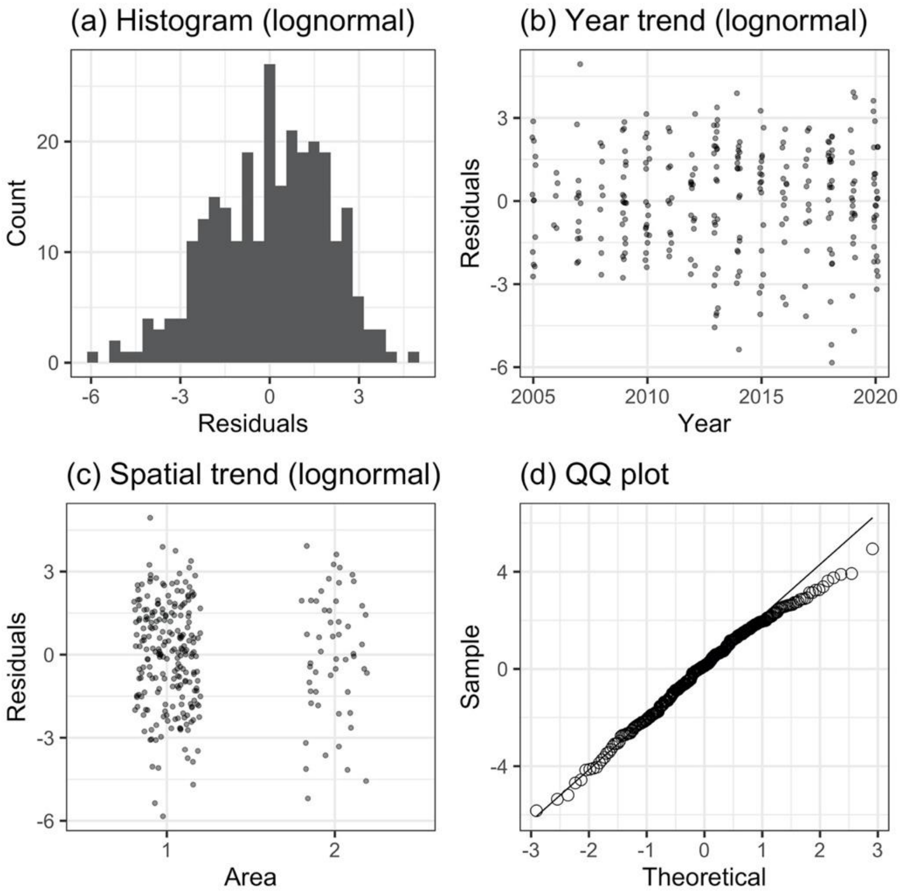


Figure 1**6**. Diagnostics of the lognormal (positive CPUE) model in the delta-GLM-tree model for the standardization of autumn CPUE. (a) Distribution of the deviance residuals, temporal (b) and spatial (c) trends of the deviance residuals, and (d) the QQ-plot.



(8) Estimated relationships between the explanatory variables and the response variable

In the best model for summer recruitment CPUE, SST, SST^2, and T50, as well as area and year were retained as the explanatory variables for the binomial model, and only year for the lognormal model (Tables 3, 4). Occurrence probability (binomial model) had a unimodal relationship with SST and a linear relationship with T50 (Fig. 17a, c).

The best model for autumn recruitment CPUE included T30, $T30^2$ in the binomial model, and SST, T30, SST:T30 (interaction term) in the gamma model (Table 5, 6). Occurrence probability (binomial model) showed a unimodal response against T30. SST and T30 interactively determined the positive CPUE values.

Figure 17. Relationship between catch probability and sea surface temperature (SST, a) or water temperature at 50m depth (T50, c), and relationship between positive CPUE and SST (b) or T50 (d) in the summer survey. The lines are predicted value with the other parameters fixed as their median values. The points are the observed values.

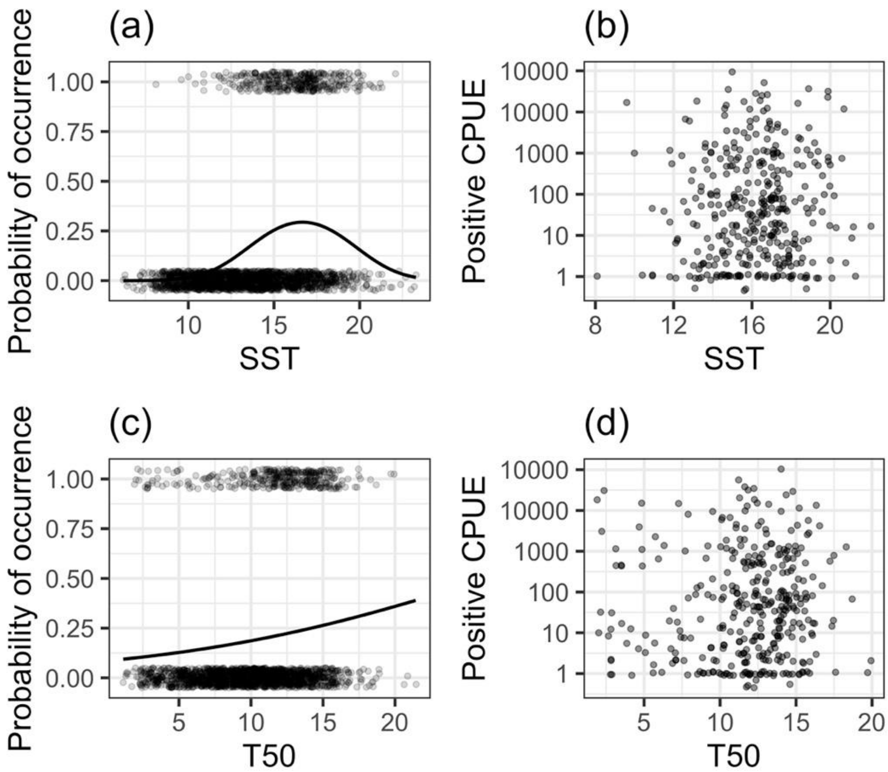
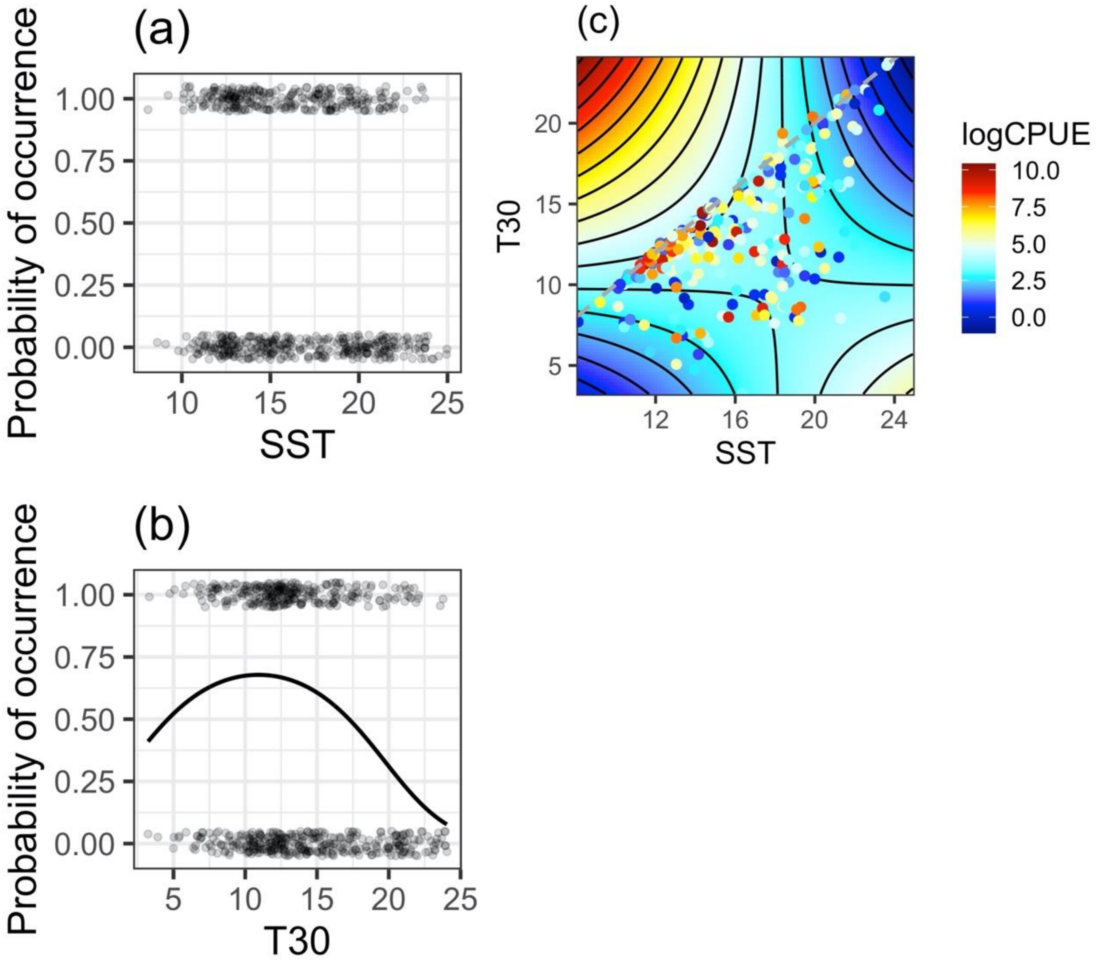


Figure 18. Relationship between the probability of occurrence and sea surface temperature (SST, a) or water temperature at 30m depth (T30, b), and (c) interactive effects of SST and T30 on the positive CPUE (log scale). The line in (b) is predicted value with the other parameters fixed as their median values, and the colors in (c) represents the predicted value where effects of other parameters were averaged. The points are the observed values.



(9) Yearly standardized CPUE and its uncertainty

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 = 1, 2, 3…, Year = 2002, 2003, 2004…, SST = 10.0, 11.0, 12.0…), and calculated the arithmetic mean (for variables except Area) and area-weighted mean of the yearly predicted values. Each area for the standardized recruitment CPUEs was assumed to be the rectangle surrounding the survey grids (Figs. 1-4). This averaging for extracting the year trend was necessary due to the nonlinearity of the logit link function in the delta-gamma model. Confidence intervals were evaluated by the bootstrap with 1000 replicates. The standardized CPUE values and confidence intervals are shown in the next section and in Table 1, 2.

(10) Comparison of the nominal and standardized CPUEs

The yearly patterns of summer recruitment CPUE trends were similar between nominal and standardized CPUEs, though the standardization estimated lower probability of positive CPUE (Fig. 19).

The yearly patterns of autumn recruitment CPUE trends were also similar between nominal and standardized CPUEs (Fig. 20). The index has been maintained at higher value since 2016 than before 2012, but with a great variability.

Figure 19. The yearly trends of nominal and standardized values of (a) the probability of positive CPUE, (b) positive CPUE after scaling (divided by means), and (c) CPUE after scaling (divided by means) of the summer recruitment CPUE. Blue shaded areas are 95% confidence intervals of standardized CPUE.

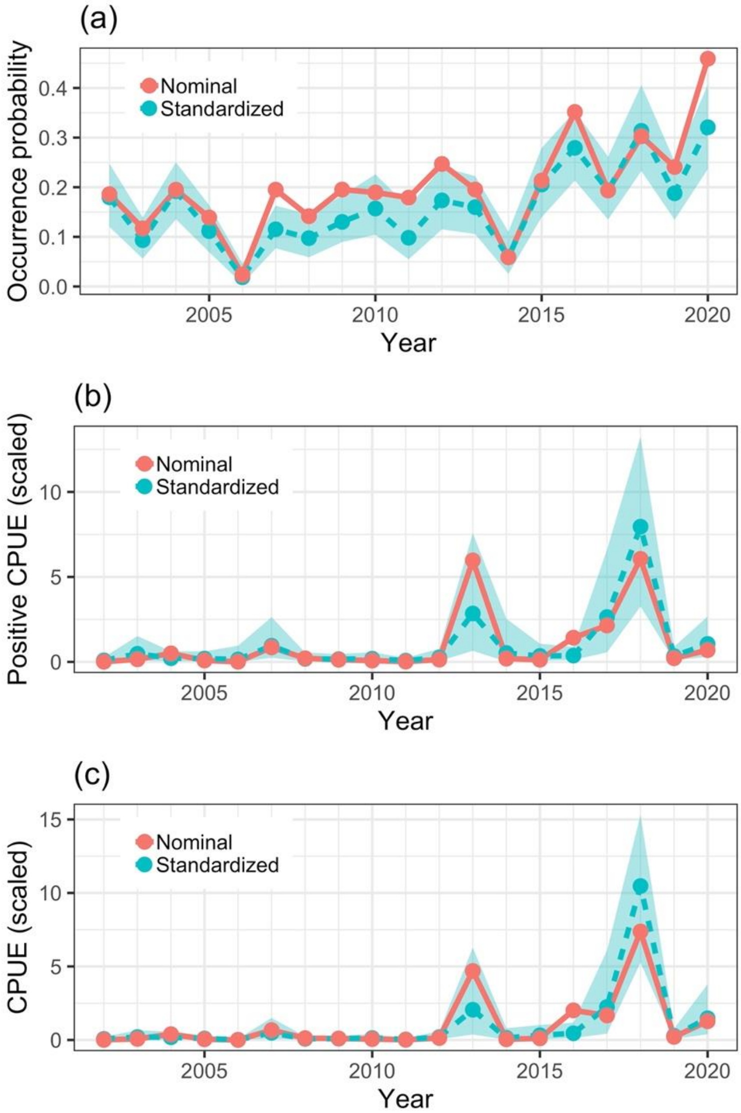
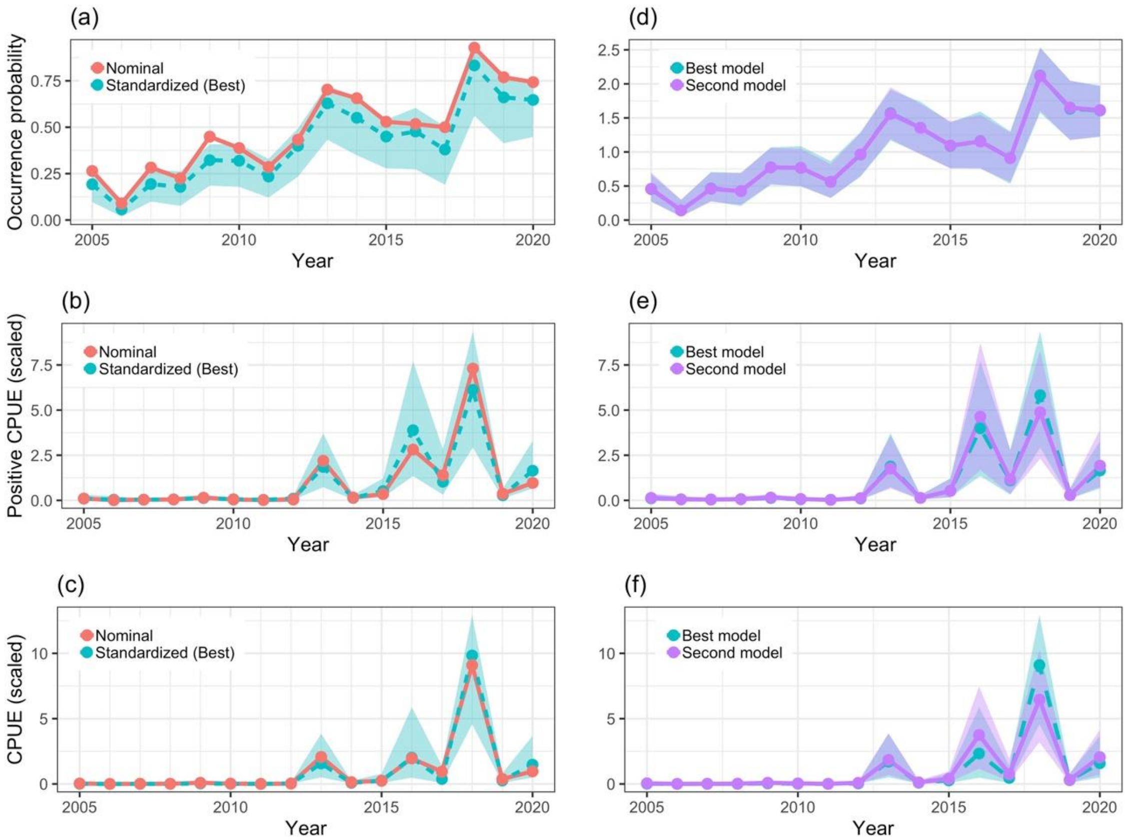


Figure 20. The yearly trends of nominal and standardized values of (a) the probability of positive CPUE, (b) positive CPUE after scaling (divided by means), and (c) CPUE after scaling (divided by means) of the autumn recruitment CPUE. Blue shaded areas are 95% confidence intervals of standardized CPUE. The comparison between the results of the best and second-best models: (d) the probability of positive CPUE, (e) positive CPUE after scaling (divided by means), and (f) CPUE after scaling (divided by means).



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