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Standardizing CPUE of Japanese commercial dip-net fishery targeting spawners of chub mackerel in the Northwest Pacific

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Summary

In this document, we provide the summary of the CPUE standardization of Japanese commercial dip-net fishery for Pacific chub mackerel following the "CPUE Standardization Protocol for Chub Mackerel". The year trend of the spawning stock biomass (SSB) was derived from standardized CPUE, by applying the catch-and-effort data of the dip-net fishery targeting spawners of chub mackerel to the delta GLM. Since we found no serious problems in the standardization, we recommend this SSB index to be utilized in the Technical Working Group for the Chub Mackerel Stock Assessment.

(1). Literature review to identify the candidate explanatory variables

Spawning chub mackerel was caught around the Izu Island chain, the main spawning ground of this stock (Fig.1) by the dip-net fishery. Although the catch amount is much smaller than that of the other common fishery such as the purse seine net fishery (Matsuda et al. 1994), the CPUE of the dip-net fishery has been used as an abundance index of SSB for the stock in the Japanese domestic stock assessment.

In the previous document, we reported the standardized CPUE values from 2003 to 2017 (Nishijima et al. 2017). Following this, we conducted CPUE standardization by removing the effects of environmental and spatial variables and updated the result. Since the dip-net CPUE of chub mackerel is known to be affected by water temperature (Nishijima et al. 2017), we used the sea surface temperature (SST) as an explanatory variable. The in-situ SST was recorded in each set. Furthermore, to account for the possible spatial autocorrelation of the CPUE, we added a spatial explanatory variable. We used the area category instead of the exact positions of fishing because a large proportion of data (383 out of 2200) lacked the information of the coordinates (longitude and latitude) but included the categorical name of the area of each catch.

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

The data of dip-net fishing from 2003 to 2020 were used (Table 1). We exclusively focused on the data from January to July, the spawning season of chub mackerel, and removed the data obtained during the other months (156 data out of 1945). The dip-net fisheries were conducted in the area approximately from 138º–140.5º E and 32.5º–35º N (Fig. 1).

Table 1. The summary of the fishery (number of fisheries, number of positive catches, and the mean nominal CPUE) and the result of standardization (standardized CPUE and the confidence interval).

year	**Number of samples**	**Number of positive catches**	**Mean nominal CPUE**	**Standardized CPUE**	**Lower 95% CI**	**Upper 95% CI**
2003	113	45	5.49	11.19	5.78	19.38
2004	161	74	4.46	9.61	5.91	14.86
2005	116	49	3.29	4.74	2.43	8.27
2006	69	30	25.46	51.69	26.93	91.40
2007	176	176	86.56	157.05	110.75	224.32
2008	81	81	45.53	57.55	38.88	84.30
2009	82	82	56.51	68.83	44.91	104.40
2010	37	37	58.37	85.66	51.90	133.68
2011	70	60	116.21	147.67	93.24	233.36
2012	65	60	120.54	130.19	82.04	198.81
2013	13	13	131.91	198.64	92.92	374.62
2014	110	108	130.84	164.94	104.97	250.76
2015	73	71	148.64	176.00	109.60	268.09
2016	122	117	199.16	234.89	161.63	332.45
2017	117	105	103.16	148.87	96.13	223.70
2018	102	102	172.02	223.87	155.99	318.84
2019	111	108	168.04	161.62	115.06	218.72
2020	171	161	200.16	166.45	122.95	222.54

Figure 1. Map of the area category (area 1 to 7). Each point represents the center of the fishing location of each category of the area, and error bars represent the dispersion (1 SD) of the fishing locations within the same category.

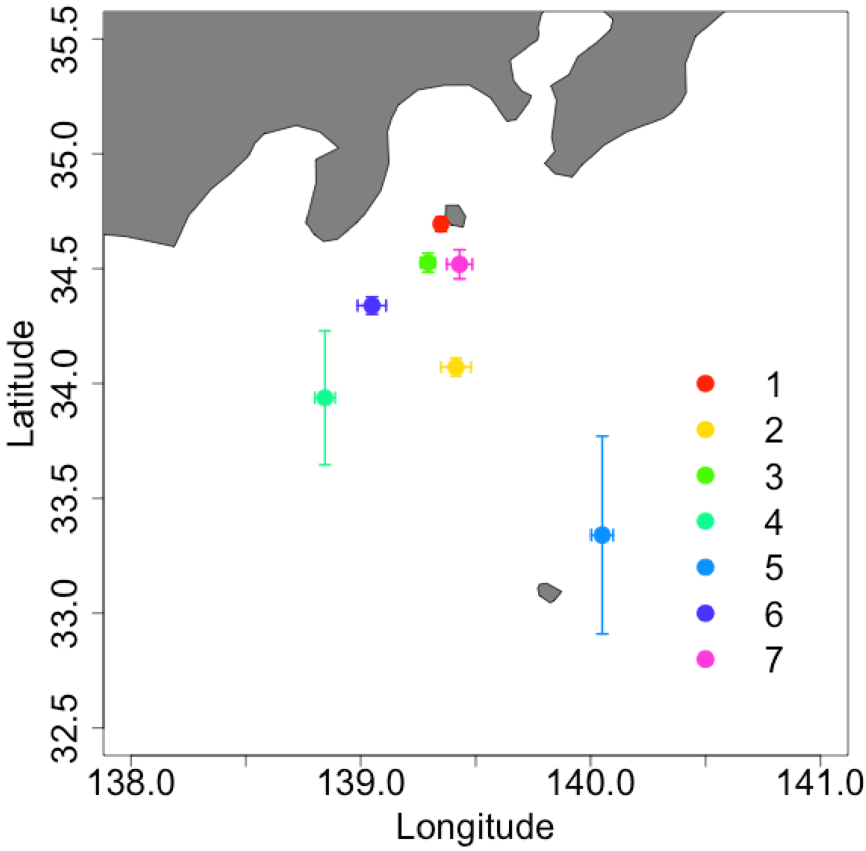


Figure 2. Spatio-temporal trends of the dip-net fishing efforts (man-hour).

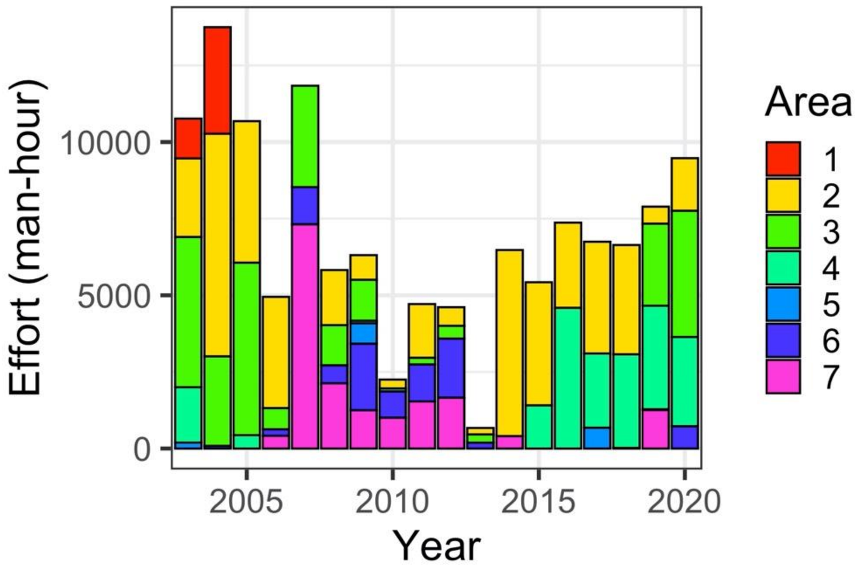
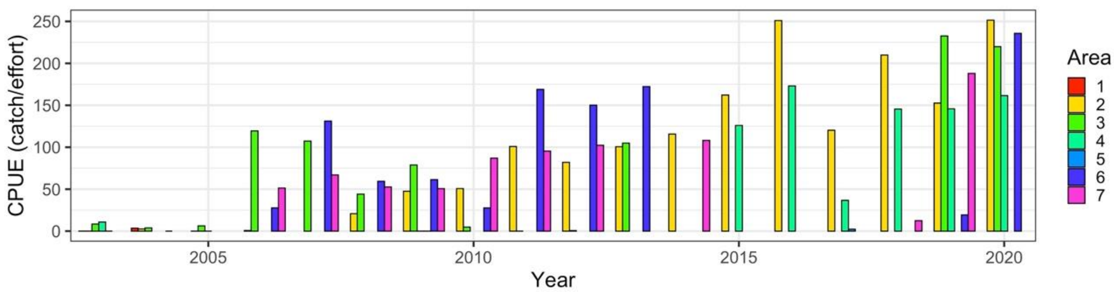


Figure 3. Spatio-temporal trends of the dip-net fishing CPUEs (catch biomass per man-hour).



(3). **Plots representing the correlation between the variables**

We present (i) the yearly trend of SST (Fig. 4), (ii) the spatial difference in SST (Fig. 5), (iii) the yearly trend of the CPUE (Fig. 6), (iv) the spatial distribution of the CPUE (Fig. 7), and (v) the relationship between SST and the CPUE (Fig. 8).

Figure 4. The yearly trend of sea surface temperature (SST).

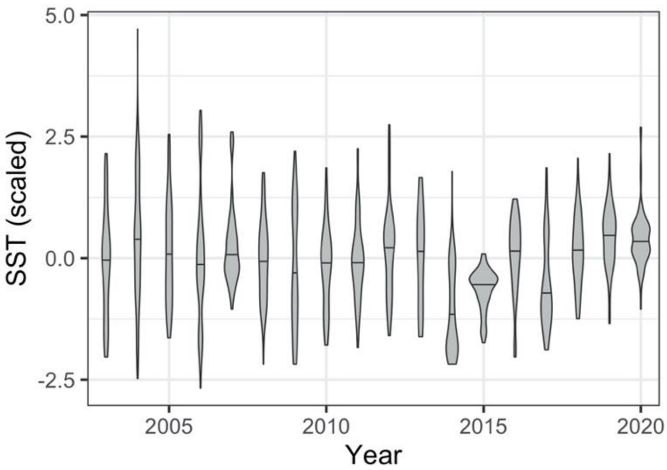


Figure 5. The spatial difference in sea surface temperature (SST).

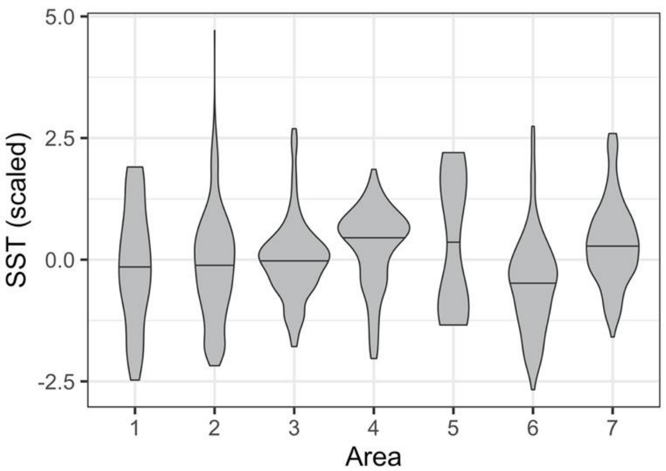


Figure 6. The yearly trend of the number of positive CPUE (left panel) and the average positive CPUE (right panel). The y-axis of the right panel is log-scaled.

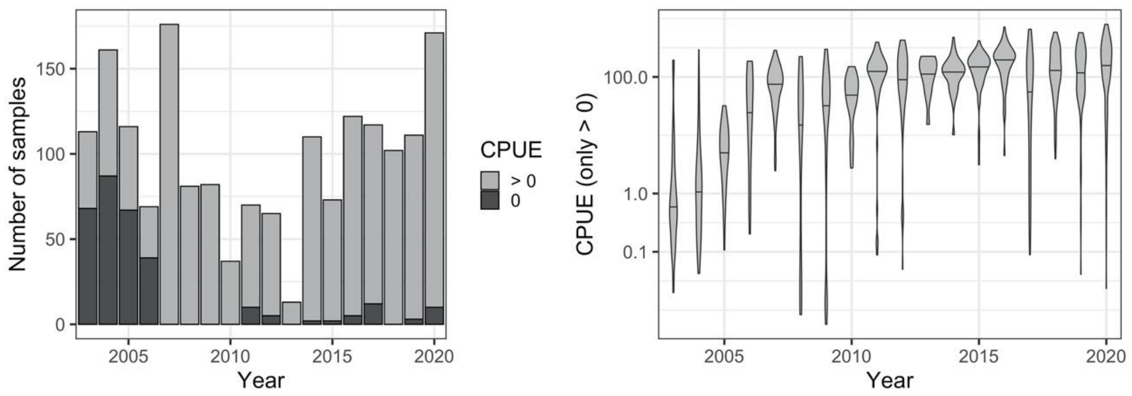


Figure 7. The spatial distribution of the number of positive CPUE (left panel) and the average positive CPUE (right panel). The y-axis of the right panel is log-scaled.

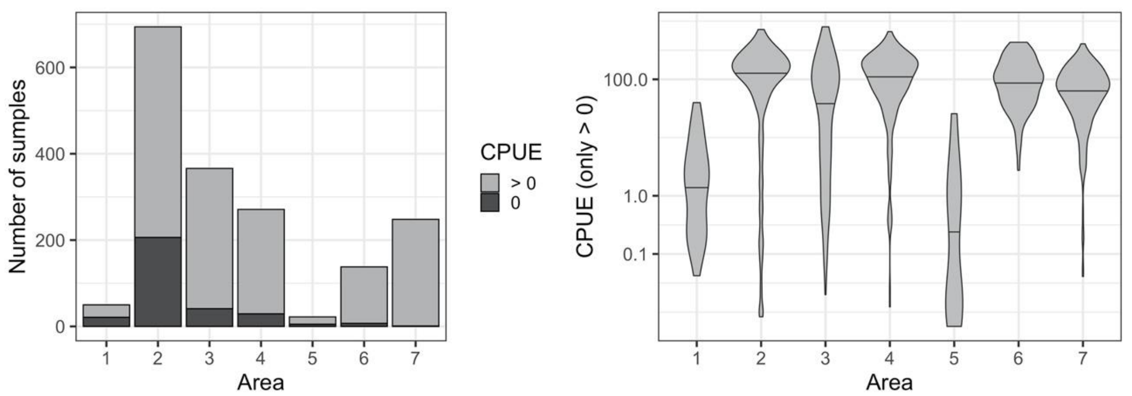
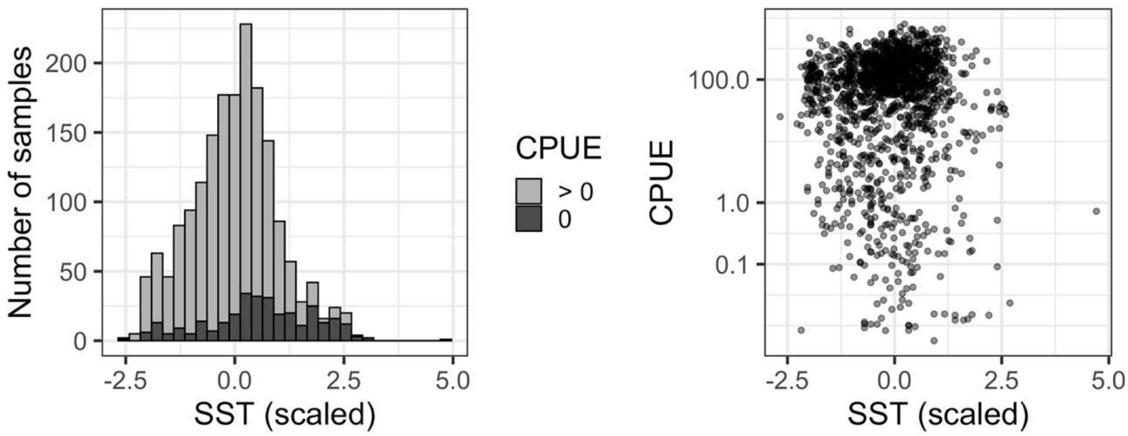


Figure 8. Relationship between sea surface temperature (SST) and the proportion of positive CPUE (left panel) or the positive CPUE values (right panel, log-scale).



(4). **Explanatory variables in the full model**

We incorporated following as the fixed effects: (i) year (categorical), (ii) month (categorical), (iii) area (categorical), (iv) ship (categorical), (v) sea surface temperature (SST) (continuous), and (vi) SST^2.

(5). **Model details**

We used delta GLM for the standardization of the dip-net fishery CPUE. Delta GLM is the two-step generalized linear model where the probability of occurrence and the density (or CPUE) when occurred were modelled separately. We modelled the probability of occurrence with binomial distribution (logit link) and the CPUE when occurred with gamma distribution (log link) or lognormal distribution (identity). The distribution of the CPUE modelling was selected based on BIC.

(6). **Best model**

We performed the brute-force model selection approach and determined the best model based on BIC (Table 2). Basically, models with gamma distribution had lower BIC values than models with lognormal distribution (Table 2). The best model with the lowest BIC was used for the standardization.

Table 2. Model selection for the standardization of summer recruitment CPUE. The selected explanatory variables in each model are indicated as "+" notation for categorical variables or coefficient values for continuous variables.

Occurrence model (binomial)										Positive CPUE model (gamma or lognormal)										
Explanatory variables					Year	df	logLik	BIC	ΔBIC	Explanatory variables						df	logLik	Distribution	BIC	ΔBIC
Area	Month	Ship	SST	SST^2						Area	Month	Ship	SST	SST^2	Year					
+	+		-0.408		+	24	-320.390	812.827	0.000	+	+	+	0.257		+	32	-7995.027	Gamma	16223.626	0.000
+	+				+	23	-324.318	813.514	0.687	+	+	+	0.257	0.003	+	33	-7995.022	Gamma	16230.915	7.289
+	+		-0.486	-0.214	+	25	-317.712	814.639	1.813	+	+		0.239		+	31	-8003.568	Gamma	16233.408	9.782
+	+	+	-0.406		+	25	-320.110	819.434	6.607	+	+	+	0.227		+	38	-7980.718	Gamma	16238.803	15.177
+	+	+			+	24	-323.991	820.028	7.201	+	+		0.241	0.007	+	32	-8003.545	Gamma	16240.662	17.036
+	+	+	-0.483	-0.210	+	26	-317.535	821.453	8.626	+	+	+			+	31	-8008.046	Gamma	16242.364	18.738
+			-0.993	-0.336	+	20	-344.643	832.657	19.830	+	+	+	0.224	-0.011	+	39	-7980.662	Gamma	16245.990	22.364
+		+	-0.994	-0.336	+	21	-344.637	839.815	26.988	+	+				+	30	-8014.839	Gamma	16248.651	25.025
+			-1.020		+	19	-355.058	846.319	33.492	+	+	+			+	37	-7990.714	Gamma	16251.495	27.869
+	+	+	-0.400		+	30	-316.115	847.288	34.461		+	+	0.268		+	26	-8052.654	Gamma	16295.084	71.458

(7). Diagnostics of the model and the residuals

The best binomial (Fig.9) and gamma (Fig.10) models were diagnosed by checking the distribution of the residuals along important variables (here, year and area).

Although there were no systematic trends in the residuals of the binomial models along years, the residuals appear to be more clustered after 2007 (Fig. 9a) probably because the probability of positive CPUE is high (Fig. 6). The residuals of the binomial models were not biased by area (Fig. 9b). In addition, the best binomial model was 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 of the binomial model was 0.938 (Fig. 9c), suggesting its good prediction.

The residuals of the best gamma model were not apparently biased by area (Fig. 10c). As for the temporal trends, however, we observed lower residuals during 2003 to 2005 (Fig. 10b), probably reflecting that most of the positive catches during that time period were observed in Area 3 where relatively higher CPUE is expected (Fig. 12). Nevertheless, the QQ-plot shows that residuals did not strongly deviate from the expected gamma distribution.

Figure 9. Diagnostics of the best binomial model. (a) Temporal and (b) spatial trends of the deviance residuals, and (c) the receiver operating characteristic (ROC) curves with the area under the curve (AUC) value.

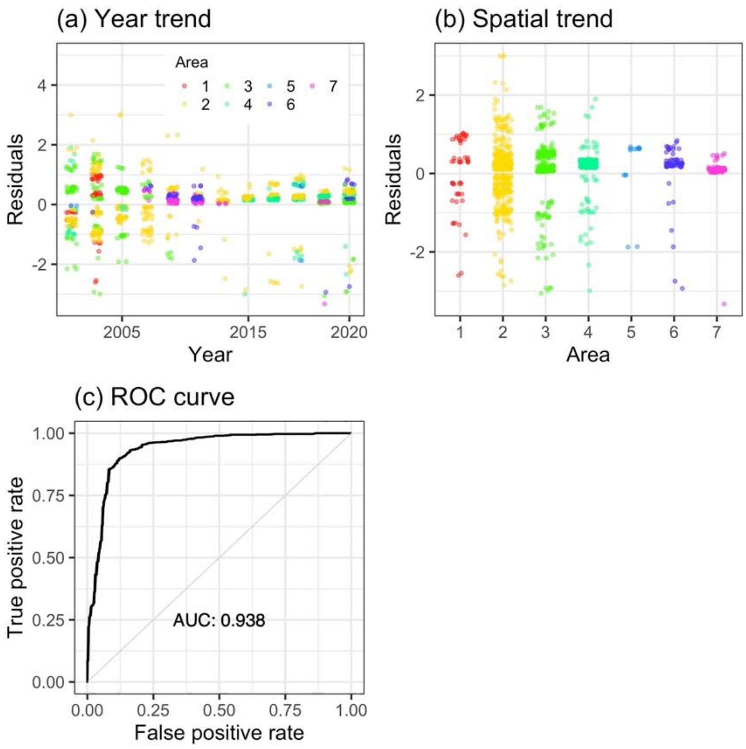
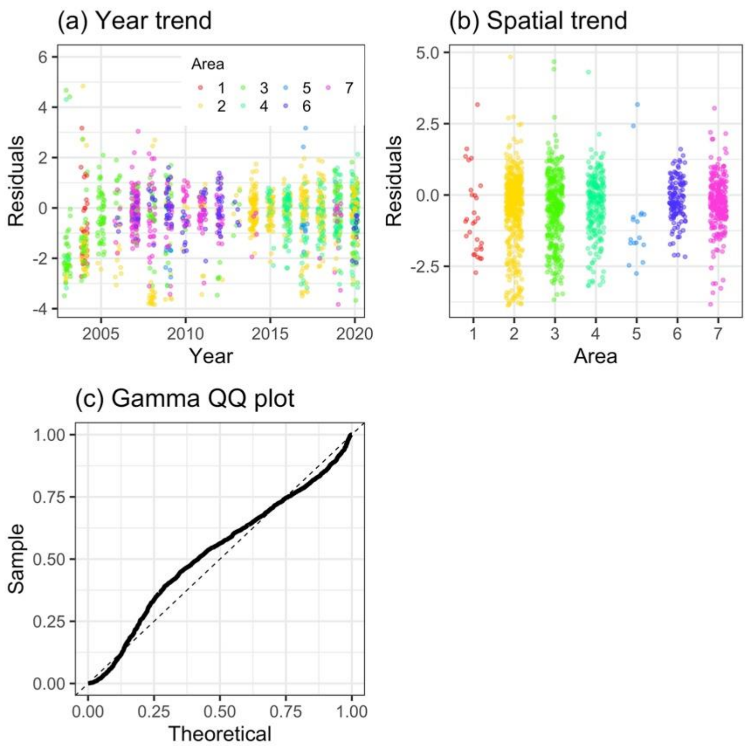


Figure 10. Diagnostics of the best gamma model. (a) Temporal and (b) spatial trends of the deviance residuals, and (c) the QQ-plot.



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

In the best binomial and gamma models, sea surface temperature (SST) was retained as an explanatory variable (Table 2). The effect of SST was contrasting between the binomial and gamma model, such that SST negatively correlated with the probability of positive catch (Fig. 11a), while it positively correlated with positive CPUE values (Fig. 11b). The probability of occurrence and the positive CPUE values differed among the areas (Fig. 12).

Figure 11. Relationship between sea surface temperature (SST) with the probability of positive catch (a) or with the positive CPUE values (b), estimated from the best binomial or gamma model, respectively. The lines were drawn based on the associated coefficient, with the other parameters fixed as their median values.

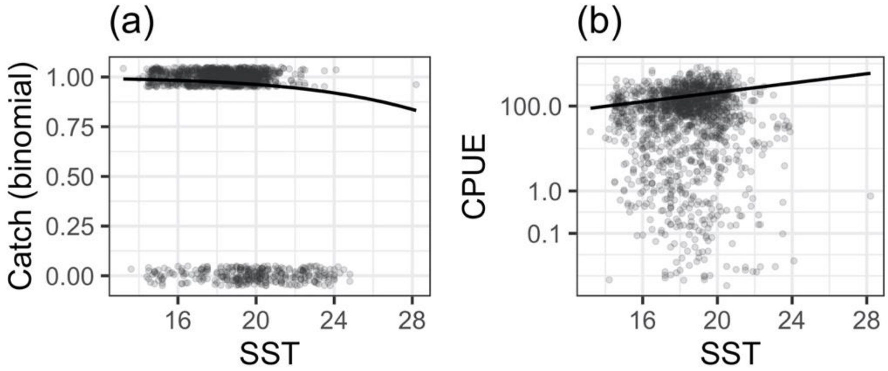
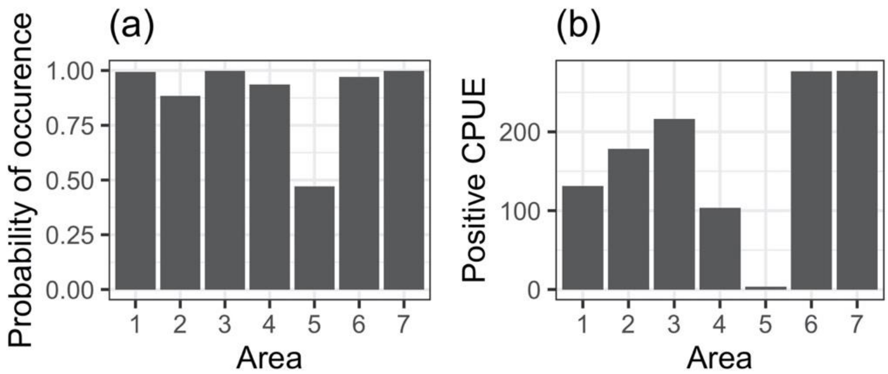


Figure 12. Difference in the (a) probability of occurrence and (b) positive CPUE value when occurred among areas. The values were obtained based on the coefficient with the other parameters fixed as their median values.



(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. This averaging for extracting the year trend was necessary due to the nonlinearity of the logit link function in the delta-gamma model.

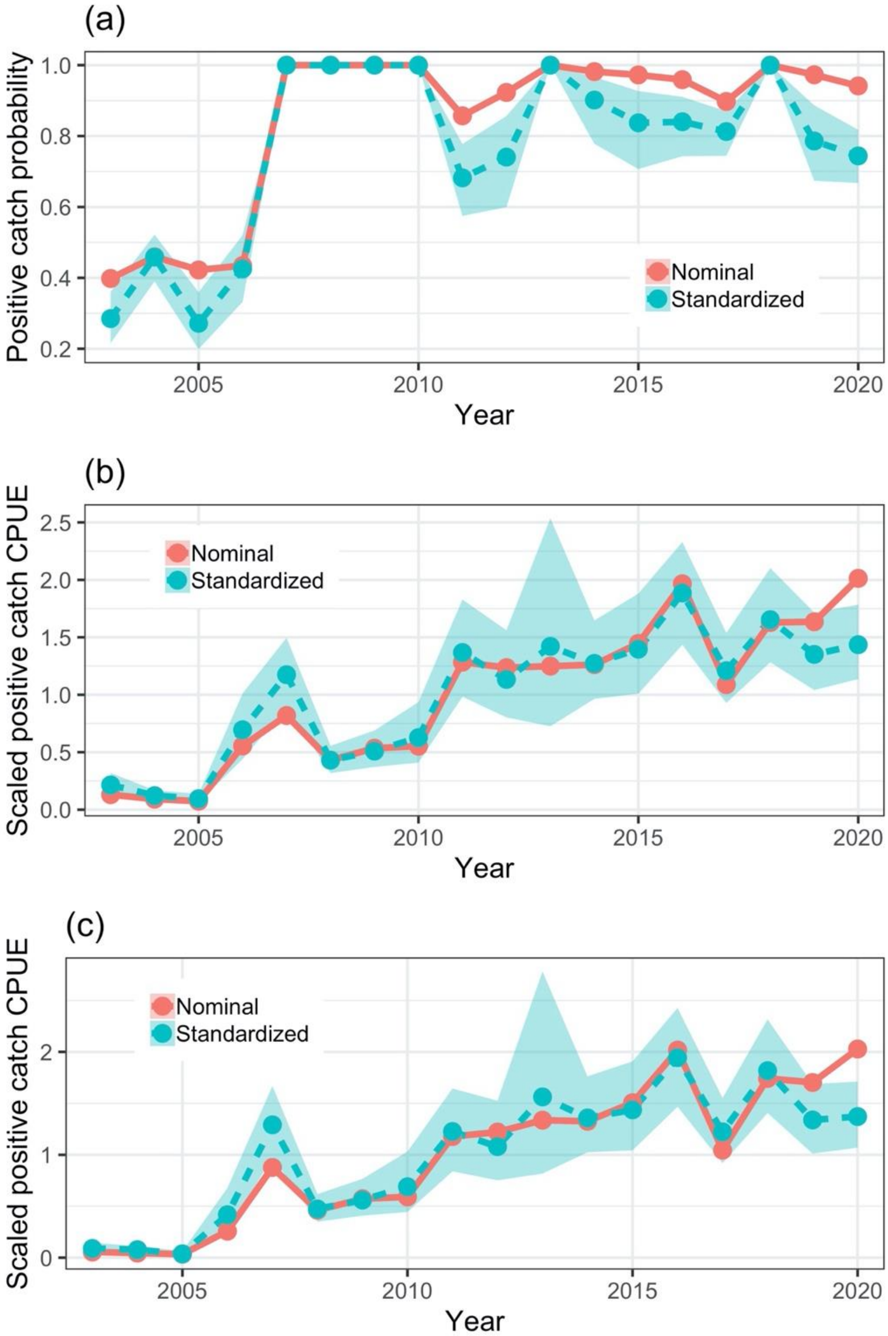
Confidence intervals were evaluated by the bootstrap with 1000 replicates.

The standardized CPUE values and confidence intervals are shown in the next section.

(10). **Comparison of the nominal and standardized CPUEs**

The overall yearly trend was similar between nominal and standardized CPUEs (Fig.13b, c), except for recent years (2019, 2020, Fig. 13b, c) when the standardized CPUE was lower than nominal value. In 2019 and 2020, a large proportion of the fishery was conducted in area 3 (Fig. 2). Area 3 was the main fishing ground also during 2003 to 2005 when the CPUE was low. Therefore, the results of the standardization for year 2019 and 2020 might be biased by the lower CPUE during 2003 to 2005, leading to the lower standardized CPUE in the recent years.

Figure 13. The yearly patterns of nominal and standardized values of (a) the probability of positive CPUE, (b) positive CPUE, and (c) average CPUE after scaling (divided by means). Blue shaded areas are 95% confidence intervals of standardized CPUE.



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