Stock Assessment of the Autumn-Spawning Stock of Japanese Flying Squid (2021) CPUE Standardization / Model Diagnostic Results (Squid Jigging Survey)

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Outline

Data	Squid-jigging survey for recruitment estimation in the Sea of Japan
Target	Catch number per squid-jigging machine per hour (individuals/machine/hour)
Period for which data is available	June to July of the 1981 to 2021 fishing year which starts from April and ends in March of the following year)
Period used for standardization	Entire period
Data extracted for standardization	Data obtained from this survey is composed of the 4,496 records. The 490 records obtained from the waters north of the geographical median line between Japan and Russia and west of 132 degrees east longitude were removed. The 233 records without sea surface temperature (SST) were also excluded. As a result, the excluded data account for 16.1% of all data.
Statistical software/packages used	R (4.1.0) was used for calculation. The \`dredge\` function in the MuMIn package was used for model selection, \`glm\` in the stats package and \`glmer\` in the lme4 package were used for modeling, and the ROCR package was used for the ROC analysis of the probability model in the 1st step.
Statistical models	Delta-type two-step model was applied to the CPUE standardization. The following statistical models were applied in two steps. 1st step: Generalized linear model with logit link function and binomial-distributed error was applied to presence/absent data. 2nd step: Generalized linear mixed model with log link function and gamma-distributed error was applied to positive catch data.
Explanatory variables in the full models	1st step: year (categorical), area (categorical), SST (continuous), and square of SST (continuous) 2nd step: year (categorical), area (categorical), SST (continuous), square of SST (continuous), mean mantle length of catch (continuous), and two interaction terms (area × mean mantle length, year × area). The interaction term of year × area was incorporated as a random effect.

Method of selecting the final models	Final models were selected from all combination of the explanatory variables that contain year as a variable based on AIC.
Explanatory variables selected for the final models	1st step: year, area, SST, and square of SST 2nd step: year, mean mantle length of catch, year ×area
Year trend extraction method	Least squared means (lsmeans) were used to estimate annual positive catch ratio and catch rate in 1st and 2nd steps, respectively. The annual catch rate was multiplied by the annual positive catch ratio to obtain annual CPUE. Finally, the standardized CPUE was calculated with area-weighting.
Confidence interval calculation method	None
Standardization result	The standardized CPUE showed a major trend that did not differ from that of nominal CPUE and the standardized CPUE assessed in previous fiscal years, increasing in the second half of the 1980s, fluctuating thereafter, and showing a declining trend since the second half of the 2010s.

1. Background

The abundance index of the autumn-spawning stock of Japanese flying squid is calculated based on CPUE (catch number per squid-jigging machine-hour) obtained from the squid-jigging survey for recruitment estimation in the Sea of Japan conducted from June to July every year. Annual recruitment is directly calculated through by multiplying the abundance index by catchability of survey gear q. Although the nominal CPUE had been applied to the estimation of recruitment up to 2017, the CPUE has been standardized to avoid biases in survey effort since 2018. Improvement of the CPUE standardization procedure has been continued up to 2020, when the delta-type two-step model was applied for the standardization to include zero-catch data and the area-weighted standardized CPUE was used to the estimation of recruitment (Kubota et al. 2021).

In the 2021 assessment, the statistical models were reviewed according to the data structure. There found, as a result, data missing for single area in 1993. Therefore, a generalized linear mixed model (GLMM) was applied to handle data missing in interaction terms (Shono 2004, Okamoto et al. 2016). The GLMM model allow us to estimate the area-weighted standardized CPUE under condition of application of interaction terms with data missing, because predictions for data-missing cells regarding interaction term between year and area can be provided thorough interpolation of those two main effects. The GLMM, consequently, was used in the 2nd step in the CPUE standardization in 2021, whereas the GLM model was applied to the 1st step.

2. Method

The catch and effort data obtained through this survey from 1981 to 2020 fishing season were used in this study (Figures 1 and 2). To keep data consistency, the data for June-July in waters under Japan jurisdiction were served for the CPUE standardization. Information obtained via fishing at each survey point are composed of catch, effort (number of squid jigging machine and duration of fishing), position, sea surface temperature (SST) and mean mantle length of catch. The data without SST were excluded. Seven areas were defined in analysis (Fig. 1). Mean mantle lengths at each point were obtained from squid catch of maximum of 100 individuals per sample.

In the 1st step, response variables were binary regarding presence/absence information, assuming binomial error. Although the GLMM model was also performed in the 1st step, it did not converge, resulting in application of the GLM model in that step. The explanatory variable candidates in the 1st step were *Year*, *Area*, *Temp* (SST) and square of *Temp*, and the logit link function was assumed in this step. The positive catch data of 3,552 records with the mean mantle length information were served in the 2nd step, where the effects of Year, Area, Temp, square of Temp, ML (mean mantle length), Area:ML and Year:Area were used as explanatory variables. The interaction term of Year:Area worked as a random effect, following a normal distribution with mean 0 and variance σ^2.

Probability model for operation with catch (full model)

$$P \sim Year + Area + Temp + (Temp)^2$$

P: probability of operation with catch

Gamma distribution model (full model)

$$CPUE \sim Year + Area + Temp + (Temp)^2 + ML + Area{:}ML + a$$

$$a \sim N(0, \sigma^2)$$

3. Results and Discussions

The best models for the 1st and 2nd steps were selected from all combinations of the explanatory variables based on the Akaike information criterion (AIC). The following variables were selected for the respective final models.

Probability model for operation with catch (final model)

$$P \sim Year + Temp + (Temp)^2$$

P: probability of operation with catch

Gamma distribution model (final model)

$$CPUE \sim Year + Area + ML + a$$

Because the area under the curve (AUC) of the ROC curve applied to the binomial distribution model for the 1st step was 0.94, the final model had sufficient performance to predict presence or absence (Figure 3). Meanwhile, model diagnostic based on Q-Q plot demonstrated that residuals from the final model almost followed the normal distribution (Figure 4).

Figure 5 shows year trends of nominal CPUE time series and three standardized CPUE time series estimated in the 2019-2021 stock assessment. No significant differences are observed among the CPUE time series. They, in general, increased in the second half of the 1980s, fluctuated thereafter, and showed a declining trend since the second half of the 2010s. The nominal CPUE peaked in 2014, whereas the standardized CPUE series touched peak in 1997. The nominal CPUE and the standardized CPUE obtained in 2021 recorded the lowest in 1986, although the remaining two CPUEs hit the bottom in 2019. Although the standardized CPUEs since 2014 were higher in the 2021 stock assessment than those estimated in the 2020, there found consistent trends between two time series.

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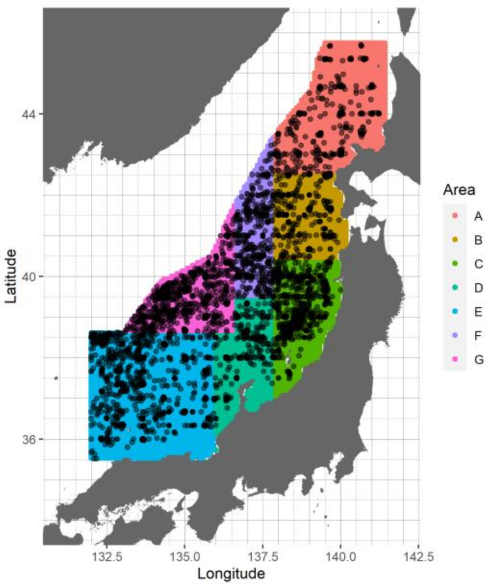

Figure 1. Area definition for the CPUE standardization. Black dots indicate the survey points, and each color indicates the areas of *A* to *G*.

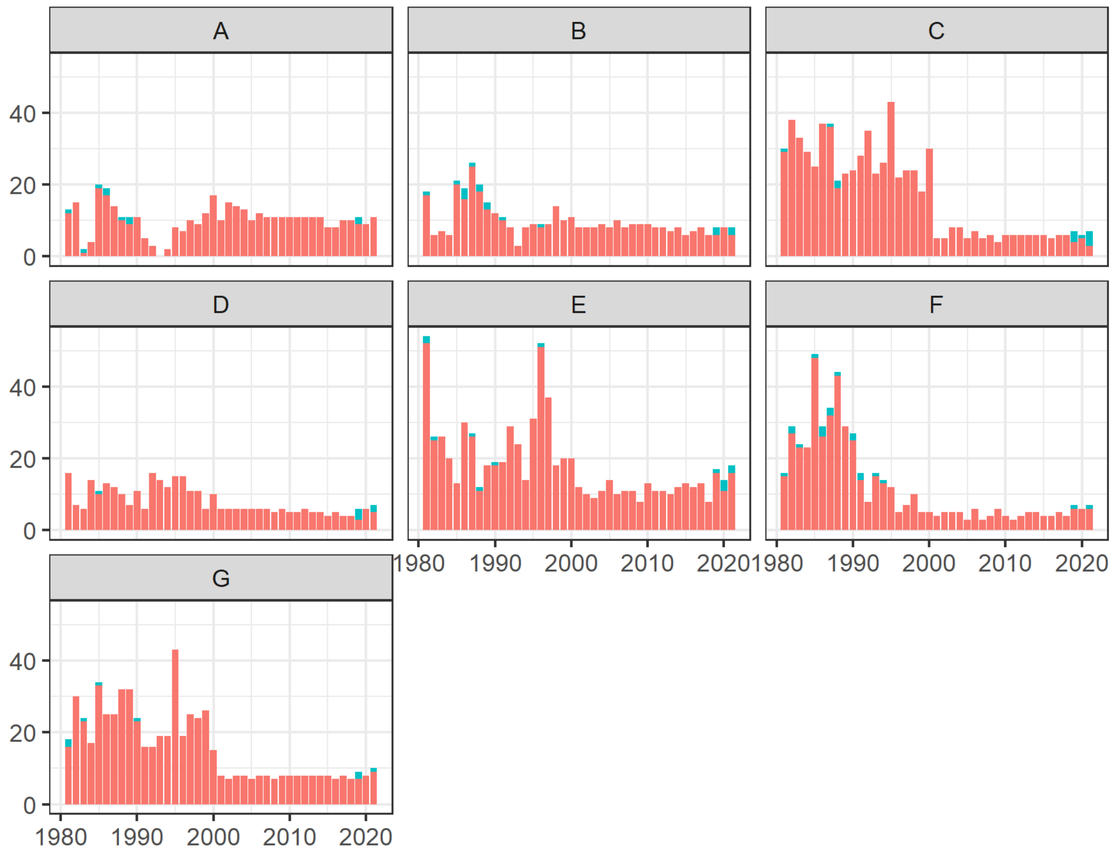

Figure 2. Annual number of records by area. Orange and blue bars indicate numbers of records of positive and zero catch data, respectively.

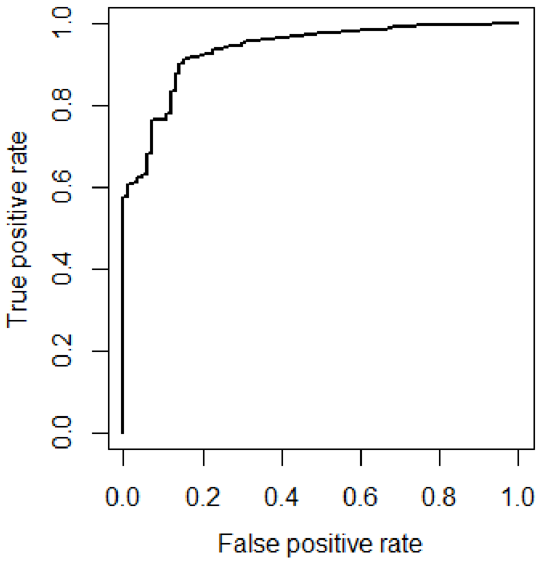

Figure 3. ROC curve applied to the binomial distribution model for the 1st step.

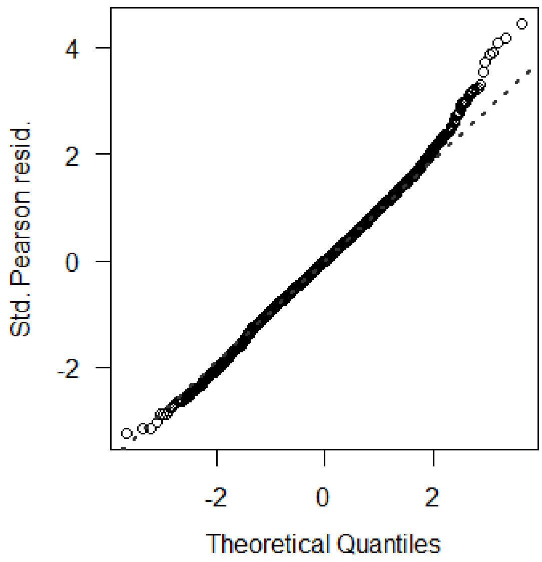

Figure 4. Q-Q plot of the log-normal model for the 2nd step.

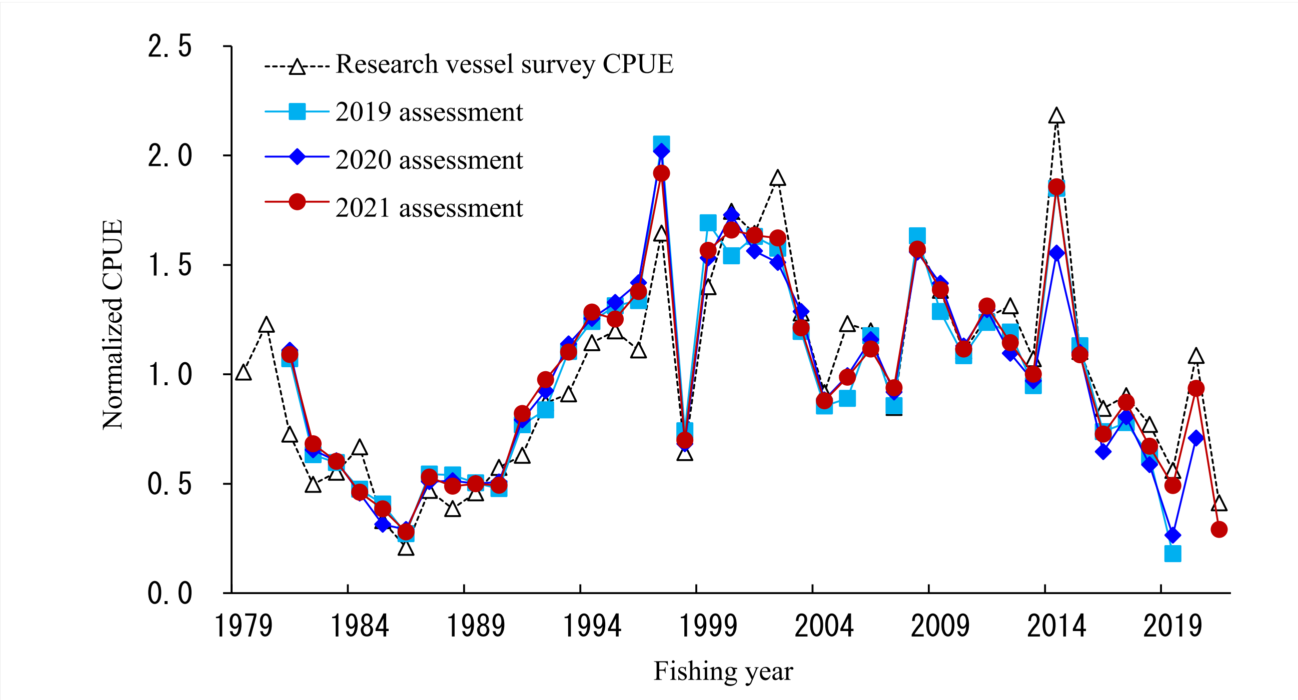

Figure 5. Year trends in nominal CPUE and the standardized CPUE time series obtained in the 2019-2021 stock assessments. Each CPUE was plotted on normalized scale.