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**Standardized CPUE of Pacific saury (*Cololabis saira*) caught**
**by the Japanese stick-held dip net fishery up to 2024**

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**Summary**
We updated the standardized catch-per-unit-effort (CPUE) of Pacific saury caught by the Japanese stick-held dip net fishery up to 2024 for the stock assessment conducted by NPFC. CPUE was standardized by a generalized linear model (GLM) incorporating explanatory variables, year, month, fishing area, vessel size, and sea surface temperature. The standardized CPUE in 2024 was the fifth lowest since 1994 and remained at a low level.

# Introduction

In the stock assessment on Pacific saury (*Cololabis saira* hereafter PS) under the framework of the North Pacific Fisheries Commission (NPFC), it was assessed that stock biomass remains at a historically low level in recent years (NPFC-2024-SSC PS14-Final Report). Since information on the latest abundance of PS stock would be useful for next PS stock assessment, we updated the standardized CPUE of PS by the Japanese stick-held dip net (hereafter SHDN) fishery up to 2024.

# Method

Standardization of CPUE for PS was conducted according to the standardization protocol (Annex E in NPFC-2019-SSC PS05-Final Report) updated in the 5th meeting of Small Scientific Committee on Pacific saury (see **Appendix I**).

1. Commercial fishery data sources

Data of the Japanese SHDN fishery for PS was obtained from two sources: the landing surveys at six major landing ports (see Suyama et al. 2018 for detailed survey procedures) during 1994 to 1999 and the logbook during 2000 to 2024. The fishery data includes information on date, fishing position (longitude and latitude), catch in weight (metric ton, mt), number of hauls, in situ sea surface temperature (SST) measured using an on-board thermometer, and size of the fishing vessels (gross register tonnage, GRT). CPUE was defined as catch in weight per number of hauls in a fishing operation conducted by one vessel in one night.

In 2024, the data obtained from 2821 fishing operations (records) carried out from August to December were used for CPUE standardization. The data covered 97% of Japanese total landing of PS in weight. Records with zero catch were very few (no records in 2024) and were eliminated from the data, because fishing operations were basically conducted only when the fish schools were detected. Fishing ground of the Japanese SHDN fishery for PS had been divided into five subareas based on oceanographic characteristics (Areas I to V in **Fig. 1**). Features of each subarea are described in Suyama et al. (2018). In recent years, fishing operations in the coastal areas of Japan (Area III) have declined and fishing grounds have shifted eastward (**Fig. 2**). In 2024, no operation was recorded in the Sea of Okhotsk (northeastern Hokkaido) and this area was included in the neighboring Area II (**Fig. 1**).

1. Statistical method
2. Model specification

A generalized linear model (GLM) was used to standardize CPUE. Factors of year, month, fishing area, size of fishing vessels and SST were incorporated as explanatory variables. CPUE varied annually and monthly with hitting its peak around October (**Fig. 3**). Differences in CPUE were observed among categories for fishing area, vessel size and SST. The correlation matrix for these explanatory variables is shown in **Fig. 4**. Full model was given as:

ln(*CPUE*) = Intercept + *Year* + *Month* + *Area* + *Grt* + *Sst* + two-way interactions + *ε*,

where *Year*, *Month* and *Area* are categorical variables, composed of 31 years (1994–2024), 5 months (August–December) and 5 subareas (I-V), respectively (**Table 1**). Vessel size was divided into 10 (*Grt1*) or 5 (*Grt2*) categories at intervals of 20 or 40 mt, respectively. SST was divided into 12 (*Sst1*) or 5 (*Sst2*) categories at intervals of 1 or 3 °C, respectively. Parameter *ε* denotes an error term with *ε* ~ *N*(0, *σ*2).

 In Japanese SHDN fisheries, no fishing operation was conducted in December in some years, and spatial allocation of fishing efforts has varied across years (**Fig. 2**). Re-stratification was therefore conducted for the explanatory variables other than *Year* used in two-way interactions (Month.int, Area.int, Grt.int, and Sst.int) in order to avoid no observation in any stratum (**Table 1**). Order of interaction terms in full model was determined based on their interpretability in terms of habitat suitability and fishing strategy (**Table 2**). For example, interaction between *Year* and *Grt* is essential, because CPUE for large vessels equipped with larger nets increased along with increase in stock biomass, while CPUE for small vessels did not increase (**Fig. 5**). Interactions with *Grt* were additionally incorporated because CPUE for small vessels did not increase compared to large vessels even in the main fishing season and main fishing ground (**Fig. 5**).

1. Model selection and diagnostics

We employed a Bayesian information criterion (BIC) to measure the predictive ability and selected the best model. The optimal categorizations regarding vessel size and SST were determined through model selections. For model diagnostics, the percent deviation explained was calculated in addition to Q-Q plot and residual plots.

1. Calculation of standardized CPUE

Time series of standardized CPUE were estimated using the best GLM. We first generated data that was composed of combinations of explanatory variable categories including realistic SST and then predicted annual values of ln(*CPUE*) for area *a* (ln(*CPUE*)*y,a*). Finally annual standardized CPUE were calculated as the area-weighted mean of (CPUE)*y,a*:

*CPUEy* = Σ*a*{ exp(ln(*CPUE*)*y,a*) × (*Aa* / Σ*A*) },

where *Aa* indicates an area of area *a*. Coefficient of variation and 95% confidential intervals for the annal standardized CPUE were calculated by bootstrap resampled residuals with 1000 replications. The annual standardized CPUE was compared with nominal CPUE (annual mean of CPUE).

# Results and discussion

1. Model selection

After removing explanatory variables one by one until BIC did not decrease (**Table 3**), following model was selected as the best model:

ln(CPUE) = Intercept + *Year* + *Month* + *Area* + *Grt1* + *Sst1* + *Year:Month.int* + *Year:Area.int* + *Year:Grt.int* + *Month.int:Area.int* + *Month.int:Sst.int* + *Area.int:Sst.int* + *Month.int:Grt.int* + *ε*.

Percent deviance explained of the selected model was 50.4%. Analysis of deviance (Type III tests) indicated that all selected explanatory variables were significant at a significant level of <0.05 (**Table 4**). Q-Q plot and residuals distribution indicated residuals were distributed normally around 0, even though long tails were observed at both ends (**Fig. 6**). Furthermore, no tendencies were found in residuals across years. It is concluded that CPUE were appropriately modeled using the selected explanatory variables.

1. Year trend of standardized CPUE

The standardized annual CPUE derived from the best GLM showed a generally similar trend with nominal CPUE (**Fig. 7**). Incorporating interactions between year and area, year and month, and year and vessel size (*Year:Area.int,* *Year:Month.int* and *Year:Grt.int*) contribute to derive the standardized CPUE (**Appendix II**). The standardized annual CPUE in 2024 was the fifth lowest since 1994 and remained at a low level. (**Table 5**).

**Reference**
Small Scientific Committee on Pacific Saury (2019) 5th Meeting Report. NPFC-2019-SSC PS05-Final Report. 44 pp. (Available at www.npfc.int)

Small Scientific Committee on Pacific Saury (2024) 14th Meeting Report. NPFC-2024-SSC PS14-Final Report. 60 pp. (Available at www.npfc.int)

Suyama S, Kidokoro H, Naya M, Hashimoto M and Vijai D (2018) Standardization of CPUE data of Pacific saury (*Cololabis saira*) caught by the Japanese stick-held dip net fishery during 1994 to 2017. NPFC-2018-SSC PS03-WP05.

# Table and figures

**Table 1** Summary of explanatory variables in GLM.

| Variables | Cases | Number of categories | Detail | Note |
| --- | --- | --- | --- | --- |
| Year | *Year* | 31 | 1994–2023 |  |
| Month | *Month* | 5 | August–December |  |
|  | *Month.int* | 4 | Aug, Sep, Oct, Nov + Dec | for interaction terms |
| Area | *Area* | 5 | I–V | see **Fig. 1** |
|  | *Area.int* | 2 | I+V, II+III+IV+VI | for interaction terms |
| Vessel tonnage | *Grt1* | 10 | Grt＜20 tons, 20≦Grt＜40, …, 180≦Grt＜200 | at intervals of 20 tons |
|  | *Grt2* | 5 | Grt＜40 tons, 40≦Grt＜80, …, 160≦Grt＜200 | at intervals of 40 tons |
|  | *Grt.int* | 3 | Grt＜80 tons, 80≦Grt＜160, 160≦Grt＜200 | for interaction terms |
| Sea surface temperature | *Sst1* | 12 | Sst＜10°C, 10≦Sst＜11, …, 20≦Sst | at intervals of 1 °C |
|  | *Sst2* | 5 | Sst＜10°C, 10≦Sst＜13, …, 19≦Sst | at intervals of 3 °C |
|  | *Sst.int* | 4 | Sst＜13°C, 13≦Sst＜16, …, 19≦Sst | for interaction terms |

**Table 2** Order based on interpretation of interaction terms.

| Interaction terms | Order in the full model | Possible interpretation |
| --- | --- | --- |
| *Year:Month.int* | 1 | Main fishing season differs among years |
| *Year:Area.int* | 2 | Main fish distribution (high density area) and/or main fishing ground (large effort) differs among years |
| *Year:Grt.int* | 3 | Annual catchability differs among vessel sizes |
| *Year:Sst.int* | - | Little difference in suitable water temperature among years |
| *Month.int:Area.int* | 4 | Main fishing season differs among fishing grounds |
| *Month.int:Grt.int* | 7 | Little difference in monthly catchability among vessel sizes |
| *Month.int:Sst.int* | 5 | Suitable water temperature differs among months |
| *Area.int:Grt.int* | 8 | Little difference in spatial catchability (e.g., accessibility to fishing ground) among vessel sizes |
| *Area.int:Sst.int* | 6 | Suitable water temperature differs among fishing areas |
| *Grt.int:Sst.int* | - | Little difference in suitable water temperature among vessel sizes |

**Table 3** Results of model selection.

| No. | Models | BIC | ΔBIC |
| --- | --- | --- | --- |
| 1 (Full) | Year + Month + Area + Grt1 + Sst1 + Year:Month.int+ Year:Area.int + Year:Grt.int + Month.int:Area.int+ Month.int:Sst.int + Area.int:Sst.int + Month.int:Grt.int+ Area.int:Grt.int | 353179 | 4.8 |
| **2 (Best)** | **Full model - Area.int:Grt.int** | **353174** | **0** |
| 3 | Full model - Area.int:Grt.int - Month.int:Grt.int | 353252 | 77.8 |
| 4 | Full model - Area.int:Grt.int - Area.int:Sst.int | 353299 | 124.8 |
| 5 | Full model - Area.int:Grt.int - Month.int:Sst.int | 353660 | 486.5 |
| 6 | Full model - Area.int:Grt.int - Month.int:Area.int | 353441 | 267.6 |
| 7 | Full model - Area.int:Grt.int - Year:Grt.int | 355044 | 1869.7 |
| 8 | Full model - Area.int:Grt.int - Year:Area.int | 353955 | 780.6 |
| 9 | Full model - Area.int:Grt.int - Year:Month.int | 358196 | 5021.9 |
| 10 | Full model - Area.int:Grt.int - Sst1 | 353346 | 172.2 |
| 11 | Full model - Area.int:Grt.int - Grt1 | 354198 | 1024.2 |
| 12 | Full model - Area.int:Grt.int – Area | 354220 | 1046.6 |
| 13 | Full model - Area.int:Grt.int - Month | 353728 | 554.3 |
| 14 (Null) | Year | 393481 | 40306.9 |

**Table 4** Analysis of deviance table (Type III tests) for the best GLM with minimum BIC.

|  | *SS* | *Df* | *F* | *Pr*(>*F*) | *Signif. codes* |
| --- | --- | --- | --- | --- | --- |
| Year | 14031 | 30 | 781.47 | < 2.2e-16 | \*\*\* |
| Month | 339 | 1 | 566.24 | < 2.2e-16 | \*\*\* |
| Area | 649 | 3 | 361.44 | < 2.2e-16 | \*\*\* |
| Grt1 | 664 | 7 | 158.53 | < 2.2e-16 | \*\*\* |
| Sst1 | 160 | 8 | 33.42 | < 2.2e-16 | \*\*\* |
| Year:Month.int | 3716 | 90 | 68.99 | < 2.2e-16 | \*\*\* |
| Year:Area.int | 683 | 30 | 38.02 | < 2.2e-16 | \*\*\* |
| Year:Grt.int | 1551 | 59 | 43.91 | < 2.2e-16 | \*\*\* |
| Month.int:Area.int | 181 | 3 | 101.02 | < 2.2e-16 | \*\*\* |
| Month.int:Sst.int | 355 | 9 | 65.99 | < 2.2e-16 | \*\*\* |
| Area.int:Sst.int | 96 | 3 | 53.43 | < 2.2e-16 | \*\*\* |
| Month.int:Grt.int | 89 | 6 | 24.85 | < 2.2e-16 | \*\*\* |
| Residuals | 90042 | 150445 |  |  |  |

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

**Table 5** Nominal and standardized annual CPUE of Japanese stick-held dip net fishery for Pacific saury from 1994 to 2024.

| Year | Nominal CPUE (metric ton/haul) | Standardized CPUE by GLM | CV (%) | Lower limit of 95% CI | Upper limit of 95% CI |
| --- | --- | --- | --- | --- | --- |
| 1994 | 5.38 | 4.10 | 4.36 | 3.78 | 4.47 |
| 1995 | 4.41 | 2.09 | 7.34 | 1.82 | 2.43 |
| 1996 | 2.45 | 1.78 | 5.49 | 1.60 | 1.98 |
| 1997 | 4.76 | 3.49 | 20.05 | 2.49 | 5.28 |
| 1998 | 1.49 | 1.05 | 3.08 | 0.99 | 1.12 |
| 1999 | 1.51 | 0.91 | 3.29 | 0.85 | 0.97 |
| 2000 | 1.78 | 1.27 | 2.15 | 1.22 | 1.33 |
| 2001 | 2.46 | 1.65 | 1.89 | 1.59 | 1.71 |
| 2002 | 1.83 | 1.10 | 2.21 | 1.06 | 1.15 |
| 2003 | 2.79 | 2.02 | 2.20 | 1.93 | 2.11 |
| 2004 | 2.98 | 2.70 | 2.22 | 2.58 | 2.82 |
| 2005 | 4.75 | 4.37 | 2.29 | 4.18 | 4.57 |
| 2006 | 4.49 | 4.54 | 2.72 | 4.31 | 4.79 |
| 2007 | 5.33 | 4.18 | 2.35 | 3.99 | 4.39 |
| 2008 | 5.61 | 5.16 | 2.66 | 4.91 | 5.43 |
| 2009 | 4.01 | 4.16 | 2.90 | 3.93 | 4.40 |
| 2010 | 2.58 | 1.79 | 2.11 | 1.72 | 1.86 |
| 2011 | 3.14 | 2.48 | 2.28 | 2.37 | 2.59 |
| 2012 | 3.29 | 2.72 | 2.43 | 2.60 | 2.85 |
| 2013 | 3.02 | 1.89 | 2.24 | 1.81 | 1.97 |
| 2014 | 4.42 | 3.27 | 2.57 | 3.13 | 3.45 |
| 2015 | 2.70 | 1.66 | 2.45 | 1.58 | 1.74 |
| 2016 | 2.94 | 1.80 | 2.81 | 1.71 | 1.90 |
| 2017 | 1.62 | 1.11 | 2.38 | 1.06 | 1.16 |
| 2018 | 3.17 | 1.95 | 2.49 | 1.86 | 2.05 |
| 2019 | 1.58 | 0.69 | 2.75 | 0.66 | 0.73 |
| 2020 | 0.88 | 0.47 | 5.12 | 0.43 | 0.53 |
| 2021 | 0.58 | 0.32 | 5.01 | 0.29 | 0.36 |
| 2022 | 0.43 | 0.28 | 4.62 | 0.26 | 0.31 |
| 2023 | 0.54 | 0.31 | 3.72 | 0.29 | 0.33 |
| 2024 | 1.02 | 0.50 | 3.94 | 0.46 | 0.54 |



**Fig.1** Area definition applied for CPUE standardization in this study.



**Fig.2** Annual changes in monthly fishing ground of Japanese stick-held dip net fishery for Pacific saury from 1994 to 2024.



**Fig.3** Relationship between CPUE and each factor (Year, Month, Area, vessel size and SST).



**Fig.4** Correlation matrix of used explanatory variables.



**Fig.5** Relation to CPUE for variables in interaction terms.



**Fig.6** Q-Q plot, histogram of residuals and residual plots across years for the best GLM.



**Fig.7** Scaled nominal CPUE and annual scaled standardized CPUE when using fishery data up to 2024. Gray zone indicates 95% confidence intervals of standardized CPUE.

**Appendix I** Checklist for the CPUE standardization protocol.

|  |  |  |
| --- | --- | --- |
| (1) | Conduct a thorough literature review to identify key factors (i.e., spatial, temporal, environmental, and fisheries variables) that may influence CPUE values; | Yes (see Suyama et al. (2018)) |
| (2) | Determine temporal and spatial scales for data grouping for CPUE standardization; | Yes (**Table 1**) |
| (3) | Plot spatio-temporal distributions of fishing efforts and catch to evaluate spatio-temporal patterns of fishing effort and catch; | Yes (**Fig. 2**) |
| (4) | Calculate correlation matrix to evaluate correlations between each pair of those variables; | Yes (**Fig. 4**) |
| (5) | Identify potential explanatory variables based on (1)-(4) as well as interaction terms to develop full model for the CPUE standardization; | Yes (**Table 1**) |
| (6) | Fit candidate statistical models to the data (e.g., GLM, GAM, Delta-lognormal GLM, Neural Networks, Regression Trees, Habitat based models, and Statistical habitat based models); | Yes (GLM) |
| (7) | Evaluate the models using methods such as likelihood ratio, AIC/BIC and cross validation; | Yes (BIC) |
| (8) | Evaluate if distributional assumptions are satisfied and if there is a significant spatial/temporal pattern of residuals in CPUE standardization modeling; | Yes (**Fig. 6**) |
| (9) | 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; | Yes (see **Method** section) |
| (10) | Recommend a time series of yearly standardized CPUE and associated uncertainty; | Yes (**Table 4**) |
| (11) | Plot nominal and standardized CPUEs over time; | Yes (**Fig.7**) |

***Appendix II*** *Essential terms that contribute to the standardization of PS CPUE.*

In this analysis, the selected model contained many explanatory variables. To identify the essential explanatory variables that contribute to improve PS abundance index, a reference model was constructed by removing one explanatory variable from the best model, and the standardized CPUE obtained from the reference model was compared with that from the best model.

As a result, the derived annual trend of CPUE was slightly changed from that of the standardized CPUE by the best model, only when interaction between year and area (upper left panel in **Fig. A1**), year and month (upper right), or year and vessel size (bottom left) was used. It is concluded that incorporating these interaction terms contribute to standardize the CPUE for the Japanese PS fishery.



**Fig.A1** Scaled nominal CPUE and annual scaled standardized CPUEs derived from the best GLM and the reference model removing one explanatory variable.