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Standardized CPUE of Pacific saury (*Cololabis saira*) caught by the Chinese Taipei stick-held dip net fishery up to 2019

Wen-Bin Huang[1], Yi-Jay Chang[2] and Chih-hao Hsieh[2]

[1] Department of Natural Resources and Environmental Studies,

National Dong Hwa University, Hualien 974.

E-mail: bruce@gms.ndhu.edu.tw

[2] Institute of Oceanography, National Taiwan University, Taipei 106.

SUMMARY

The Pacific saury catch and effort data for the Chinese Taipei stick-held dip net fishery in the Northwestern Pacific Ocean were collected from 2001-2019. Two alternative approaches, generalized linear models (GLMs) and generalized additive models (GAMs), were used to standardize the catch per unit effort (CPUE) of Pacific saury, with an assumption of lognormal error distribution. In this study an updated version (incorporating 2019 data) of the previous year's CPUE standardization data set derived from fishing logbooks was used. Most of the main explanatory variables and interaction terms used in the modeling analyses were statistically significant. The results derived from both approaches, GLMs and GAMs, were almost identical. Standardized CPUE of Pacific saury for the Chinese Taipei stick-held dip net fishery in the Northwestern Pacific Ocean showed a general oscillating trend with a slight increase observed from 2001-2010, followed by a sharp increase through to 2014, a sharp decline until 2017, a dramatic increase in 2018, and then an abrupt decrease in 2019.

KEYWORDS

Pacific saury, standardized CPUE, GLM, GAM, stick-held dip net

1. BACKGROUND of the PACIFIC SAURY FISHERY

Pacific saury (*Cololabis saira* Brevoort, 1856) exhibit a wide distribution and can be found in the subarctic and subtropical regions of the North Pacific Ocean, extending from the inshore waters of Japan and the Kuril Islands eastward to the Gulf of Alaska and southward to Mexico (TWG PSSA01, 2017). Pacific saury is a commercially important fish in the Northwestern Pacific Ocean (NWPO) (Hubbs and Wisner, 1980). Most Pacific saury are caught by the stick-held dip net fishery, which is made up of harvesting fleets from members of the North Pacific Fisheries Commission (NPFC), and only a small proportion of catches are acquired through the use of other gear, such as gill nets and set-nets (TWG PSSA01, 2017). There are six harvesting fleets, originating from Japan, Chinese Taipei, Russia, Korea, China, and Vanuatu, all of which are NPFC members. Based on the results of the Pacific saury stock assessment in early 2019, current stock biomass (B) was below Bmsy (average B/Bmsy from 2016-2018 = 0.82) and fishing mortality (F) was below Fmsy (average F/Fmsy from 2015-2017 = 0.82) (TWG PSSA04, 2019). Results indicate that the stock declined from near carrying capacity in the mid-2000s, a period of high productivity, to current levels. Exploitation rates increased moderately during this period but remained lower than Fmsy. Point estimates indicate that stock biomass fell to the lowest value since 1980 (B/Bmsy = 0.63) in 2017, then increased to Bmsy in 2018. Biomass estimates show long-term fluctuations and interannual variability. Due to the onset of the COVID-19 pandemic in early 2020, the TWG PSSA meetings could not be held as scheduled, and consequently the annual saury stock assessment could not be updated.

The Chinese Taipei saury fishery is a torch-light fishery which commenced in 1967 (Huang, 2007), and is a far-sea fishery with fishing grounds located mainly on the high-seas (Huang, 2010). Inter-annual variation of monthly fishing ground location of the Chinese Taipei stick-held dip net fishery from 2001 to 2019 is shown in **Fig. 1**. The stick-held dip net is the only type of fishing gear used by the Chinese Taipei saury fishery. The catch of the Chinese Taipei saury fishery increased dramatically from about 40,000 mt in 2001 to about 230,000 mt, the highest historical level, in 2014 (Huang et al., 2017). The current catch in 2019 was about 84,000 mt, which is less than half of the catch from 2018 (~ 180,000 mt).

The standardization of catch per unit effort (CPUE) of Pacific saury for various fleets operating in the NWPO was conducted for use as basic input data in stock assessments (TWG PSSA01, 2017). The stock assessments are based on the assumption of a single North Pacific-wide stock of Pacific saury, since there is no evidence of genetic structuring groups in this population (Chow et al., 2009). At the meeting of the TWG PSSA05 in NPFC, standardized CPUE of Pacific saury for the 2001-2018

Chinese Taipei stick-held dip net fishery showed a general oscillating trend with a slight increase observed from 2001-2010, followed by a sharp increase through to 2014, a sharp decline until 2017, and then a dramatic increase in 2018 (Huang et al., 2019). The objectives of this study were to use generalized linear models (GLMs) and generalized additive models (GAMs) to standardize the Pacific saury CPUE for the Chinese Taipei saury fishery in the NWPO using an updated dataset (2001-2019), and then to compare the results derived from these approaches.

2. MATERIALS and METHODS

2.1. Fishery data and water temperature

Data, collected from the Chinese Taipei saury fishery in the NWPO, included records of daily catch (weight of Pacific saury), fishing effort (number of hauls), and sea surface water temperature from 2001-2019. A thermometer equipped beneath the bottom of each vessel measured sea surface water temperature as fishing was underway. These data were obtained from the Overseas Fisheries Development Council (OFDC) which compiled data from logbooks. CPUE is expressed as the weight of fish in metric tons per haul (mt/haul). The data set used in this study contained 117,010 catch-effort records reported on a daily basis for each vessel. This data set is an updated version (includes 2019 data) of the data set used for the CPUE standardization in last year's assessment. Inter-annual variation of monthly fishing ground location of the Chinese Taipei stick-held dip net fishery from 2001 to 2019 is shown in **Fig. 1**.

2.2. Full model descriptions and model selection

Both GLMs and GAMs were used in this study to standardize the nominal CPUE for the Chinese Taipei saury fishery. Lognormal error distribution was assumed in the standardization. GLMs are the most commonly used approach for standardizing catch and effort data, assuming that the expected value of a transformed response variable is related to a linear combination of exploratory variables (Maunder and Punt, 2004). GAMs are a semi-parametric extension of GLMs with the underlying assumption that the response variable is related to smooth additive functions of the explanatory variables (Maunder and Punt, 2004).

Six items in four groups of possible explanatory variables were considered for CPUE standardization, including year and month for the temporal variable, latitude and longitude for the spatial variable, gross registered tonnage (*Grt*) for the fishing vessel size variable, and sea surface water temperature (*Sst*) for the environmental variable. Prior to fitting the GLMs/GAMs, correlation between the 6 possible explanatory variables and nominal CPUE was evaluated. The correlation matrix is shown in

Fig. 2.

The full models of GLMs and GAMs including interactions were expressed as follows:

GLM: *ln(CPUE) = Year +Month +Area +Sst-l +Grt-l +two-way IAs +IC +*$\mathcal{E}$

GAM: *ln(CPUE) = Year +Month +Area +s(Sst-c) +s(Grt-c) +two-way IAs +IC +*$\mathcal{E}$

where *Year* is a categorical variable from 2001 - 2019 (19 years), *Month* is a categorical variable with 6 calendar months from June to November, *Sst-l* is a categorical variable with 12 levels from 8-19 ^oC with an interval of 1 ^oC, *Sst-c* is a continuous variable from 8-19 ^oC, *Grt-l* is a categorical variable with 4 levels: 700 t, 800 t, 900 t, and > 1,000 t, *Grt-c* is a continuous variable from 700-1400 t, *Area* is a categorical variable with 4 regions based on bathymetric contours, *two-way IAs* are two-way interaction terms, *IC* is an intercept, and ε is an error term with $\varepsilon \sim N(0, \sigma^2)$. *s(X)* denotes a spline smoother function of the variable *X*. Month data from May and December were incorporated into June and November, respectively, because the data from May and December were limited. Definition of the 4 *Area* regions was modified based on Huang et al. (2007), which examined the geographical distribution of Pacific saury in the NWPO. The 4 regions used in our analyses are the continental shelf and slope area (CSS), abyssal plain area 1 (AP1) and abyssal plain area 2 (AP2), and the abyssal mountain area (AM). A summary of used explanatory variables in the GLM and GAM analyses is shown in **Table 1.**

Model assumptions followed the assumptions for GLMs and GAMs. Lognormal error distribution was assumed in the standardization. A forward stepwise approach was employed for the model selection. The improvement of each model that adds an additional predictor was examined using the changes in deviance explained and the proportions of deviance explained relative to the total explained deviance. In addition, since the maximum likelihood is employed for the parameter estimation, the Bayesian information criterion (BIC) was used to conduct objective model selection. Various diagnostic plots, including the distribution of residuals and the quantile-quantile plots (Q-Q plots), were used to assess the assumption of error distribution in the models and model fits for standardizing the nominal CPUE of Pacific saury in the NWPO. Five-fold cross-validation tests with the Pearson's correlation coefficients and mean squared errors (MSE) were conducted to compare prediction performances of the selected models in the GLM and GAM analyses.

2.3. Yearly trend extraction

The standardized CPUE and its standard deviation (SD) represent the estimates of the mean and SD of predictions from the suggested model, respectively. If the best model includes area and the size of spatial strata differs or the best model includes interactions between time and area, then standardized CPUE should be calculated with area weighting for each time step. The 2019 updated version of the checklist for the CPUE standardization protocol is shown in **Appendix I**.

3. RESULTS and DISCUSSION

This fishery operated mainly in the high seas of the NWPO during 2001-2019 and high fishing efforts aggregated in the south eastern portion of the boundary between the exclusive economic zones and high seas **(Appendix IIa)**. However, high CPUEs of Pacific saury appeared to be distributed mainly in the waters between 146-155 °E and 37-44 °N, and to a lesser degree between 160-164 °E and 36-40 °N **(Appendix IIb)**.

Most of the main explanatory variables used in the modeling analyses were statistically significant in the GLM and GAM (**Table 2**). In the GLM, all of the 5 main explanatory variables were significant (**Table 2a**). In the GAM, the main explanatory variable of *Grt* was not significant and as such was excluded, however, the interaction terms of *Grt* with *Sst* and *Month* were significant (**Table 2b**). The deviance explained and BIC in the best GLM and GAM are 33.72 % and 254878 **(Table 2a)**, and 34.4 % and 253260 **(Table 2b)**, respectively. Analysis of deviance for the best models of GLM and GAM is shown in **Table 3**. The Q-Q plot, histogram of residuals and residual plots across years for the best GLM and GAM indicated that the residual distributions from the GLM and GAM analyses appeared normal for both best models and confirmed the assumption of lognormal error distribution for both models used to standardize the CPUE (**Fig. 3**). Results of the 5-fold cross-validation tests indicated higher Pearson's correlation coefficients and lower mean squared error in the GAM than the GLM (**Appendix III**).

The standardized Pacific saury CPUE results derived from the GLM and GAM were remarkably similar, and the inclusion or omission of some explanatory variables and interaction terms did not affect this equivalency (**Figs. 4a and 4b**). In general, the standardized CPUE of Pacific saury for the Chinese Taipei saury fishing fleets showed a general oscillating trend with a slight increase observed from 2001-2010, followed by a sharp increase through to 2014, a sharp decline until 2017, a dramatic increase in 2018, and then an abrupt decrease in 2019 (**Fig. 4**). We suggest using the standardized CPUE series of Pacific saury derived from the GAM (**Table 4**), because this approach explained more deviance, had a lower BIC, and demonstrated better performance in the cross-validation tests than the GLM approach.

4. REFERENCES

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Table 1. Summary of explanatory variables used in the GLM and GAM analyses for Pacific saury CPUE standardization.

Variables	Abbreviation	Number of categories	Detail	Note
Year	*Year*	19	2001–2019	
Month	*Month*	6	June–November	
Fishing area	*Area*	6	CSS(I), AP1(II), AP2(III), AM(IV)	*see* Fig. 1
Vessel size	*Grt-l*	4	*Grt* < 800, 800≦*Grt* <900, 900≦*Grt* <1000, 1000≦*Grt*<1300	
	Grt-c	Continues (spline)		
Sea surface temperature	*Sst-l*	12	*Sst*(8)< 9°C, 9°≦ *Sst*(9) <10°C,…, 18°C≦ *Sst*(18)< 19°C, 19 ≦*Sst*(19)	at intervals of 1°C
	Sst-c	Continues (spline)		

Table 2. Results of model selection using an (a) GLM approach and (b) GAM approach for Pacific saury CPUE standardization.

(a) GLM

No.	GLM	Adj. R^2	Dev. expl. %	AIC	BIC
1	ln(CPUE) ~ IC + *Month*	0.141	14.1	281944	282012
2	ln(CPUE) ~ IC + *Month + Year*	0.234	23.4	268513	268755
3	ln(CPUE) ~ IC + *Month + Year + Grt-l*	0.247	24.7	266574	266845
4	ln(CPUE) ~ IC + *Month + Year + Grt-l + Area*	0.255	25.5	265372	265672
5	ln(CPUE) ~ IC + *Month + Year + Grt-l+ Area + Sst-l*	0.256	25.6	265224	265630
6	ln(CPUE) ~ IC + *Month + Year + Grt-l+ Area + Sst-l+ Month:Year*	0.312	31.3	256077	257326
7	ln(CPUE) ~ IC + *Month + Year + Grt-l+ Area + Sst-l+ Month: Year + Year:Area*	0.323	32.4	254307	255961
8	ln(CPUE) ~ IC + *Month + Year + Grt-l+ Area + Sst-l+ Month: Year + Year:Area + Year: Grt-l*	0.329	33.0	253228	255298
9	ln(CPUE) ~ IC + *Month + Year + Grt-l+ Area + Sst-l+ Month: Year + Year:Area + Year: Grt-l + Month: Sst-l*	0.334	33.5	252476	255067
10	**ln(CPUE) ~ IC + *Month + Year + Grt-l+ Area + Sst-l+ Month: Year + Year:Area + Year: Grt-l + Month: Sst-l +Month:Area***	**0.336**	**33.7**	**252151**	**254878**

IC: intercept

(b) GAM

No.	GAM	Adj. R^2	Dev. expl. %	AIC	BIC
1	ln(CPUE) ~ IC + *Month*	0.141	14.1	281944	282012
2	ln(CPUE) ~ IC + *Month + Year*	0.234	23.4	268513	268755
3	ln(CPUE) ~ IC + *Month + Year + s(Grt-c)*	0.253	25.3	265671	265999
4	ln(CPUE) ~ IC + *Month + Year + s(Grt-c)+ Area*	0.261	26.1	264369	264726
5	ln(CPUE) ~ IC + *Month + Year + s(Grt-c)+ Area + s(Sst-c)*	0.262	26.2	264202	264634
6	ln(CPUE) ~ IC + *Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year*	0.319	32.0	254870	256141
7	ln(CPUE) ~ IC + *Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area*	0.330	33.1	253067	254740
8	ln(CPUE) ~ IC + *Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c)*	0.337	33.8	251897	253771
9	ln(CPUE) ~ IC + *Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c) + s(Grt-c:Area)*	0.339	34.1	251409	253595
10	ln(CPUE) ~ IC + *Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c) + s(Grt-c:Area) + Month:Area*	0.341	34.3	251093	253417
11	**ln(CPUE) ~ IC + *Month + Year + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c) + s(Grt-c:Area) + Month:Area + s(Sst-c :Month)***	**0.343**	**34.4**	**250864**	**253260**

Table 3. Analysis of deviance table of the (a) GLM approach and (b) GAM approach for Pacific saury CPUE standardization.

(a) **GLM:** ln(CPUE) ~ IC + *Month* + *Year* + *Grt-l*+ *Area* + *Sst-l*+ *Month: Year* + *Year:Area* + *Year: Grt-l* + *Month: Sst-l* +*Month:Area* + ε

Parametric terms:

	SS	df	F	Pr(>F)	Signif. codes
Month	12506	5	4963.47	< 0.001	***
Year	8288	18	913.74	< 0.001	***
Grt-l	1120	3	740.83	< 0.001	***
Area	687	3	454.25	< 0.001	***
Sst-l	96	11	17.32	< 0.001	***
Month: Year	5056	87	115.33	< 0.001	***
Year: Area	959	42	45.33	< 0.001	***
Year: Grt-l	595	43	27.45	< 0.001	***
Month:Sst-l	436	54	16.01	< 0.001	***
Month: area	178	14	25.20	< 0.001	***

***, < 0.001; **, < 0.01; *, < 0.05

(b) **GAM:** ln(CPUE) ~ IC + *Month* + *Year* + *Area* + *s(Sst-c)* + *Month:Year* + *Year:Area* + *s(Grt-c, Sst-c)* + *s(Grt-c:Area)* + *Month:Area* + *s(Sst-c :Month)* + ε

Parametric terms:

	df	F	p-value	Signif. codes
Month	5	22.02	< 0.001	***
Year	18	46.57	< 0.001	***
Area	3	3.47	0.0154	*
Month:Year	90	81.14	< 0.001	***
Year:Area	49	47.51	< 0.001	***
Month:Area	15	23.15	< 0.001	***

***, < 0.001; **, < 0.01; *, < 0.05

Approximate significance of smooth terms:

	edf	Ref. df	F	p-value	Signif. codes
s(Sst-c)	8.80	8.88	20.62	< 0.001	***
s(Grt-c, Sst-c)	27.67	27.78	58.30	< 0.001	***
s(Grt-c):areaCSS	7.29	7.66	46.66	< 0.001	***
s(Grt-c):areaAP1	8.59	8.77	70.67	< 0.001	***
s(Grt-c):areaAP2	8.59	8.77	70.04	< 0.001	***
s(Grt-c):areaAM	8.80	8.80	69.62	< 0.001	***
s(Sst-c):Month	8.02	8.80	26.95	< 0.001	***

***, < 0.001; **, < 0.01; *, < 0.05

Table 4. Catch, number of nets, nominal CPUE, standardized CPUE and summary statistics from GLM and GAM analyses for the Chinese Taipei saury fishing vessels in the Northwestern Pacific Ocean from 2001-2019

Year	Nominal CPUE (mt/haul)	Standardized CPUE by GLM	SD by GLM	95% CI by GLM		Standardized CPUE by GAM	SD by GAM	95% CI by GAM	
				Lower	Upper			Lower	Upper
2001	2.38	1.48	0.03	1.43	1.54	1.58	0.03	1.53	1.64
2002	2.12	1.62	0.03	1.57	1.67	1.63	0.02	1.59	1.67
2003	2.62	2.76	0.06	2.65	2.88	2.68	0.06	2.58	2.80
2004	1.92	1.41	0.02	1.38	1.45	1.46	0.02	1.43	1.49
2005	2.27	2.56	0.05	2.48	2.65	2.40	0.04	2.31	2.48
2006	1.83	1.23	0.01	1.20	1.26	1.27	0.01	1.25	1.30
2007	2.65	2.40	0.04	2.33	2.50	2.36	0.04	2.29	2.44
2008	3.34	2.98	0.04	2.90	3.07	2.92	0.04	2.85	2.99
2009	1.90	1.57	0.02	1.53	1.62	1.58	0.02	1.54	1.63
2010	2.31	1.92	0.02	1.88	1.97	1.94	0.02	1.90	1.98
2011	2.90	2.51	0.03	2.46	2.58	2.51	0.03	2.46	2.57
2012	3.27	2.44	0.03	2.38	2.51	2.47	0.03	2.41	2.52
2013	3.69	2.98	0.04	2.91	3.06	2.80	0.03	2.75	2.86
2014	4.32	3.93	0.05	3.84	4.04	3.64	0.04	3.56	3.71
2015	4.08	2.31	0.05	2.23	2.43	2.44	0.05	2.36	2.54
2016	3.63	2.30	0.03	2.25	2.36	2.45	0.02	2.40	2.49
2017	2.37	1.98	0.03	1.92	2.05	1.85	0.02	1.80	1.89
2018	4.21	3.39	0.05	3.30	3.49	3.10	0.04	3.05	3.19
2019	2.09	1.32	0.02	1.29	1.36	1.41	0.01	1.39	1.44

Note: The formulas for the estimate the standardized CPUE in R were expressed as follows:

GLM: ln(CPUE) ~ IC + *Month* + *Year* + *Grt-l*+ *Area* + *Sst-l*+ *Month: Year* + *Year:Area* + *Year: Grt-l* + *Month: Sst-l* +*Month:Area*

GAM: ln(CPUE) ~ IC + *Month* + *Year* + *Area* + *s(Sst-c)* + *Month:Year* + *Year:Area* + *s(Grt-c, Sst-c)* + *s(Grt-c:Area)* + *Month:Area* + *s(Sst-c :Month)*

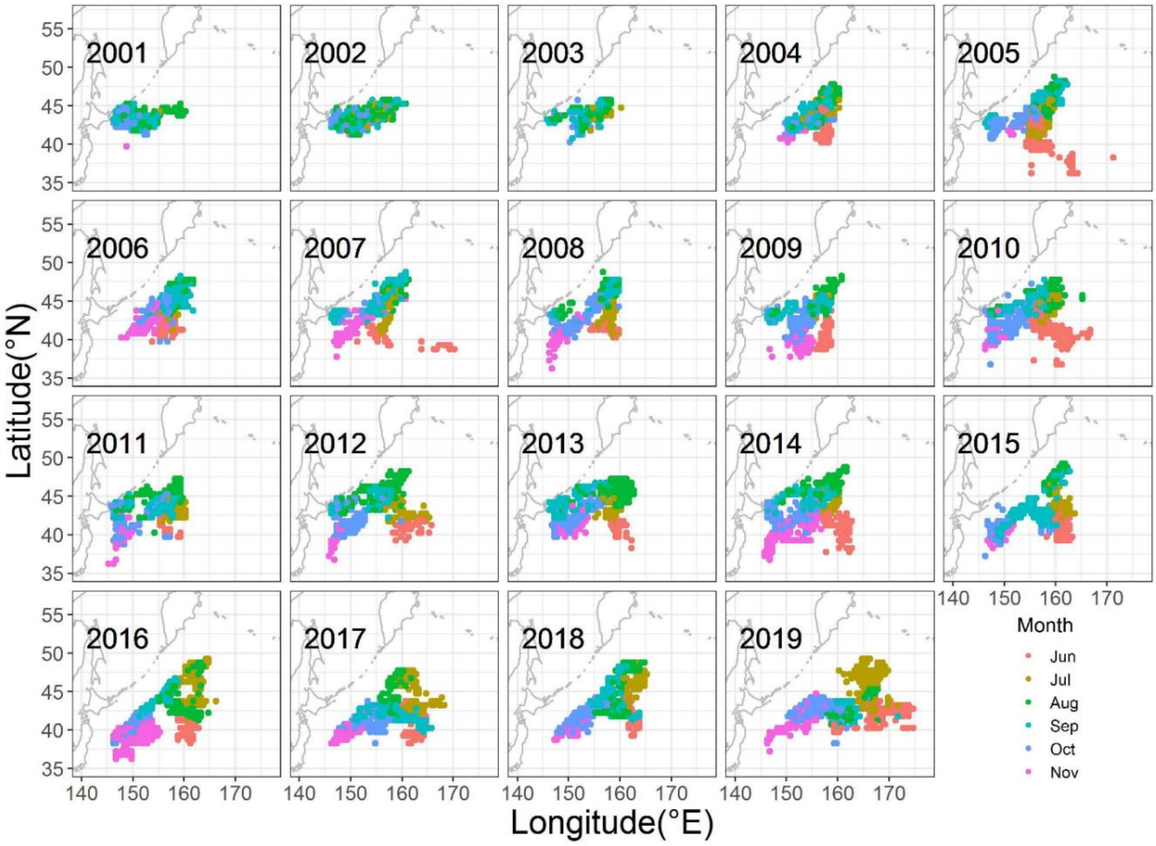


Fig. 1. Inter-annual variation of monthly fishing ground location of the Chinese Taipei stick-held dip net fishery for Pacific saury from 2001 to 2019.

Fig. 2. Correlation matrix of explanatory variables used in the GLM and GAM analyses for Pacific saury CPUE standardization.

(a) GLM (b) GAM

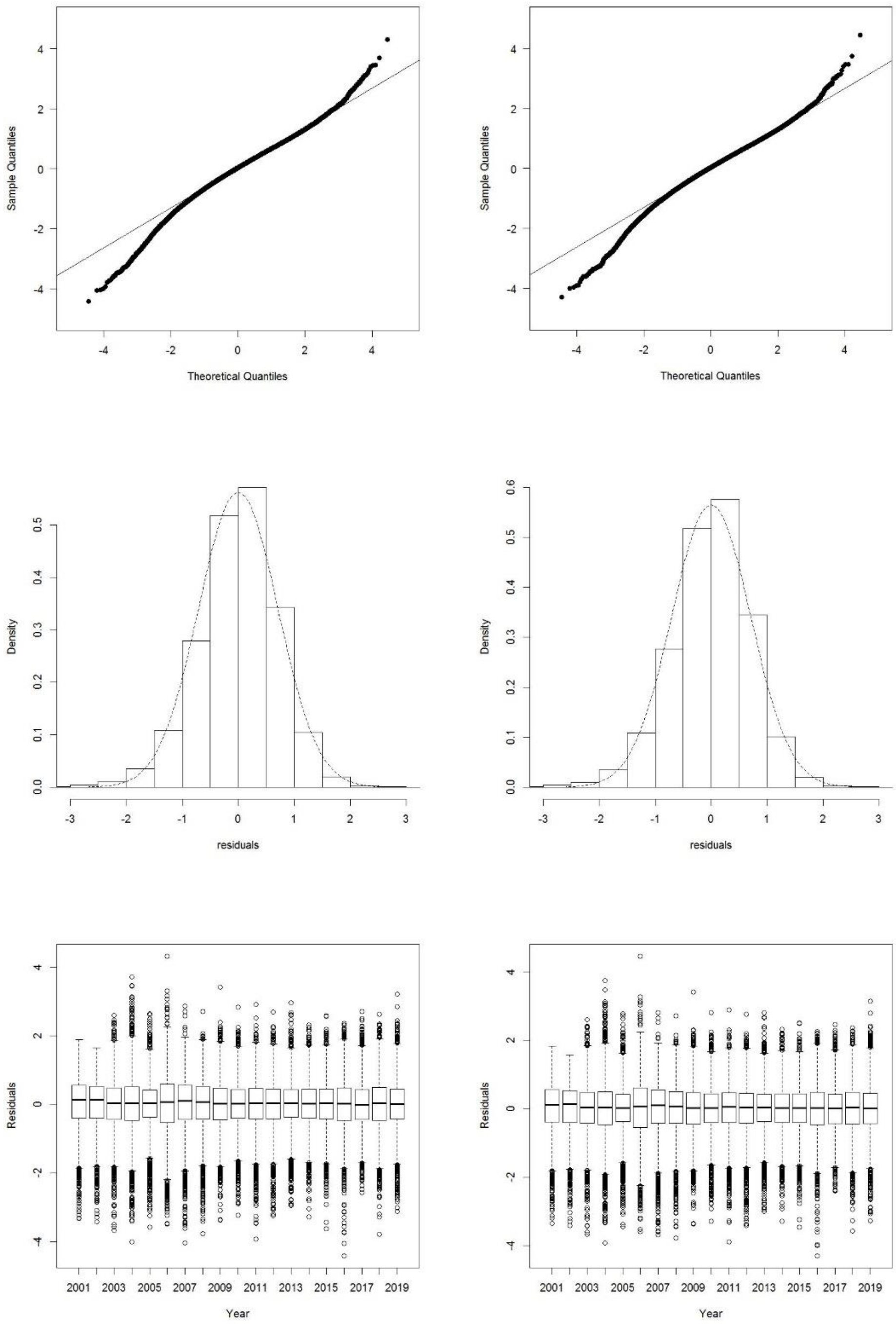


Fig. 3. Q-Q plots, histograms of residuals and residual plots across years for the best models from the (a) GLM and (b) GAM approaches.

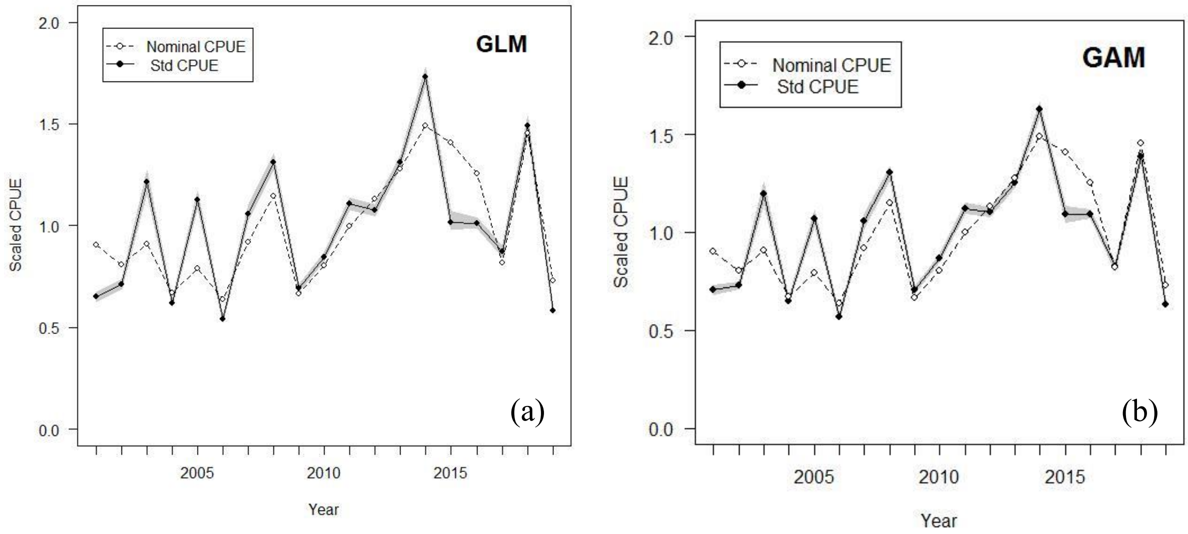


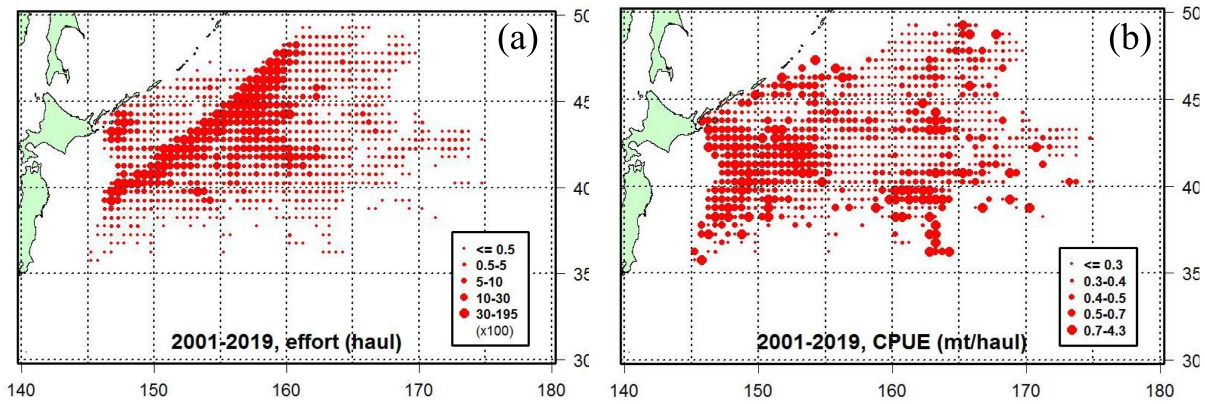
Fig. 4. A scaled nominal CPUE series (dashed line) and scaled standardized CPUE series (solid line) from the best models of the (a) GLM and (b) GAM approaches including catch and effort data up to 2019. Gray shading indicates the 95% confidence interval for the standardized CPUE.

APPENDICES.

Appendix I. Checklist for the CPUE standardization protocol

No.	Step-by-step protocols	yes/no	Note
1	Conduct a thorough literature review to identify key factors (i.e., spatial, temporal, environmental, and fisheries variables) that may influence CPUE values	yes	Tian et al. 2003, 2004 Huang et al. 2007, 2010 Tseng et al. 2011, 2013 TWG PSSA, 2018, 2019
2	Determine temporal and spatial scales for data grouping for CPUE standardization	yes	See 2.1 Fishery data and water temperature, page 3 & last paragraph, page 3 to first paragraph, page 4
3	Plot spatio-temporal distributions of fishing efforts and catch to evaluate spatio-temporal patterns of fishing effort and catch	yes	See Appendix II, page 14
4	Calculate correlation matrix to evaluate relationship between each pair of variables	yes	See Figure 2, page 10
5	Identify potential explanatory variables based on steps 1-4 as well as interaction terms to develop a full model for the CPUE standardization	yes	See 2.2 Statistical models, pages 3-4
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	See Table 2.3, page 7-8
7	Evaluate the models using methods such as likelihood ratio, AIC/BIC and cross-validation	yes	See 2.3 Model selection and diagnosis, page 4
8	Evaluate if distributional assumptions are satisfied and if there is a significant spatial/temporal pattern of residuals in CPUE standardization modeling	yes	See Figures 3, page 11
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 an area weighting for each time step. Models with interactions between area and season or month require careful consideration on a case by case basis	yes	See Figure 4(a)(b), page 12
10	Recommend a time series of yearly standardized CPUE and associated uncertainty	yes	
11	Plot nominal and standardized CPUEs over time	yes	
12	This protocol can be used for joint CPUE standardization	yes	

Appendix II. Distribution of (a) fishing effort (10^2 hauls) and (b) nominal CPUE (mt/haul) for the Chinese Taipei saury fishing fleets in the Northwestern Pacific Ocean from 2001-2019



Appendix III. Five-fold cross-validation for the selected model in the GLM and GAM analyses.

	GLM		GAM	
Case	r	MSE	r	MSE
1	0.5732	0.7186	0.5756	0.7101
2	0.5800	0.7143	0.5851	0.7066
3	0.5785	0.7045	0.5821	0.7075
4	0.5778	0.7127	0.5873	0.7034
5	0.5789	0.7042	0.5837	0.7109
Total	0.5807	0.7090	0.5865	0.7053

r: Pearson's correlation coefficient

MSE: Mean squared error