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Standardized CPUE of Pacific saury (*Cololabis saira*) caught by the Chinese Taipei stick-held dip net fishery up to 2020

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SUMMARY

The Pacific saury catch and effort data for the Chinese Taipei saury fishery in the Northwestern Pacific Ocean were collected from 2001-2020. 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 2020 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 saury 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 to 2020. We suggest using the standardized CPUE series derived from the GAM as basic input data in stock assessments.

KEYWORDS

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

1. BACKGROUND of the PACIFIC SAURY FISHERY

Pacific saury (*Cololabis saira* Brevoort, 1856) exhibits 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. Results of stock assessments in early 2021 indicated that the saury stock declined with an inter-annual variability from near carrying capacity in the mid-2000's after a period of high productivity to current levels (Scientific Committee, 2021). The results also indicated that stock biomass (B) was below B_{MSY} and fishing mortality (F) was above F_{MSY}. The saury stock biomass fell to the lowest value since 1980 in 2017 and has been still at a historically low level in recent years (2017-2019).

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 2020 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 2020 was about 57,000 mt, which is less than 1/3 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 were based on the assumption of a single North Pacific-wide stock of Pacific saury, since there was no evidence of genetic structuring groups in this population (Chow et al., 2009). At the meeting of the SSC PS06 in NPFC, standardized CPUE of Pacific saury for the 2001-2019 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, a dramatic increase in 2018, and then an abrupt decrease in 2019 (Huang et al., 2020). 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 (2001-2020), 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 2001-2020. 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 122,290 catch-effort records reported on a daily basis for each vessel. This data set is an updated version (includes 2020 data) of the data set used for the CPUE standardization in last year's assessment.

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, Spearman correlation coefficient among explanatory variables were calculated. In addition, variance inflation factor (VIF) was employed to measure the amount of multi-collinearity among the independent variables in models.

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

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

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

where *Year* is a categorical variable from 2001 - 2020 (20 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) **(Fig. 2)**. 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 was 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 2020 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 2001-2020 and high fishing efforts aggregated in the south eastern portion of the boundary between the exclusive economic zones and high seas **(Fig. 3a)**. 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 **(Fig. 3b)**.

All Spearman's correlation coefficients between each pair of variables used in the model were significant (p < 0.001) **(Fig. 4, Table 2)**. All variance inflation factors (VIFs) were less than 3, indicating that there was no serious multi-collinearity among the independent variables in models **(Table 2)**.

All of the main explanatory variables used in the modeling analyses were statistically significant in the GLM and GAM (**Table 3**). The deviance explained and BIC in the best GLM and GAM are 36.1 % and 267086 **(Table 3a)**, and 36.5 % and 265391 **(Table 3b)**, respectively. Analysis of deviance for the best models of GLM and GAM is shown in **Table 4**. 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. 5**). 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 (**Table 5**).

The standardized Pacific saury CPUE results derived from the GLM and GAM were remarkably similar, and the inclusion or omission of some interaction terms did not affect this equivalency (**Figs. 6a and 6b**). 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 to 2020 (**Fig. 6**). We suggest using the standardized CPUE series of Pacific saury derived from the GAM as basic input data in stock assessments (**Table 6**), 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

Chow S, Suzuki N, Brodeur RD, Ueno Y (2009) Little population structuring and recent evolution of the Pacific saury (*Cololabis saira*) as indicated by mitochondrial and nuclear DNA sequence data. *J Exp Mar Biol Ecol* 369:17-21.

Huang WB (2007) Body length, weight, and condition factor of Pacific saury (*Cololabis saira*) from the landed size-classes of Taiwanese catch in comparison with Japanese statistics. *J Fish Soc Taiwan* 34(4): 361-368.

Huang WB (2010) Comparisons of monthly and geographical variations in abundance and size composition of Pacific saury between the high-seas and coastal fishing grounds in the Northwestern Pacific. *Fish Sci* 76(1): 21-31.

Huang WB, Chang YJ, Hsieh CH (2017) Summary of CPUE standardization report from Chinese Taipei. NPFC-2017-TWG PSSA01-WP04. 4 pp.

Huang WB, Chang YJ, Hsieh CH (2020) Standardized CPUE of Pacific saury (*Cololabis saira*) caught by the Chinese Taipei stick-held dip net fishery up to 2019. NPFC-2020-SSC PS06-WP05. 14 pp.

Huang WB, Lo NCH, Chiu TS, Chen CS (2007) Geographical distribution and abundance of Pacific saury fishing stock in the Northwestern Pacific in relation to sea temperature. *Zool Stud* 46(6): 705-716

Hubbs CL, Wisner RL (1980) Revision of the sauries (Pisces, Scomberesocidae) with descriptions of two new genera and one new species. *Fish Bull US* 77:521–566.

Maunder MN, Punt AE (2004) Standardizing catch and effort data: A review of recent approaches. *Fish Res* 70: 141-159.

Scientific Committee (2021) 1st Special Meeting Report. NPFC-2021-SCsm01-Final Report. 47 pp. (Available at www.npfc.int)

TWG PSSA01 (1st Meeting of the Technical Working Group on Pacific Saury Stock Assessment) (2017) 1st Meeting Report. NPFC-2017-TWG PSSA01-Final Report. 120 pp. (Available at www.npfc.int)

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*	20	2001–2020	
Month	*Month*	6	June–November	
Fishing area	*Area*	6	CSS(I), AP1(II), AP2(III), AM(IV)	*see* Fig. 2
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. Spearman correlation coefficient and variance inflation factor (VIF) among explanatory variables.

	Coefficient \ *p* value						VIF
	Year	**Month**	**Grt**	**Long.**	**Lat.**	**SST**	
Year		<0.001	<0.001	<0.001	<0.001	<0.001	1.59
Month	0.08		<0.001	<0.001	<0.001	<0.001	2.18
Grt	0.44	0.10		<0.001	<0.001	<0.001	1.26
Long.	0.20	-0.69	0.10		<0.001	<0.001	2.96
Lat.	-0.17	-0.46	-0.07	0.57		<0.001	1.74
SST	0.26	0.20	0.13	-0.12	-0.23		1.13

Spearman correlation coefficients are under the slope line; *p* values are above the slope line.

Table 3. Results of model selection using an (a) GLM approach and (b) GAM approach for Pacific saury CPUE standardization.

(a) GLM

No.	GLM model	BIC	Explained deviance (%)	R^2
1	ln(CPUE) ~ *IC+ Month*	301108	13.2	0.1316
2	ln(CPUE) ~ *IC+ Month + Year*	283498	25.0	0.2495
3	ln(CPUE) ~ *IC+ Month + Year + Grt-l*	281546	26.2	0.2616
4	ln(CPUE) ~ *IC+ Month + Year + Grt-l + Area*	280070	27.1	0.2706
5	ln(CPUE) ~ *IC+ Month + Year + Grt-l + Area + Sst-l*	279766	27.3	0.2732
6	ln(CPUE) ~ *IC+ Month + Year + Grt-l + Area + Sst-l + Month: Year*	269608	33.7	0.3372
7	ln(CPUE) ~ *IC+ Month + Year + Grt-l + Area + Sst-l + Month: Year + Year:Area*	268096	34.8	0.3481
8	ln(CPUE) ~ *IC+ Month + Year + Grt-l + Area + Sst-l + Month: Year + Year:Area + Year: Grt-l*	267338	35.5	0.3550
9	ln(CPUE) ~ *IC+ Month + Year + Grt-l + Area + Sst-l + Month: Year + Year:Area + Year: Grt-l + Month: Sst-l*	267166	35.9	0.3592
10	**ln(CPUE) ~ *IC+ Month + Year + Grt-l + Area + Sst-l + Month: Year + Year:Area + Year: Grt-l + Month: Sst-l+ Month:Area***	**267086**	**36.1**	**0.3605**

IC: intercept

(b) GAM

No.	GAM model	BIC	Explained deviance (%)	R^2
1	ln(CPUE) ~ *IC+ Month*	301108	13.2	0.1317
2	ln(CPUE) ~ *IC+ Month + Year*	283498	24.9	0.2495
3	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c)*	280545	26.8	0.2680
4	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area*	278967	27.8	0.2776
5	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area + s(Sst-c)*	278612	28.0	0.2802
6	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year*	268202	34.5	0.3447
7	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area*	266663	35.6	0.3556
8	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c)*	265518	36.3	0.3629
9	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c) + s(Sst-c:Month)*	265425	36.4	0.3638
10	ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c) + s(Sst-c:Month) + Month:Area*	265404	36.5	0.3648
11	**ln(CPUE) ~ *IC+ Month + Year + s(Grt-c) + Area + s(Sst-c) + Month:Year + Year:Area + s(Grt-c, Sst-c) + s(Sst-c:Month) + Month:Area + s(Grt-c:Area)***	**265391**	**36.5**	**0.3651**

Table 4. 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	12726	5	5022.65	< 0.001	***
Year	11389	19	1182.96	< 0.001	***
Grt-l	1170	3	769.34	< 0.001	***
Area	876	3	576.40	< 0.001	***
Sst-l	250	11	44.77	< 0.001	***
Month:Year	6179	94	129.73	< 0.001	***
Year:Area	1054	44	47.25	< 0.001	***
Year:Grt-l	665	46	28.52	< 0.001	***
Month:Sst-l	409	54	14.95	< 0.001	***
Month:area	129	15	17.03	< 0.001	***

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

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

Parametric terms:

	df	F	*p*-value	Signif. codes
Month	5	24.91	< 0.001	***
Year	19	47.41	< 0.001	***
Area	3	3.25	0.021	*
Month:Year	95	89.88	< 0.001	***
Year:Area	52	48.11	< 0.001	***
Month:Area	15	26.87	< 0.001	***

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

Approximate significance of smooth terms:

	edf	Ref. df	F	*p*-value	Signif. codes
s(Grt-c)	3.95	4.37	12.44	< 0.001	***
s(Sst-c)	8.01	8.41	16.12	< 0.001	***
s(Grt-c, Sst-c)	24.66	27.00	31.68	< 0.001	***
s(Sst-c):Month	8.79	9.27	18.73	< 0.001	***
s(Grt-c):area	4.09	4.85	8.01	< 0.001	***

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

Table 5. Five-fold cross-validation for the selected model in the GLM and GAM analyses.

	GLM		GAM	
Case	r	MSE	r	MSE
1	0.6034	0.7112	0.6054	0.7046
2	0.5975	0.7207	0.6028	0.7081
3	0.5931	0.7105	0.5981	0.7118
4	0.5998	0.7117	0.6024	0.7078
5	0.5930	0.7109	0.6014	0.7173
Average	0.5974	0.7130	0.6020	0.7099

r, Pearson's correlation coefficient

MSE, Mean squared error

Table 6. Nominal CPUE, standardized CPUE and summary statistics from GLM and GAM approaches for the Chinese Taipei saury fishing vessels in the Northwestern Pacific Ocean from 2001-2020.

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	**1.57**	**0.03**	1.52	1.62
2002	2.12	1.62	0.03	1.57	1.67	**1.63**	**0.02**	1.59	1.67
2003	2.62	2.83	0.07	2.71	2.97	**2.67**	**0.05**	2.57	2.78
2004	1.92	1.41	0.02	1.38	1.45	**1.45**	**0.02**	1.42	1.49
2005	2.27	2.55	0.05	2.47	2.65	**2.39**	**0.04**	2.31	2.47
2006	1.83	1.23	0.01	1.20	1.26	**1.27**	**0.01**	1.25	1.30
2007	2.65	2.41	0.04	2.33	2.49	**2.37**	**0.04**	2.30	2.46
2008	3.34	2.97	0.05	2.90	3.08	**2.91**	**0.04**	2.84	2.98
2009	1.90	1.57	0.02	1.53	1.61	**1.57**	**0.02**	1.53	1.61
2010	2.31	1.91	0.03	1.87	1.97	**1.94**	**0.02**	1.90	1.97
2011	2.90	2.51	0.03	2.45	2.58	**2.51**	**0.03**	2.46	2.57
2012	3.27	2.44	0.03	2.37	2.50	**2.47**	**0.03**	2.42	2.52
2013	3.69	2.97	0.04	2.90	3.05	**2.79**	**0.03**	2.74	2.85
2014	4.32	3.93	0.05	3.84	4.04	**3.63**	**0.04**	3.56	3.70
2015	4.08	2.31	0.05	2.23	2.45	**2.42**	**0.04**	2.35	2.52
2016	3.63	2.30	0.03	2.24	2.36	**2.43**	**0.02**	2.39	2.48
2017	2.37	1.98	0.03	1.93	2.04	**1.83**	**0.02**	1.79	1.87
2018	4.21	3.40	0.05	3.30	3.50	**3.09**	**0.04**	3.02	3.16
2019	2.09	1.36	0.02	1.33	1.40	**1.41**	**0.01**	1.38	1.44
2020	1.83	1.08	0.02	1.05	1.11	**1.24**	**0.01**	1.21	1.27

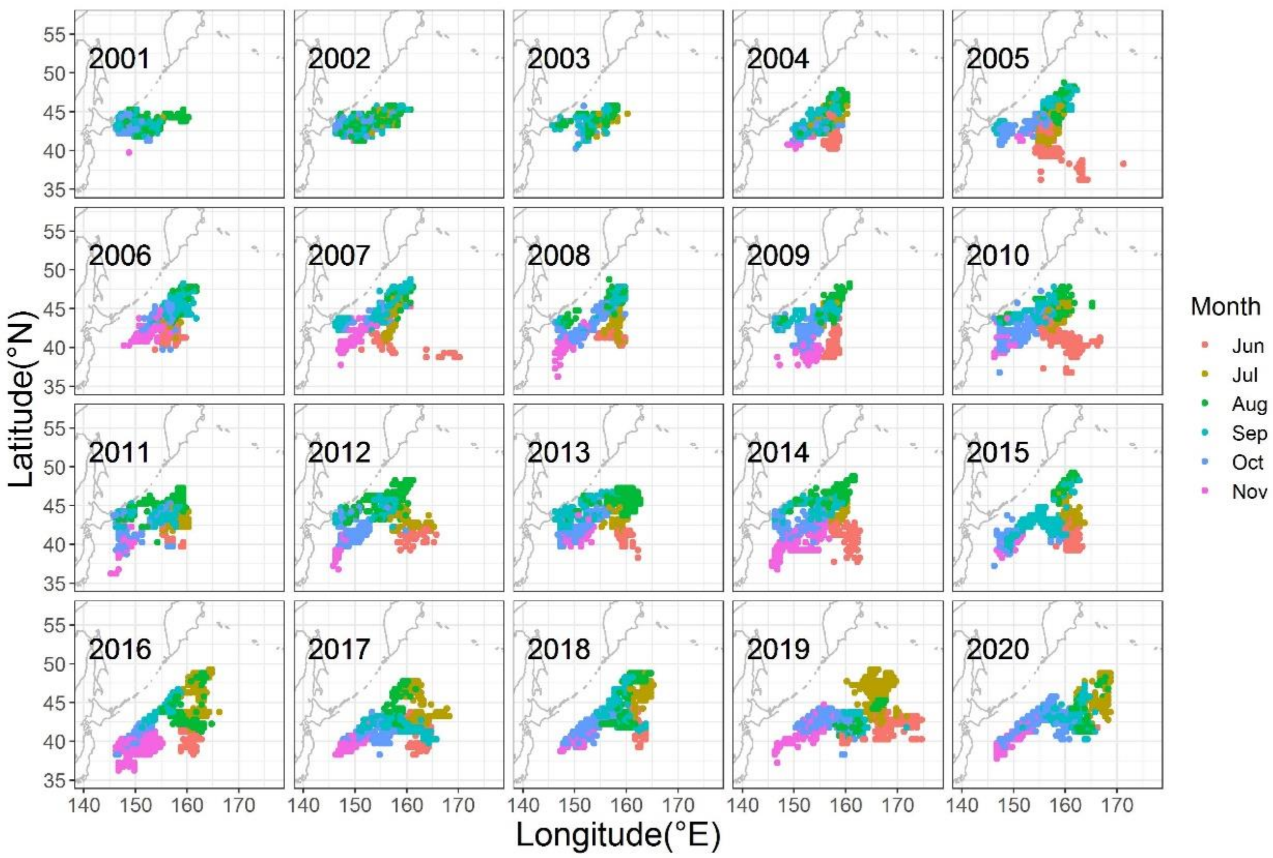

Fig. 1. Annual changes in monthly fishing grounds of Chinese Taipei stick-held dip net fishery for Pacific saury from 2001 to 2020.

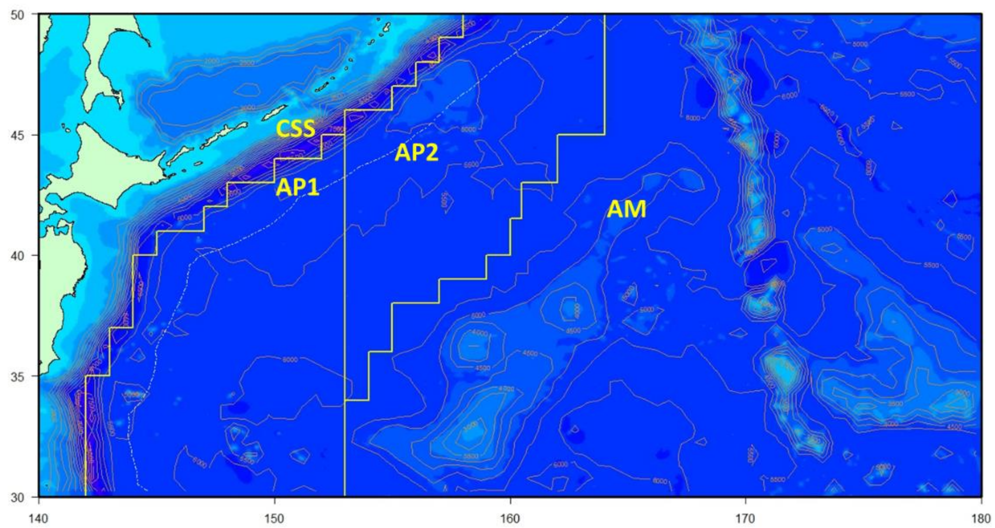

Fig. 2. Definition of four geographic regions based on bathymetric contours and Pacific saury aggregations (modified from Huang et al. (2007)). CSS, continental shelf and slop area; AP1, abyssal plain area 1; AP2, abyssal plain area 2; and AM, abyssal mountain area.

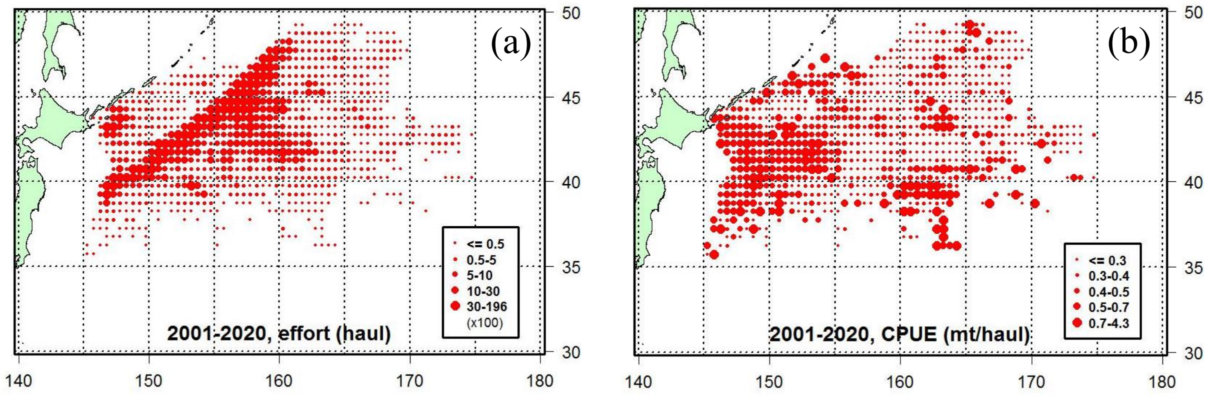

Fig. 3. Distribution of (a) fishing effort (10^2 hauls) and (b) nominal CPUE (mt/haul) for the Chinese Taipei saury fishing fleets in the Northwestern Pacific Ocean from 2001-2020.

Fig. 4. Correlation matrix of explanatory variables used in the GLM and GAM analyses for Pacific saury CPUE standardization.

(a) GLM (b) GAM

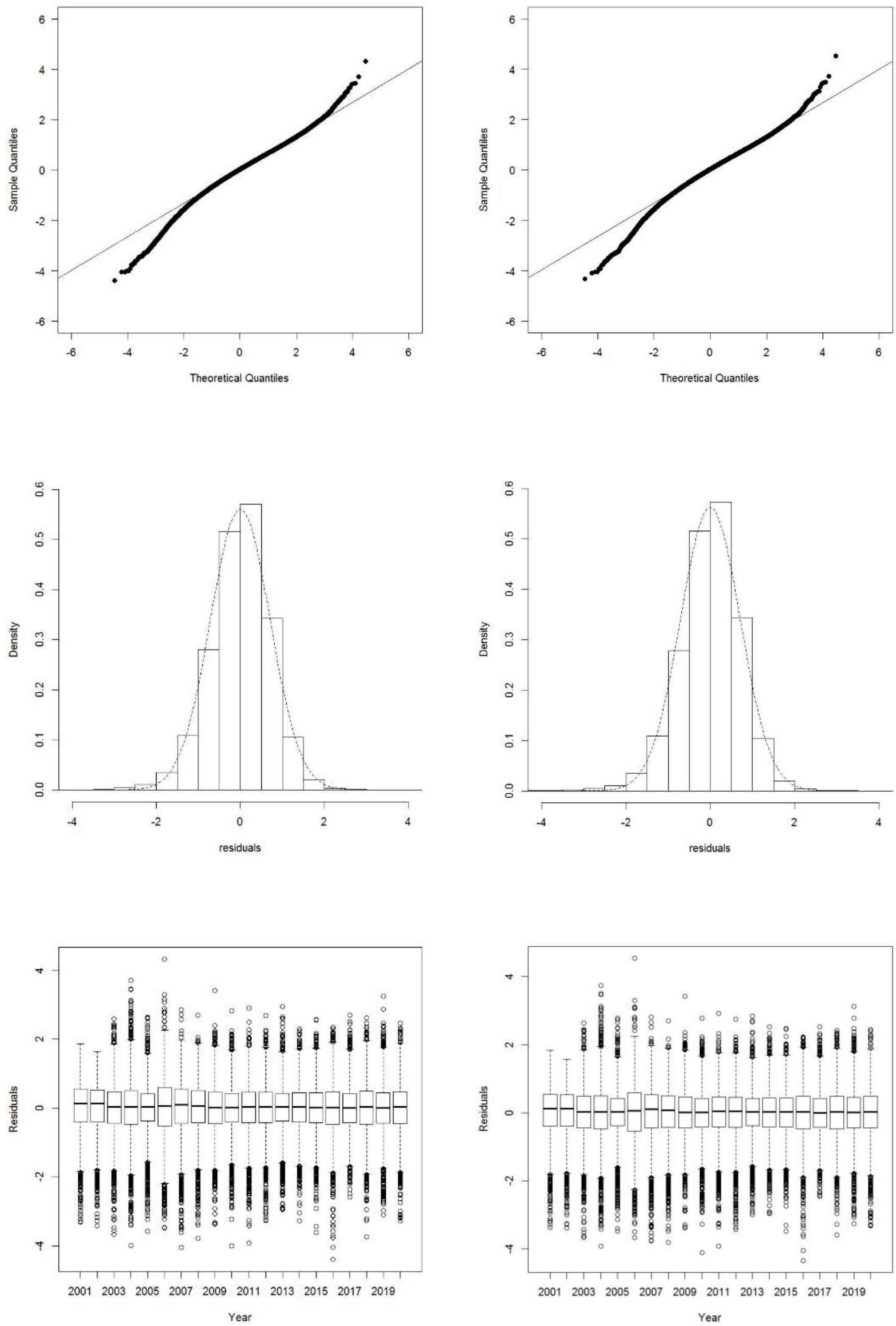

Fig. 5. Q-Q plots, histograms of residuals and residual plots across years for the best models from the (a) GLM and (b) GAM approaches.

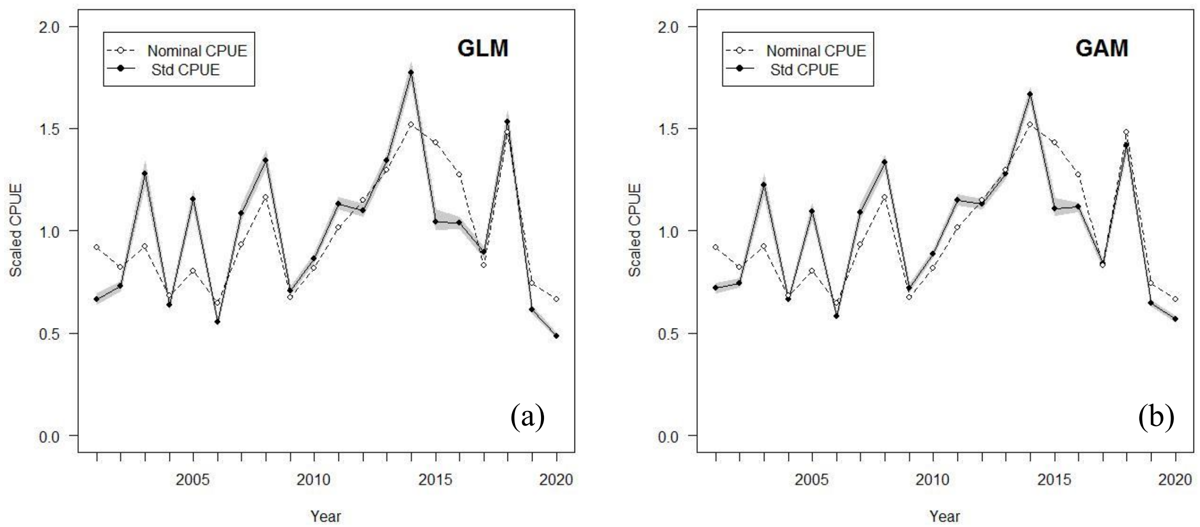

Fig. 6. A scaled nominal CPUE series (dashed line) and scaled standardized CPUE series (solid line) from the best models of the (a) GLM and (b) GAM approaches from 2001 to 2020. Gray shading indicates the 95% confidence interval for the standardized CPUE.

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*, p. 3 & *2.2. Full model descriptions and model selection*, 2nd last par., p. 3 to 1st par., p. 4
3	Plot spatio-temporal distributions of fishing efforts and catch to evaluate spatio-temporal patterns of fishing effort and catch	yes	See Fig. 3, p. 13
4	Calculate correlation matrix to evaluate relationship between each pair of variables	yes	See Fig. 4, p. 13
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. Full model descriptions and model selection*, 2nd last paragraph, p. 3 to 1st par., p. 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 Tables 3 & 4, p. 8-9
7	Evaluate the models using methods such as likelihood ratio, AIC/BIC and cross-validation	yes	See *2.2. Full model descriptions and model selection*, 2nd par., p. 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 Fig. 5, p. 14
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 *2.3. Yearly trend extraction*, p. 4
10	Recommend a time series of yearly standardized CPUE and associated uncertainty	yes	See Table 6, GAM, p. 11
11	Plot nominal and standardized CPUEs over time	yes	See Fig. 6, p. 15