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CPUE standardization of Pacific saury (*Cololabis saira*) for the Chinese Taipei's stick-held dip net fishery in the Northwestern Pacific Ocean from 2001-2018

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SUMMARY

The catch and effort data of Pacific saury for the Chinese Taipei's stick-held dip net fishery in the Northwestern Pacific Ocean were collected from 2001 - 2018. Two alternative approaches, generalized linear models (GLMs) and generalized additive models (GAMs), were applied 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 2018 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's 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, and then a dramatic increase in 2018.

KEYWORDS

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

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1. Introduction

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 2019, current stock biomass (B) was below Bmsy (average B/Bmsy during 2016-2018 = 0.82) and fishing mortality (F) was below Fmsy (average F/Fmsy during 2015-2017 = 0.82) (TWG PSSA04, 2019). Results indicate that the stock declined from near carrying capacity in the mid-2000's after a period of high productivity to current levels. Exploitation rates were increasing slowly 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.

The Chinese Taipei's saury fishery is a torch-light fishery which commenced in 1967 (Huang, 2007), and it is a far-sea fishery with fishing grounds located mainly on the high-seas (Huang, 2010). The stick-held dip net is the only type of fishing gear used by the Chinese Taipei's saury fishery. The catch of the Chinese Taipei's 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), and the current catch in 2018 was about 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, based on the findings of no genetic structuring groups in this population (Chow et al., 2009). In the meeting of the TWG PSSA03 in NPFC, standardized CPUE of Pacific saury for the 2001 - 2017 Chinese Taipei's stick-held dip net fishery in the NWPO showed a general oscillating trend with a slight increase observed from 2001 - 2010, followed by a sharp increase through to 2014, and then a sharp decline until 2017 (Huang et al., 2018). 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's saury fishery in the NWPO using an updated dataset (2001 - 2018), 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's saury fishery in the NWPO, included records of daily catch (weight of Pacific saury), fishing effort (number of hauls), and sea surface water temperature (WT) from 2001 - 2018. A thermometer was equipped beneath the bottom of each vessel to measure WT 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 110,291 catch-effort records on a daily basis for each vessel. This data set is an updated version (includes 2018 data) of the data set used for the CPUE standardization in last year's assessment.

2.2 Statistical model

Both GLMs and GAMs were used in this study to standardize the nominal CPUE for the Chinese Taipei's 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 (WT) 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 **Figure 1**.

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

GLM: *ln(CPUE) = Year +Month +Area +WT-l +Grt-l +two-way IAs +IC +ℰ*

GAM: *ln(CPUE) = Year +Month +Area +s(WT-c) +s(Grt-c) +two-way IAs +IC +ℰ*

where *Year* is a categorical variable from 2001 - 2018 (18 years), *Month* is a categorical variable with 6 calendar months from June to November, *WT-l* is a categorical variable with 12 levels from 8 - 19 ºC with an interval of 1 ºC, *WT-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 ε~ N (0, σ^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 scarce. 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 GLM and GAM analyses is shown in **Table 1.** The standardized CPUE and its standard error (SE) represent the estimates of the mean and SE of predictions from the suggested model, respectively.

2.3 Model selection and diagnosis

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, as indicated by R^2. 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 (lognormal distribution was assumed in this study) 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.

3. Results and discussion

This fishery operated mainly in the high seas of the NWPO during 2001 - 2018 and high fishing efforts aggregated in the south eastern portion of the boundary between the EEZs and high seas (**Figure 2**). However, high CPUEs of Pacific saury appeared to be distributed mainly in the waters between 146 - 153 °E and 37 - 44 °N, and to a lesser degree between 160 - 164 °E and 36 - 40 °N (**Figure 3**). The residual distributions from the GLM and GAM analyses appeared normal for both models (**Figure 4**). The Q-Q plots also confirmed the assumption of lognormal error distribution for both models used to standardize the CPUE (**Figure 5**).

Most of the main explanatory variables used in the modeling analyses were statistically significant in the GLM and GAM (**Table 2**). In the GLM, the main explanatory variable of WT and its interaction terms were not significant and were excluded (**Table 2(a)**). In the GAM, the main explanatory variables of WT and Area were not significant and as such were excluded, however, their interaction terms were significant (**Table 2(B)**). The R^2 and BIC in the GLM and GAM are 0.3355 and 235946, and 0.3450 and 234399, respectively (Table 1). Results of the 5-fold cross validation tests indicated higher Pearson's correlation coefficients and lower mean squared error were found in the GAM than those in the GLM (**Table 3**).

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 (**Figure 6**). In general, the standardized CPUE of Pacific saury for Chinese Taipei's saury fishing fleets showed a general oscillating trend with a slight increase observed from 2001 - 2010, followed by a sharp increase through to 2014 and in reverse a sharp decline until 2017, and then a dramatic increase in 2018 (**Figure 6**). We suggest using the standardized CPUE series of Pacific saury derived from the GAM (**Table 4**), because more explained deviance, lower BIC, and better performance in the cross validation test were found in the GAM than those in the GLM.

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Table 1. Summary of used explanatory variables in GLM and GAM analyses.

Variables	Cases	Categorical or continuous	Detail
Year	Year	18 Categories	18 years from 2001 to 2018
Month	Month	6 Categories	6 months from June to November
Area	Area	4 Categories	CSS(I), AP1(II), AP2(III), AM(IV)
Vessel tonnage	Grt_I	4 Categories	Grt < 800, 800≦Grt <900, 900≦Grt<1000, 1000≦Grt<1300
	Grt_c	Continues (spline)	
Sea surface temperature	WT_I	12 Categories	8°C≦WT <9°C, 8°C≦WT <9°C, …, 18°C≦WT <19°C, (at intervals of 1°C)
	WT_c	Continues (spline)	

Table 2. Results for the models selected to standardize the catch and effort data of the Taiwanese saury fishery from 2001 - 2018 using generalized linear model (GLM) and generalized additive model (GAM).

(a) GLM

Best GLM selected based on BIC and R^2 values

Best model in GLM analysis	AIC	BIC	% deviance explained
ln(CPUE) ~ IC + Month + Year + Grt_I + Area + Month:year + Year:Area + Year:Grt_I + Month:Area +ε	233986	235946	33.55

Parametric Terms:

	SS	Df	F	p-value	Signif. codes
Month	12288	5	5027.21	<0.001	***
Year	6999	17	842.18	<0.001	***
Grt_I	1019	3	694.70	<0.001	***
Area	673	3	459.19	<0.001	***
Month: Year	4511	82	112.53	<0.001	***
Year: Area	928	40	47.434	<0.001	***
Year: Grt_I	565	40	28.91	<0.001	***
Month: area	159	12	27.08	<0.001	***

Residuals 53754 109956

Signif. codes: ***, < 0.001; **, < 0.01; *, 0.05

(b) GAM

Best GAM selected based on BIC and R^2 values

Best model in GAM analysis	AIC	BIC	% deviance explained
ln(CPUE) ~ IC + Month + Year + s(Grt_c) + Year:Month + Year:Area + s(Grt_c:WT_c) + s(WT_c:Area) + Month:Area + s(Grt_c:Year) +ε	232353	234399	34.5

Parametric Terms:

	df	F	p-value	Signif. codes
Month	5	20.94	<0.001	***
Year	17	40.35	<0.001	***
Year:Month	85	84.18	<0.001	***
Year:Area	48	40.78	<0.001	***
Month:Area	14	28.59	<0.001	***

Approximate significance of smooth terms:

	edf	Ref. df	F	p-value	Signif. codes
s(Grt_c)	5.04	5.19	4.94	<0.001	***
s(Grt_c, WT_c)	22.17	23.24	44.03	<0.001	***
s(WT_c):Area I	3.47	4.37	5.17	<0.001	***
s(WT_c):Area II	4.35	5.38	24.23	<0.001	***
s(WT_c):Area III	5.55	6.63	10.59	<0.001	***
s(WT_c):Area IV	8.53	8.78	6.14	<0.001	***
s(Grt_c):Year	3.80	3.96	6.27	<0.001	***

Signif. codes: ***, < 0.001; **, < 0.01; *, 0.05

R-sq.(adj) = 0.344, Deviance explained = 34.5%, n = 110159

Table 3. Five-fold cross validation for the selected model in GLM and GAM analyses.

	GLM		GAM	
Case	r	MSE	r	MSE
1	0.5753	0.7039	0.5870	0.6921
2	0.5801	0.6964	0.5826	0.6976
3	0.5729	0.7021	0.5870	0.6993
4	0.5772	0.7022	0.5875	0.6909
5	0.5771	0.6964	0.5827	0.6942
Total	0.5792	0.6985	0.5877	0.6933

r: Pearson's correlation coefficient

MSE: Mean squared error

Table 4. Catch, number of nets, nominal CPUE, and standardized CPUE and its related statistics from GLM and GAM analyses for Taiwanese saury fishing vessels in the Northwestern Pacific Ocean from 2001 – 2018.

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	1.78	0.31	1.76	1.81	1.79	0.37	1.76	1.82
2002	2.12	1.59	0.43	1.56	1.62	1.59	0.45	1.57	1.62
2003	2.62	2.29	1.07	2.23	2.35	2.29	1.06	2.23	2.35
2004	1.92	1.57	0.79	1.53	1.62	1.57	0.79	1.53	1.62
2005	2.27	1.93	0.81	1.90	1.97	1.93	0.79	1.89	1.97
2006	1.83	1.34	0.26	1.32	1.35	1.34	0.29	1.33	1.36
2007	2.65	2.12	1.04	2.06	2.17	2.12	1.06	2.07	2.18
2008	3.34	2.71	0.91	2.67	2.75	2.73	0.97	2.68	2.77
2009	1.90	1.46	0.52	1.43	1.48	1.46	0.53	1.44	1.48
2010	2.31	1.88	0.57	1.85	1.90	1.89	0.62	1.86	1.91
2011	2.90	2.34	0.75	2.30	2.37	2.35	0.80	2.32	2.39
2012	3.27	2.65	0.73	2.61	2.68	2.66	0.78	2.62	2.69
2013	3.69	3.06	1.29	3.00	3.12	3.05	1.24	3.00	3.11
2014	4.32	3.54	1.38	3.47	3.60	3.55	1.42	3.49	3.61
2015	4.08	3.27	1.81	3.18	3.36	3.29	1.86	3.19	3.38
2016	3.63	2.75	1.18	2.70	2.81	2.77	1.25	2.71	2.83
2017	2.37	1.85	0.72	1.81	1.88	1.86	0.78	1.83	1.90
2018	4.21	3.26	2.13	3.15	3.36	3.26	2.15	3.15	3.36

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

GLM: ln(CPUE) ~ IC + Month + Year + Grt_I + Area + Month:year + Year:Area + Year:Grt_I + Month:Area +ε

GAM: ln(CPUE) ~ IC + Month + Year + s(Grt_c) + Year:Month + Year:Area + s(Grt_c:WT_c) + s(WT_c:Area) + Month:Area + s(Grt_c:Year) +ε

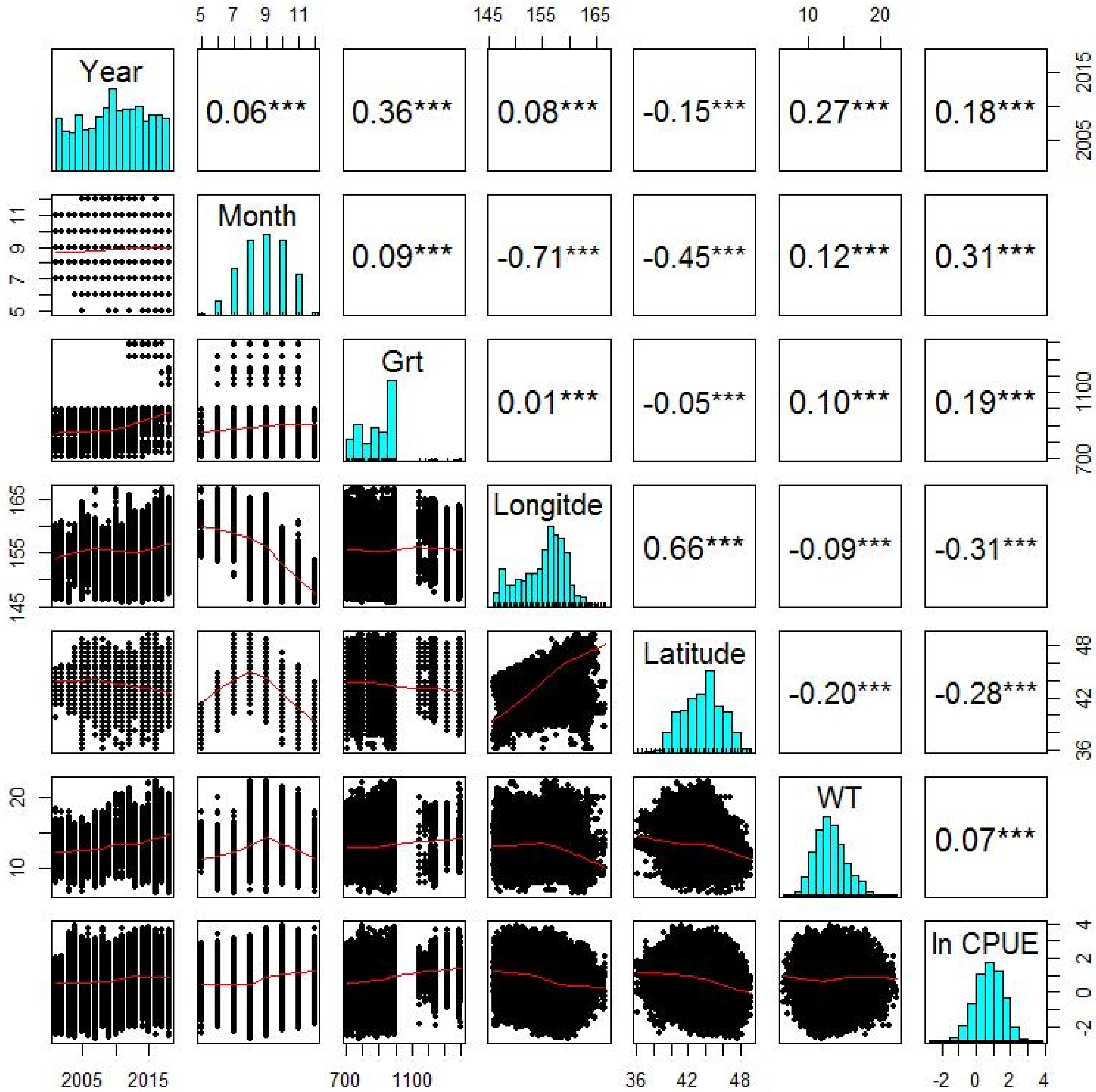

Figure 1. Correlation matrix of variables.

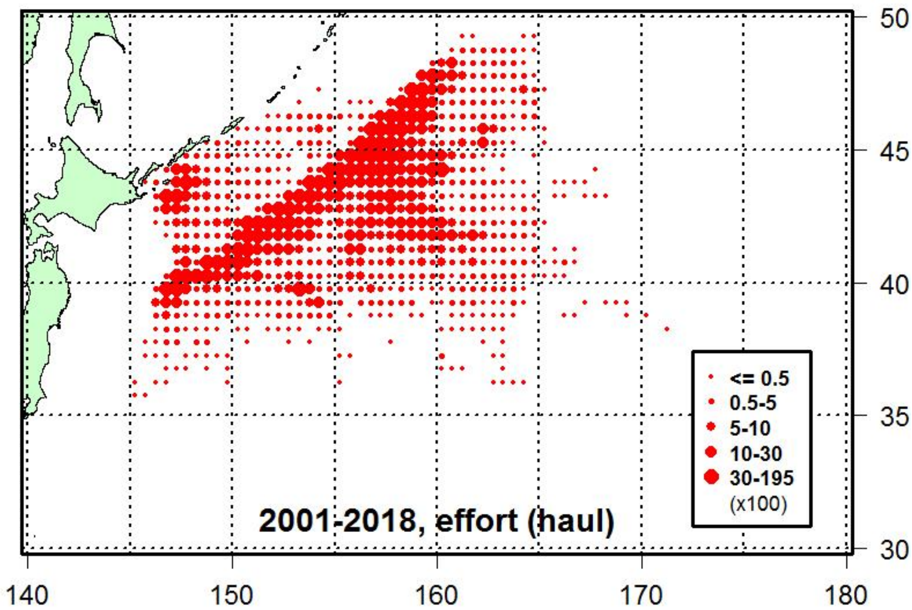

Figure 2. Distribution of fishing effort (10^2 hauls) for Taiwanese saury fishing fleets in the Northwestern Pacific Ocean from 2001 - 2018.

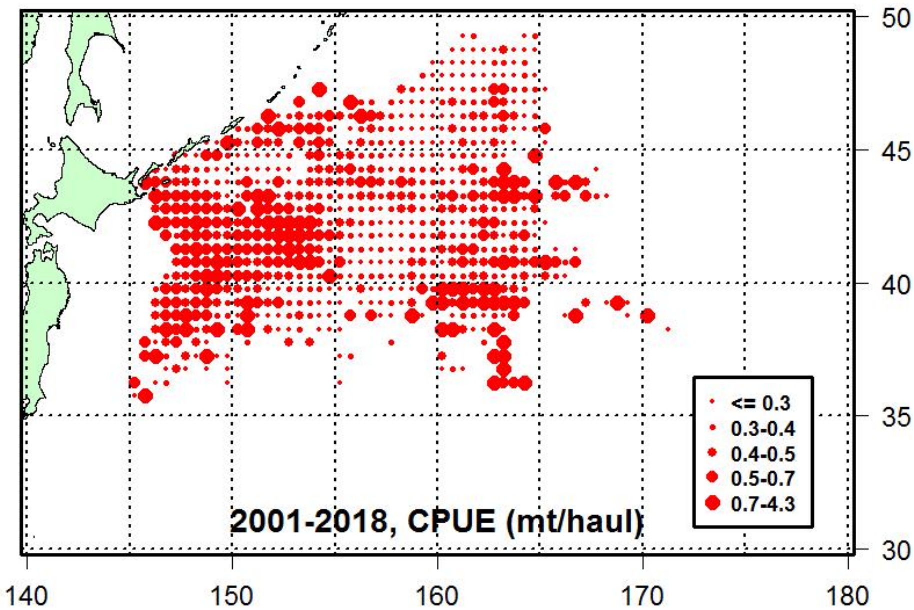

Figure 3. Distribution of nominal CPUE (mt/haul) for the Pacific saury caught by Taiwanese saury fishing fleets in the Northwestern Pacific Ocean from 2001 - 2018.

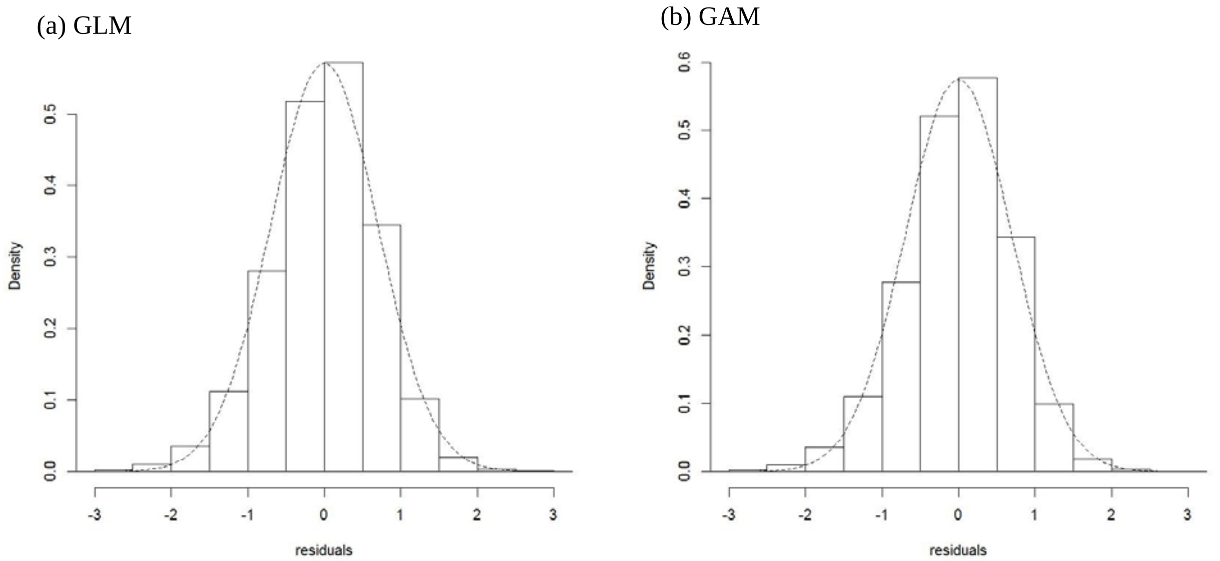

Figure 4. Diagnostic plots (residual distributions) for the GLM and GAM used to standardize the CPUE of Pacific saury for the Taiwanese saury fishery in the Northwestern Pacific Ocean from 2001 - 2018.

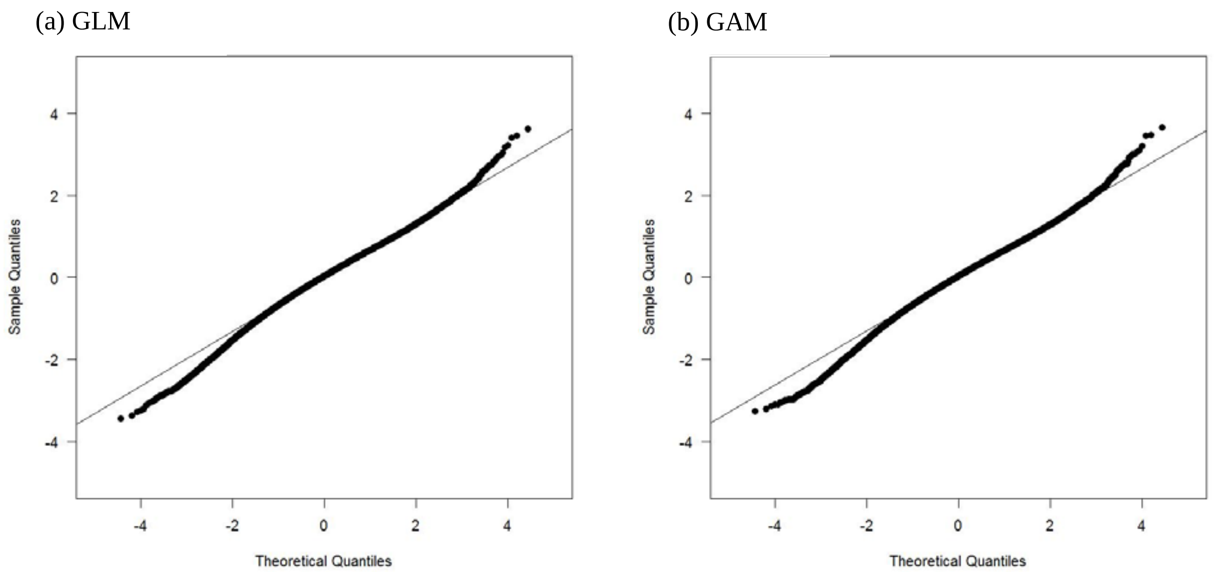

Figure 5. Diagnostic plots (Q-Q plots) for the GLM and GAM used to standardize the CPUE of Pacific saury for the Taiwanese saury fishery in the Northwestern Pacific Ocean from 2001 - 2018.

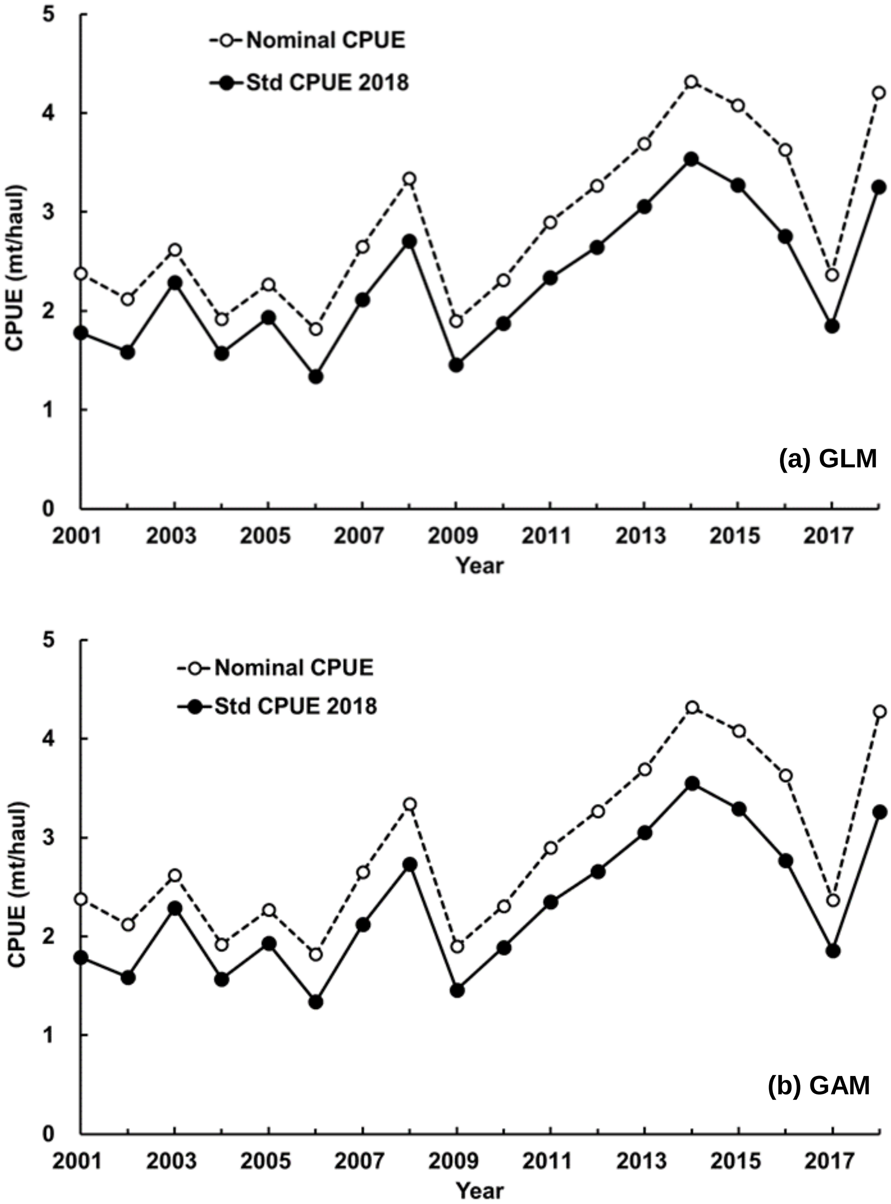

Figure 6. The nominal (open circles with dotted line) and standardized (solid circles with solid line) CPUE (mt/haul) of Pacific saury for the Chinese Taipei's saury fishery in the Northwest Pacific Ocean from 2001 - 2018 using the GLM and GAM.