Volume 27 | Issue 5 Article 9

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Recommended Citation

Huang, Wen-Bin; Hsieh, Chih-Hao; Chiu, Tai-Sheng; Hsu, Wei-Ting; and Chen, Chih-Shin (2019) "CPUE standardization for the Pacific saury (Cololabis saira) fishery in the Northwest Pacific," *Journal of Marine Science and Technology*: Vol. 27: Iss. 5, Article 9.
DOI: 10.6119/JMST.201910_27(5).0009
Available at: https://jmstt.ntou.edu.tw/journal/vol27/iss5/9

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Acknowledgements

We thank the staff of the Overseas Fisheries Development Council of the Republic of China for allowing us to use its fisheries data. We also thank the staff of the Taiwan Squid Fishery Association for providing essential information of the fishery. This study was partially funded by the Ministry of Science and Technology and Fishery Agency, Council of Agriculture, Executive Yuan of Republic of China (Taiwan), through the grant: MOST 103-2611-M-259-001 and 105AS11.1.3-FA-F1. We greatly appreciate the constructive comments from anonymous reviewers.

Journal of Marine Science and Technology, Vol. 27, No. 5, pp. 472-480 (2019)
DOI: 10.6119/JMST.201910_27(5).0009

CPUE STANDARDIZATION FOR THE PACIFIC SAURY *COLOLABIS SAIRA* FISHERY IN THE NORTHWEST PACIFIC

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Key words: CPUE standardization, *Cololabis saira*, Pacific saury fishery, Northwest Pacific, fisheries management.

ABSTRACT

In stock assessment and fisheries management, the standardization of catch per unit effort (CPUE) is critical to derive an effective index of the abundance of exploited fish stocks. In addition to developing various statistical models, a method including the relative fishing power (RFP) of individual vessels has been developed from an intuition concept and applied to bottom trawl fisheries using logbook-based data. This is a convenient and straightforward approach for standardizing the catch-effort data of a fishery. The Pacific saury is a pelagic fish species, and its stock in the Northwest Pacific has been targeted by international fleets since the early 1980s; annual production ranged from 328,000 to 630,000 tons during 2001-2016. The Pacific saury stock has been one of the resources managed by the North Pacific Fisheries Commission (NPFC) since 2015. In this study, the RFP method in CPUE standardization was applied to the Taiwanese Pacific saury fishery in the Northwest Pacific, and the effects of varying the parameters of the model were analyzed. The results indicate that more than 98.8% of the fishing effort can be standardized according to the estimated RFP, with 20 being the minimum number of required comparisons in each of the 4-year periods during 2001-2016. The RFP values of the model generally correlate with the length and gross tonnage of fishing vessels in the saury fishery. The result of the model, applied to the Pacific saury fishery, is robust when the model considers the effects of varying the model parameters (the minimum number of comparisons and standard vessel). This study suggests that first, the RFP method is appropriate for the CPUE standardization of the Pacific saury fishery, and that second, the resulting CPUE can be an effective index of abundance that reflects the annual variability of the Pacific saury stock in the Northwest Pacific.

I. INTRODUCTION

For determining the effects of fisheries and environmental factors and estimating parameters of life history (such as natural mortality), the estimation of stock abundance in exploited fish species is critical (King, 2007). Although information on the absolute abundances of stocks are necessary for effective fisheries management, estimates of relative abundances are usually sufficient. Catch per unit effort (CPUE) is a relative abundance index that is mostly applied in fisheries (Maunder and Punt, 2004; King, 2007). Catch and effort data are usually collected in all managed fisheries, either from research surveys (fishery-independent data) or from commercial operations (fishery-dependent data). The CPUE data collected from commercial fisheries can be misleading because catch rates may change over time due to factors other than abundance changes (Maunder and Punt, 2004). However, the standardization of fishing effort in a fishery is an appropriate process for removing (or adjusting for) the influences of these factors.

In the CPUE standardization process, the factors that explain variations in fishing efficiency (or fishing power) across vessels should be considered (Chen and Chiu, 2009). The relative fishing power (RFP) of a given vessel is defined as its fishing efficiency (catch) relative to that of a standard (or even hypothetical) vessel (Maunder and Punt, 2004). Factors that are most likely to affect fishing power are vessel size

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(tonnage and length), vessel age, engine power, skipper experience, and the fishing technology used (Gulland, 1983). For example, to maximize their catch, experienced skippers in the Pacific saury fishery may fine-tune operational parameters such as the number of lamps, color of lights, manpower assignment, and operational hours per haul.

Traditionally, in the CPUE standardization process, factors that potentially affect fishing power are included in statistical models, such as generalized linear or additive models (Kimura, 1981; Hilborn and Walters, 1992; Maunder and Punt, 2004). Hence, the adjusted (or standardized) CPUE can be calculated from a statistically selected model. By contrast, a straightforward approach for CPUE standardization is to calculate the RFP of two specific vessels when they harvest the same stock density (Beverton and Holt, 1957). In this method, one vessel from the fleet is selected as the standard vessel, and the RFP for all paired comparisons of the vessels that can be practically feasible in the fleet is calculated. Despite its limitations, the approach has been effectively applied to the Norwegian bottom trawl fishery (Salthaug and Godø, 2001) and the Taiwanese squid-jigging fishery (Chen and Chiu, 2009). The RFP approach is a convenient and straightforward method for CPUE standardization and uses only the catch and effort data of a fishery. However, some issues should be addressed when applying this approach for CPUE standardization. These issues include the effectiveness of a selected standard vessel and influences from multiple factors, such as month and area (Maunder and Punt, 2004).

The Pacific saury *Cololabis saira* is an oceanic pelagic fish species of economic value and is commercially exploited by international fishing fleets, including those from China, Japan, Korea, Russia, and Taiwan (Technical Working Group on Pacific Saury Stock Assessment [TWG PSSA], 2017). During 2001-2016, the annual productions of Pacific saury ranged from 335,000 to 631,000 metric tons (t), with an average of 447,000 t (FAO, 2018). The annual catch of Pacific saury by the Taiwanese fleet varied from 40,000 to 230,000 t during the same period, with an average of 121,000 t, which accounted for 27.0% of the global production (FAO, 2018). Low diversity in nucleotide and haplotype was discovered for the Pacific saury collected throughout the North Pacific (Chow et al., 2009), suggesting that there might be one single stock of Pacific saury in the North Pacific. Due to the high production and substantial economic value of Pacific saury, a number of studies on the Pacific saury population have examined its distribution and migration (Fukushima, 1979; Hubbs and Wisner, 1980; Kosaka, 2000; Kurita, 2001; Huang et al., 2007; Huang, 2010; Baitaliuk et al., 2013; Miyamoto et al., 2019), age, growth and maturation (Hatanaka, 1955; Hotta, 1960; Watanabe and Lo, 1989; Kosaka, 2000; Kurita, 2001; Suyama, 2002; Kurita et al., 2004; Nakaya et al., 2010; Suyama et al., 1992, 1996, 2006; Huang and Huang, 2015), and environmental effects on population dynamics (Tian et al., 2003, 2004; Ito et al., 2004). In Japan, stock assessment for the Pacific saury has been performed using fishery-independent data (research surveys) and fishery-dependent data (Suyama et al., 2016). However, CPUE standardizations for the Pacific saury fishery in the Northwest Pacific are still scarce.

In a previous study, the CPUE standardization of the Pacific saury was performed using a generalized linear model that included the factors of year, month, location, and water temperature. However, the results had low explanatory ability (Suyama et al., 2016). In the present study, instead of using statistical models, the RFPs of individual vessels in a fleet were calculated by comparing their catch on the fishing grounds. The resulting adjusted CPUE based on the RFP is a potentially effective abundance index for the Pacific saury in the Northwest Pacific. In this study, the standardization coefficients for each vessel in the Taiwanese Pacific saury fleet were estimated using the RFP. In addition, the effects of varying the parameters in the RFP standardization process, such as the standard vessel chosen and minimum number of comparisons for estimating the RFP, were explored.

II. MATERIALS AND METHODS

1. Fisheries data

Fisheries data used in this study were daily logbook data from the Taiwanese Pacific saury fleet in the Northwest Pacific. The Taiwanese Pacific saury fleet commenced operations in 1967 and has targeted the Pacific saury; it is equipped with stick-held dip net. The fishing gear and method of the Taiwanese saury fishery are a variant of those used in torch-light fisheries; lights are used to gather fishes, which are then harvested by net. In 2001, the fishery had 41 vessels, and in 2016, it had 91; most had a gross registered tonnage (GRT) of 700-1000 tonnages, whereas some newer vessels (4-5 vessels) had a GRT greater than 1000 tonnages. The logbooks of the fishery have been collected and maintained by the Overseas Fisheries Development Council of the Republic of China since 2001. Each record includes the vessel license number, vessel length (in meters), GRT, operating date, position (latitude and longitude), and catches (in metric tons). These logged data covered 100% of the total Taiwanese Pacific saury catch in the analyzed period between 2001 and 2016. During the analyzed period, the fishing area occupied by the Taiwanese Pacific saury fleet was 40°-50°N and 145°-165°E (Fig. 1). The nominal CPUE was calculated using the following formula: total saury catches (by weight) divided by the vessels involved and operation days (ton/vessel/day).

2. Standardization model

The standardization model was modified from those of Salthaug and Godø (2001) and Chen and Chiu (2009), which were based on a concept previously proposed by Beverton and Holt (1957) and Gulland (1983). When two vessels harvest fish at the same time and in a close area, the density distribution of fish can be considered to be invariant for these two vessels in this spatiotemporal unit. Thus, we can compare the catches of

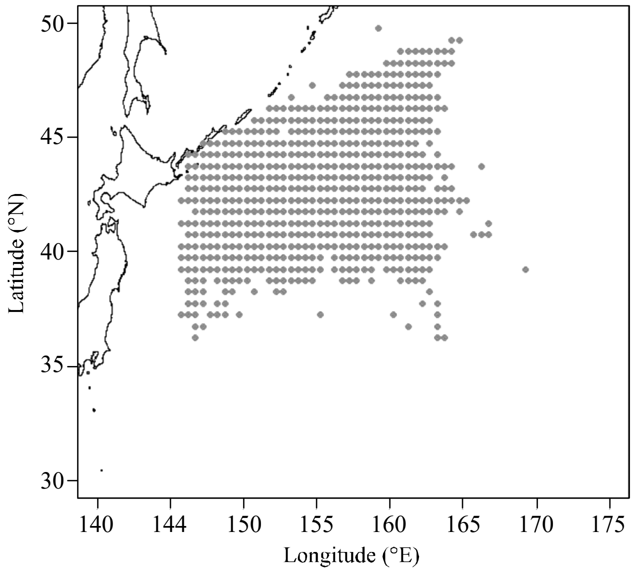

Fig. 1. The potential fishing ground (grey circles) for the Taiwanese Pacific saury fishery in the Northwest Pacific during 2001-2016.

a pair of vessels harvesting in the same spatiotemporal units.

This study used a temporal unit of 1 day and a spatial grid of 0.5° by latitude and longitude. The Pacific saury population within such a spatiotemporal unit is assumed to have a fairly monotonic density distribution. The standardization procedure involved two steps: first, we calculated the local power factor (LPF), which was defined as the ratio of the CPUEs for each pair of vessels; second, we calculated the global power factor (GPF), which was the final factor (i.e., standardization coefficients) adjusted from LPFs in proportion to a specific standard vessel. All CPUE ratios for pairs of vessels located in the same spatiotemporal unit were calculated. The standard vessel was defined as the most active vessel during a fishing season (period); it is the vessel with the highest number of CPUE comparisons with the other vessels in the fleet. The fishing power of the standard vessel is assumed to be the same throughout the fishing period in the standardization process. This assumption is reasonable for the Taiwanese Pacific saury fishery because the skippers could not greatly modify their fishing methods at sea (e.g., in their net machines, lights, and employment of fishers) during the fishing season.

The RFPs between two arbitrary individual vessels were obtained by estimating the ratio of their CPUEs (i.e., LPFs). A single estimate of the RFP between the vessels was defined as a comparison. A standard vessel was chosen, and the RFPs of the other vessels, relative to the standard vessel, were defined as the GPF. Using a vessel's GPF, the applied effort can be converted to the effort units of the standard vessel.

(1) LPF

The LPF is defined as:

$$P_{ik} = \text{median}\left[\frac{\text{CPUE}_{ij}}{\text{CPUE}_{kj}}\right], j = 1, \ldots, n, n \geqq Y \tag{1}$$

where P_{ik} is the LPF of vessel i relative to vessel k, $CPUE_{ij}$ and $CPUE_{kj}$ are their respective CPUE values in comparison j, n is the number of comparisons used, and Y is the minimum number of required comparisons to estimate a LPF between the two vessels (Y = 20 in this study; see the Discussion section). To minimize the effect of extreme values, the median value of the CPUE ratios was selected to estimate the LPF (Salthaug and Godø, 2001).

(2) GPF

The GPF is the CPUE ratio between the standard vessel and the other vessels that harvested within the same spatiotemporal unit. The value of standardized CPUE was the quotient of nominal CPUE and GPF.

When calculating the GPF, vessels were categorized into at least three levels according to whether we could directly or indirectly compare their CPUEs with that of the standard vessel. Vessels for which we could directly compare CPUEs with the standard vessel were assigned to level 1. For vessels at level 1, GPFs are their LPFs. Vessels for which we could compare CPUEs with the level 1 vessels, but not the standard vessel, were assigned to level 2. The GPFs of level 2 vessels were calculated to be:

$$F_{js}^{(2)} = \frac{1}{n}\sum\nolimits_{i=1}^{n} P_{ji}P_{is} \tag{2}$$

where n is the number of vessels at level l with estimated LPFs in relation to vessel j (at level 2), P_{ji} is the LPF of vessel j relative to vessel i, and P_{is} is the LPF of vessel i relative to the standard vessel s.

A similar comparison can be extended to level 3. Vessels in the fleet that are missing at level 2 can be related to the standard vessel to obtain a GPF $F_{ks}^{(3)}$ at level 3. Specifically,

$$F_{ks}^{(3)} = \frac{1}{n}\sum\nolimits_{j=1}^{n} P_{kj}F_{js}^{(2)} \tag{3}$$

where n is the number of vessels at level 2 with estimated LPFs in relation to vessel k, P_{kj} is the LPF of vessel k (at level 3) relative to vessel j, and $F_{js}^{(2)}$ is the GPF of vessel j.

For vessel standardization, data selection criteria—such as the standard vessel, minimum number of comparisons for estimating the LPF, and duration of standardization period—require definition. The effect of varying some of these factors will be detailed in a later section. The minimum number of required CPUE comparisons to estimate an LPF was set at 20 for each pair of vessels (see the Discussion section). The standard vessel was defined as the vessel having the highest number of comparisons with other vessels during the analyzed period of 16 years. Standardization of the fleet is executed

Table 1. Numbers of active vessels and standardized vessels, proportions of records and vessels standardized, and linear regression parameters between global power factors (GPF, dependent variable) and length (m)/gross registered tonnage (t) of the vessels for the Taiwanese Pacific saury fishery in each of the four periods across 2001-2016

Period	No. of active vessels	No. of standardized vessels	No. of vessels standardized at level 1	Proportion of records standardized (%)	Proportion of vessels standardized (%)	Vessel length - GPF		Gross registered tonnage - GPF	
						R^2	slop	R^2	slop
2001-2004	72	69	64	98.9	95.8	0.209	0.0239***	0.154	0.0011***
2005-2008	72	72	72	100.0	100.0	0.102	0.0116***	0.098	0.0006***
2009-2012	91	89	85	98.8	97.8	0.396	0.0307***	0.274	0.0015***
2013-2016	115	112	96	99.7	97.4	0.415	0.0475***	0.229	0.0018***

***, $p < 0.001$

across four 4-year periods, and the same standard vessel was used for each period (Salthaug and Godø, 2001). We assumed that the RPF between the vessels was constant over 4 years (Salthaug and Godø, 2001).

Because vessel size purportedly explains fishing power, we conducted linear regression analysis between vessel size (length and GRT) and power factor (Salthaug and Godø, 2001) The frequency distribution of the CPUE ratio of some vessels, which were obtained from comparisons with the standard vessel, was analyzed to evaluate the method used for estimating LPFs and to visually illustrate uncertainty.

2. Effects of varying the parameters

The critical parameters in the standardization model that may affect the estimations of LPFs and thereby GPFs are the minimum number of required CPUE comparisons (CPUE ratios) to estimate a LPF between two vessels (Y in Eq. (1)) and the chosen standard vessel. To explore the effects of these parameters on the estimation, we used data from the latest period (2013-2016), because these data best represent the current situation in the fishery and its higher fishing activity (in terms of the number of fishing vessels; Table 1).

3. Minimum number of CPUE comparisons

The value set for the minimum number of required CPUE comparisons to estimate an LPF will affect how many vessels are retained for the next analytical step, which subsequently affects the procedure of selecting a standard vessel. Two approaches were used to explore how the criterion for this minimum number of comparisons influences the estimation of power factors. First, to compare the differences in the LPF when the number of CPUE comparisons was varied from 1 to 20, 10 vessels were randomly chosen and their LPFs were calculated relative to an active standard vessel. Values of the LPFs were plotted against the numbers of comparisons used in the calculation (Y in Eq. (1)). The comparisons were taken chronologically from the start of the fishing season. Second, the relationship between the increase in the minimum number of required comparisons to estimate an LPF and the decrease in the total number of standardized vessels (i.e., the amount of information lost) was also evaluated.

4. Effect of the standard vessel

To investigate the effect of varying the vessel chosen as the standard vessel on the GPF, GPFs were calculated in relation to 20 standard vessels (Salthaug and Godø, 2001). Thus, each vessel in the fleet had 20 GPFs or 19 if it was the standard vessel. These GPFs were again adjusted to the level of one of the 20 standard vessels. This vessel was termed the basic standard vessel, and it was randomly chosen. The adjusted GPFs for the standard vessels in the fleet are given by:

$$F^*_{jks} = F_{jk} F_{ks} \tag{4}$$

where F^*_{jks} is the adjusted GPF between vessel j and standard vessel k to the randomly chosen basic standard vessel s, F_{jk} is the original GPF between vessel j and standard vessel k, and F_{ks} is the GPF of standard vessel k relative to the basic standard vessel s. The standard vessels were the top 20 vessels with the most CPUE comparisons. The minimum number of required comparisons for estimating an LPF was set at 20. For each vessel, the coefficient of variation (CV) in the F_{jks}^*s was calculated, and the distribution of these was explored (Salthaug and Godø, 2001). The value of CV_j in the GPFs of vessel j is given by:

$$CV_j(\%) = 100 \times \frac{standard\ deviation}{mean} = 100 \times \frac{s_j}{\left(\frac{1}{n}\right)\sum_{k=1}^{n} F^*_{jks}} \tag{5}$$

where s_j is the standard deviation of F^*_{jks} for vessel j and n is the number (20 or 19) of different standard vessels.

III. RESULTS

1. Standardization

The CPUE of the Taiwanese Pacific saury fishery in the

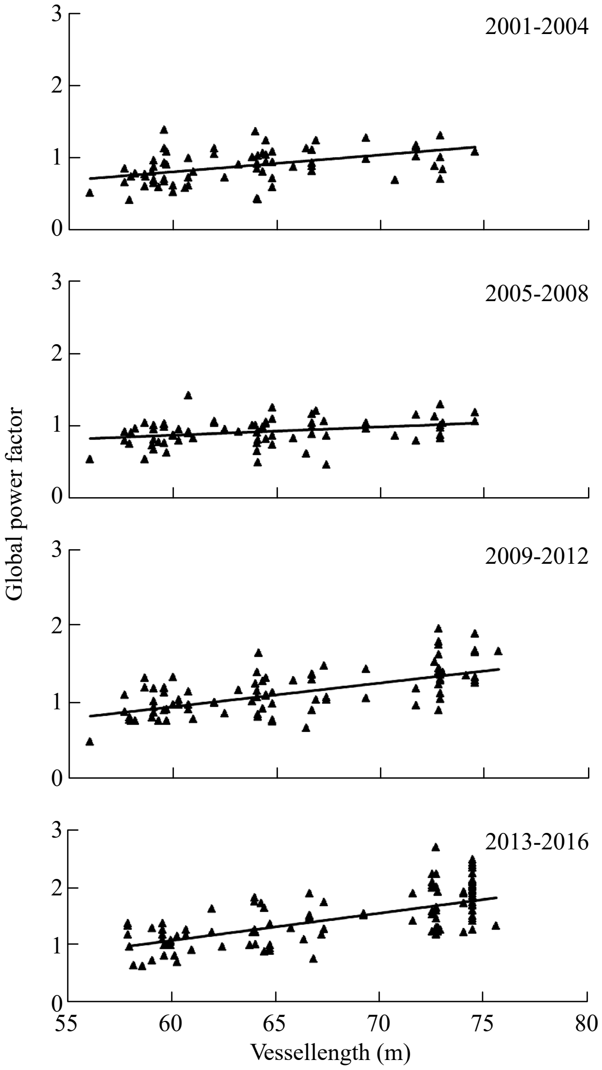

Fig. 2. Global power factors in relation to vessel lengths for the standardized vessels for the four periods across 2001-2016. Linear regression lines are displayed and regression parameters are detailed in Table 1.

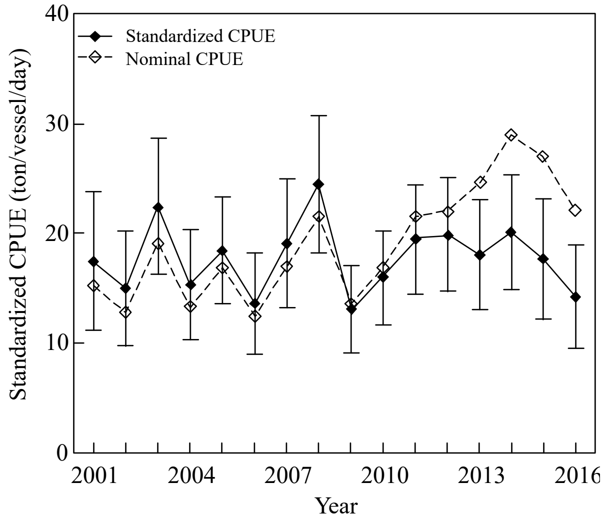

Fig. 3. Annual variations in nominal and standardized CPUE (ton/vessel/day) of the Taiwanese Pacific saury fishery in the Northwest Pacific during 2001-2016.

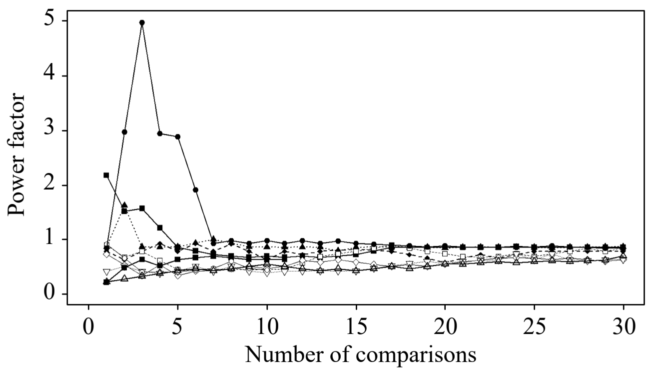

Fig. 4. Variations in local power factors for ten vessels (marked by different symbols) relative to a standard vessel when increasing the number of required comparisons in the estimation process.

Northwest Pacific during 2001-2016 was standardized using the RFP method. More than 98.8% and 95.8% of CPUE observations—by the daily records and number of vessels, respectively—were standardized over the four periods (Table 1). No vessel was at level 3 during the standardization process in the four periods, and all vessels were standardized at level 1 in 2005-2008 (Table 1).

GPF was significantly correlated with both vessel length and GRT in each period (Table 1). From linear models, vessel length ($R^2 = 0.102 - 0.415$) could explain more variation of the GPF than vessel GRT ($R^2 = 0.098 - 0.229$; Fig. 2). In 2013-2016, the correlations of GPF to vessel length and GRT were greater than those in the other periods (Table 1). This period had a higher number of active fishing vessels that were harvesting Pacific saury. Although the slopes of the model regressions were significant ($p < 0.001$), their magnitudes varied widely, and no clear trend was evident across the four periods.

The standardized CPUE, as estimated using the RFP approach, and the nominal CPUE for the Taiwanese Pacific saury fishery in the Northwest Pacific were compared across 2001-2016 (Fig. 3). The nominal and standardized CPUE values exhibited a consistent trend across these 16 years. However, compared with their nominal counterparts, the standardized CPUE values were larger before 2009 and smaller after 2010. The CPUE values fluctuated between 2001 and 2009, with peaks at 2003 and 2008. The CPUE values increased slightly from 2009 to 2014 and decreased thereafter.

2. Effects of varying parameters

The number of required comparisons in calculations to stabilize the value of LPFs varied across the vessels; the LPF seems to be stable when the number of comparisons was larger

Table 2. Coefficient of variation (CV_j) of the 115 individual vessels in adjusted global power factors (F_{jk}*) when using each of the 20 standard vessels as the basic standard vessel as well as the top 1 vessel as the basic standard vessel.

CV	20 basic standard vessels		Top 1 vessel[a] as the basic standard vessel
	Mean	Range	
Mean	19.7	16.6-24.2	18.4
Median	18.4	15.0-22.3	16.5
Maximum	35.9	29.3-43.0	32.0

[a] the top 1 vessel was the vessel with highest number of comparisons with other vessels during the analyzed period of 16 years

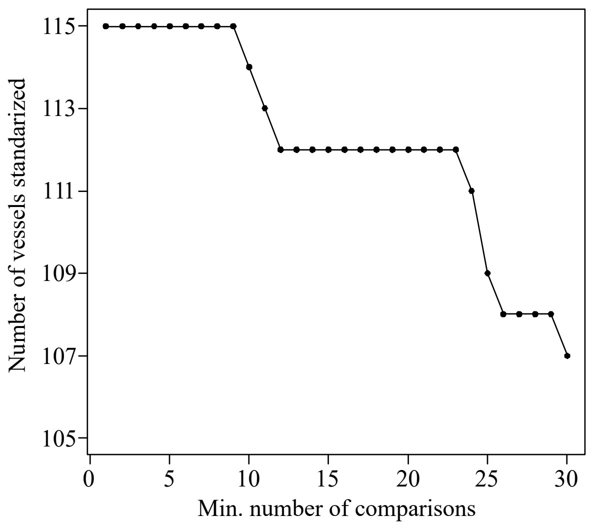

Fig. 5. Decrease in number of standardized vessels in 2013-2016 upon an increase the minimum number of required comparisons for estimating a local power factor.

than 20 for all analyzed vessels (Fig. 4). When increasing the minimum number of comparisons required for estimating an LPF, some vessels were lost, as they did not meet the requirement. For examples, in 2013-2016, zero, three, and seven vessels were lost when the minimum number of required comparisons ranged from 1 to 9, 12 to 23, and 26 to 29, respectively (Fig. 5). Considering the consistency of the power factor and reduction in the information retained, the use of 20 comparisons appeared to be the critical condition for obtaining a reasonable RFP estimate for pairs of vessels in this study. This criterion of 20 comparisons allowed for more than 99.7% observations of the daily record observations and 97.4% of the data of vessels in 2013-2016 to be retained for further analysis (Table 1).

The selection of standard vessel did not seem to have a large effect on the GPF values of vessels (Table 2). When the most active vessel was used as the basic standard vessel, the mean, median and maximum of the CVs of the adjusted GPFs for the 115 vessels (estimated from 20 standard vessels) during 2013-2016 were 18.4%, 16.5% and 32.0%, respectively (Fig. 6). A similar CV distribution pattern was found when using each of the other 19 standard vessels as the basic standard vessel. The means, medians and maximums of the CVs of the adjusted GPFs were in the ranges 16.6-24.2%, 15.0-22.3%, 29.3-43.0%, respectively (Table 2).

3. Discussion

In this study, the RFP method was applied to standardize the catch-effort data of the Taiwanese Pacific saury fishery in the Northwest Pacific. Most of the vessels in the fleet aggregated in nearby spatiotemporal units and had a consistent movement pattern during the fishing season. Thus, their daily catch could be compared in pairs with other vessels. Analyses also indicated that calculation of RFP from paired vessels, after taking into account the effects of varying parameters, could be useful information for an abundance index of the Pacific saury in the Northwest Pacific.

4. Standardization approaches

A statistical CPUE standardization method, such as the generalized linear models and the generalized additive models, has been used for analyses of Pacific saury in the Northwest Pacific in the meetings of the North Pacific Fisheries Commission (NPFC). A recent preliminary evaluation of the stock status of the Pacific saury has been conducted (TWG PSSA, 2017). Factors, such as year, month, location and vessel size, were considered in the statistical CPUE standardization method, which explain 33.8% of the variance of CPUE. Generally, more of the variance of CPUE can be explained when more factors (explanatory variables) are added to a model (Maunder and Punt, 2004). However, this addition (although it reduces bias) increases the variances of the abundance index (Maunder and Punt, 2004). The resulting temporal trend in the CPUE of the Pacific saury is similar to that observed in this study. Nevertheless, alternative methods for CPUE standardization have been suggested in NPFC meetings (TWG PSSA, 2017). Alternative methods promise greater opportunity to exclude factors other than stock abundance and thus yield a more accurate estimate of stock abundance value for effective fisheries management (Maunder and Punt, 2004). In this study, the RFP method for the CPUE standardization of the Taiwanese Pacific saury fishery was used. Instead of considering the variables that affect a statistical model, the RFP approach compares CPUEs directly for every pair of vessels under the assumption (due to the pair being in a small area over a short time) of consistent abundance density (Beverton and Holt, 1957; Salthaug and Godø, 2001). The Taiwanese Pacific saury fleet targets on the Pacific saury stock in the Northwest Pacific. The fishing method involves a set of dip nets, and fishing is conducted with the assistance of lights (Huang et al., 2007). The Pacific saury stock potentially aggregate on the fronts of sea surface temperature and/or other oceanographic conditions (Saitoh et al., 1986; Huang et al., 2007; Tseng et al., 2011). A fishing fleet can use lights to

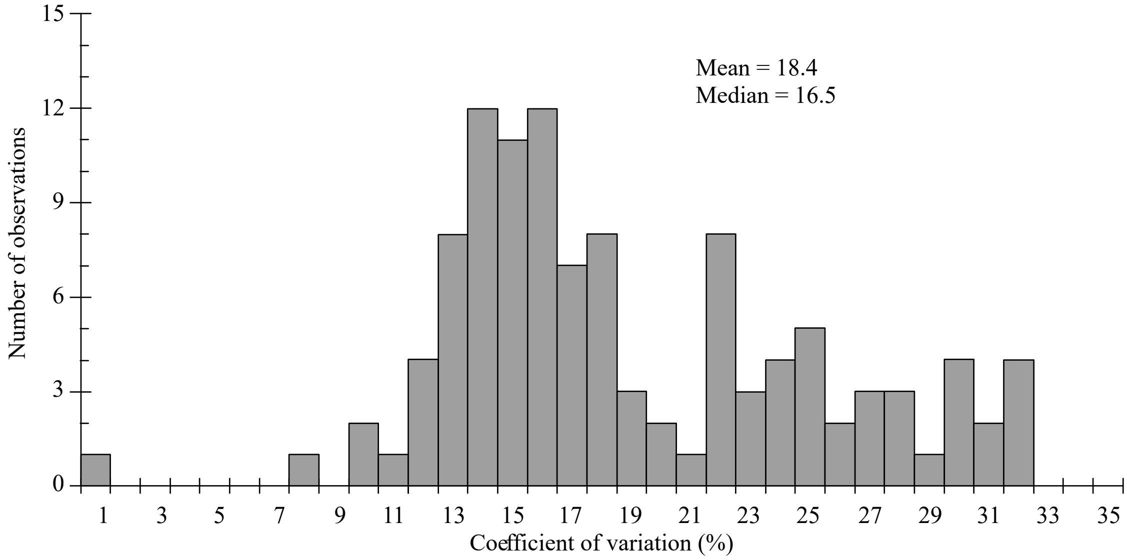

Fig. 6. Frequency plot of the coefficient of variation of 115 individual vessels in adjusted global power factors when using 19 standard vessels and the standard vessel with the highest comparison number as the basic standard vessel.

attract the fish stock and draw them to the side with the dip net. Factors (explanatory variables) influencing the fishing power of a vessel should be considered in a statistical model for CPUE standardization (Maunder and Punt, 2004). These factors pertaining fishermen's experiences are rarely included in statistical models for CPUE standardization, which these may be reflected to a degree in the RFP method for CPUE standardization (Beverton and Holt, 1957). The RFP method may provide an alternative approach in CPUE standardization for the Pacific saury in the Northwest Pacific, and a similar temporal trend in abundance index for the Pacific saury was noted in our study.

The study duration (in years) should be considered in a CPUE standardization using the RFP method. Theoretically, the entire data set (every years) should be processed in that period in which every vessel is comparable with the same standard vessel during the study period. However, the essential assumption is the constant fishing power of the standard vessel throughout the study period (Salthaug and Godø, 2001). Some latent factors that affect the fishing power of the standard vessels, such as fishing skill and skipper experience, are unlikely to remain constant for a long time (e.g., 16 years in this present study). However, shorter periods reduce the available data set for comparison, potentially resulting in high uncertainty for the values of GPFs at level 3 (Salthaug and Godø, 2001). When the study period was less than 4 years in the present study, the proportions of standardized and level 3 vessels decreased and increased, respectively (unpublished data).

In addition, the appropriate study period can depend on the biological characteristics of the exploited fish. The CPUE standardization process was analyzed annually in the *Illex argentinus* fishery in the Southwest Atlantic. The fishery targets species with a 1-year lifespan, with new recruits expected in the annual fishing season (Beddington et al., 1990; Chen and Chiu, 2009). The inter-annual relationship between the spawning stock biomass and recruitment of annual squid species has been weak (Rosenberg et al., 1990; Basson et al., 1996). Thus, the CPUE standardization of squid fishery can be on a yearly basis. The Pacific saury has a maximum lifespan of 4 years, and the fishery in the Northwest Pacific targets age-0 and age-1 cohorts (Suyama et al., 2006). The inter-annual relationship between spawning stock biomass and recruitment of the Pacific saury is expected. Thus, new recruits (age-0 cohort) are found annually in the fishery (Suyama et al., 2006). A 4-year study period of CPUE standardization for the Pacific saury fishery can cover the potential recruitment for the fish's lifespan in the fishery.

5. Parameters in the models

In this study, the RFP method modified from Salthaug and Godø (2001) was used to standardize the CPUE of the Taiwanese Pacific saury fishery. The proportion of standardized observation records was 98.8% in this study (Table 1), while was 84.8% for the bottom trawl fleet (Salthaug and Godø, 2001). The consequential parameters in the RFP method that should be examined are the minimum number of CPUE comparisons (CPUE ratios) and the choice of standard vessel (Salthaug and Godø, 2001; Chen and Chiu, 2009). Setting the appropriate number of CPUE comparisons during the standardization process is a trade-off between the effective vessels involved and loss of available data (on vessels). The RFP varied slightly when the available data for CPUE comparisons changed (Fig. 4). However, when increasing the minimum number of comparisons, no vessel was lost with increase from 1 to 9, three vessels were lost with increase from 12 to 23, and seven vessels were lost with increases from 26 to 29 during 2013-2016 (Fig. 5). In this study, we chose 20 as the minimum number of required CPUE comparisons, and a resultant 97.4% of the vessels remained in the data set for further analysis (Fig. 5).

The selection of a standard vessel, the most active vessel during a fishing season, may also influence the calculation of GPFs (Salthaug and Godø, 2001). When varying the standard vessels during the standardization process, the CV in this study was higher than that of the bottom trawl fleet (Salthaug and Godø, 2001). However, the results in this study indicate that the selection of the standard vessel is unlikely to have a substantial effect on the values of the GPFs for the Taiwanese Pacific saury fishery. The potential explanations for the low effects (in this study) on fleet GPFs from variations in the standard vessel are as follows. First, the fleet for the Taiwanese Pacific saury fishery comprises approximately 90 fishing vessels with GRTs of 700-1000 tonnages. The 20 standard vessels chosen for analysis are of similar size (750-1000 tonnages) which imply a smaller variation in fishing power across the vessels during a fishing season. Second, the skippers of most vessels did not change during the study period. Thus, knowledge from experience (on where to harvest) and operational skill (on how to harvest) are largely invariant for the vessels throughout the study period. This might result in similar fishing powers across vessels during a fishing season. Third, the fleet of the Taiwanese Pacific saury fishery targeted the Pacific saury, a stock with feeding- and spawning-migration in the Northwest Pacific (Huang et al., 2007). There may be two cohorts (age-0 and age-1) of the Pacific saury in the Northwest Pacific (Suyama et al., 2006), although molecular analysis suggested that the Pacific saury comprises only one unit stock in the North Pacific by molecular analysis (Chow et al., 2009). The fleet targeted the same migratory stock of the Pacific saury, which potentially and partially explains the slighter fishing variation in fishing power. Nonetheless, the annual stock abundances and distribution patterns of the Pacific saury in the Northwest Pacific may be influenced by variations in the oceanographic conditions of the North Pacific, such as that from El Niño events (Tian et al., 2003).

6. Pacific saury fishery in the Northwest Pacific

The Pacific saury is a commercially important marine resource in the Northwest Pacific. Its stock in the Northwest Pacific is straddling and highly migratory and has been exploited by international fleets in the high seas of the North Pacific since the 1970s (Huang et al., 2007; TWG PSSA, 2017). The significant increase in production and international fleets (including those of China, Japan, Korea and Taiwan) that have been increasingly involved in the Pacific saury fishery has drawn much attention from the regional fisheries management organization (the NPFC). The NPFC has developed relevant conservation and management measures for the Pacific saury, since 2015, it has organized a series of workshops on the stock assessment of Pacific saury (NPFC, 2016); a statistical CPUE standardization method has been applied, and a recent preliminary evaluation of the stock status of the Pacific saury has been conducted (TWG PSSA, 2017). A decreasing trend of the quantity of the Pacific saury has been noted in recent years according to the CPUE standardization reports from Japan, Russia, and Taiwan (Scientific Committee, 2018). Conservation and management measures for the Pacific saury has been proposed and adopted in the NPFC, the members of which are required to adopt fishing efforts (vessels) limitations, discards control, and measures against juvenile catch (NPFC, 2018). Nevertheless, the development of other CPUE standardization approaches is also suggested to more effective estimate the abundance index for the Pacific saury in the Northwest Pacific. In this study, we performed the RFP method to standardize the CPUE of the Taiwanese Pacific saury fishery in the Northwest Pacific. The result—a decreasing trend of the quantity for the Pacific saury in recent years—is similar to that of the statistical CPUE standardization method (Scientific Committee, 2018). This method seems likely to be appropriate for the Pacific saury fishery because the fleet's characteristics satisfy the assumptions of the approach. However, the effects of varying the parameters in the model (such as the numbers of CPUE comparison and the standard vessel) should be examined carefully when the model is applied to other fisheries. The results demonstrated that the temporal trend of the standardized CPUE values was consistent with the nominal CPUE values during 2001-2016. These results provide an alternative approach for the CPUE standardization of the Pacific saury fishery in the Northwest Pacific and could be applied to stock assessment and management measures in regional fisheries management organizations.

ACKNOWLEDGEMENT

We thank the staff of the Overseas Fisheries Development Council of the Republic of China for allowing us to use its fisheries data. We also thank the staff of the Taiwan Squid Fishery Association for providing essential information of the fishery. This study was partially funded by the Ministry of Science and Technology and Fishery Agency, Council of Agriculture, Executive Yuan of Republic of China (Taiwan), through the grant: MOST 103-2611-M-259-001 and 105AS-11.1.3-FA-F1. We greatly appreciate the constructive comments from anonymous reviewers.

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