

Short Paper

Abundance index for longline fishery targeting spawning Pacific bluefin tuna *Thunnus orientalis* in south-western North Pacific Ocean

HUI HUA LEE* AND CHIEN CHUNG HSU

Institute of Oceanography, National Taiwan University, Taipei, Taiwan

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Pacific bluefin tuna *Thunnus orientalis* is a highly migratory species, distributing throughout the Pacific Ocean.¹ This species is among the quality tunas of high economic value and has been historically exploited mainly by Japanese, US, Mexican and Taiwanese fleets. Approximately 10% of catches were made by the Taiwanese fleet after 1999;² particularly, the individuals caught were all giant spawners.^{3,4} Taiwanese small-scale longliners (vessels < 100 t) target the stock in the south-western North Pacific from late April through June. Because of the significant catch of spawners, any assessment of this stock should include data from the Taiwanese fleet.

Many reports have been issued to describe the stock status of the Pacific bluefin tuna during the past two decades; however, other than biological studies, there have been few stock assessments with the abundance index derived from Japanese fleets and purse seiners in the eastern Pacific Ocean.² Because this species is exposed to multiple fisheries over most fishing grounds, historical statistics from different fishing parties is essential. To assess and propose management measures for the Pacific bluefin tuna, collection of catch and effort data as well as development of a reliable abundance index to represent the spawning stock are urged for the Taiwanese fishery. Therefore, the objective of this study was to model a time-series catch per unit effort (CPUE) that can be used as an index of abundance for the Taiwanese fishery from 1999 to 2004.

Daily catch data from auction records and time records of vessels in and out, which can trace the fishing effort of each vessel, were collected and compiled at Tungkang port, where most bluefin tuna are landed. Two criteria were used in screening the daily record. First, catch with matching effort information for a vessel was screened. Second, the time difference between date of auction and date of disembarking from port was no more than three days to obtain quality fish meat for vessels without freezers. According to interviews with captains of small-scale longline vessels, approximately 1200–1600 hooks per day can be deployed regardless of vessel size. Large vessels can store more fish than small vessels and may stay at sea longer. Fishing effort was then converted from fishing days to number of hooks operated with an assumed average of 1400 hooks lifted daily. The estimated fishing days were decreased by two days because the vessel took approximately one day to travel from Tungkang port to the fishing ground and *vice versa*.

Catch and effort information were summarized as CPUE. Based on the assumption that catch is proportional to the product of fishing effort and density, the ability to use CPUE as an index of abundance depends on being able to remove the influences of factors that change fishing efficiency among vessels and cause differences between trips for the same vessel other than abundance.⁵ A generalized linear model (GLM)⁶ was applied to remove the influential factors and, in the present analysis, the available factors for each vessel trip compiled in the catch and effort data include year (1999–2004), month (May and June) and size of

*Corresponding author: Tel: 886-2-2362-2987.

Fax: 886-2-2366-1198. Email: d91241003@ntu.edu.tw

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Table 1 Analysis of deviance of explanatory variables in generalized linear model

Model	d.f.	Deviance	Change deviance	% of deviance	$P(\chi^2)$
Intercept	3189	2748.70			<0.0001
Y	3184	2508.26	240.44	8.75	<0.0001
Y + M	3183	2210.19	298.07	11.88	<0.0001
Y + M + S	3181	2187.51	22.68	1.03	<0.0001
Y + M + S + M $\times$ S	3179	2187.27	0.24	0.01	0.8412

Per cent deviance refers to the percentages of change in deviance divided by deviance in previous model, and $P(\chi^2)$ values indicate the 5% χ^2 probability between consecutive models.

d.f., degrees of freedom; M, month effect; M $\times$ S is the two-way interaction term between month and size of vessel; S, effect of size of vessel; Y, year effect.

vessel (grouped as 10–19, 20–49 and 50–100 t). Considering all bluefin fisheries from the western North Pacific, the Taiwanese fishery appears to be a local fishery with a marked fishing season even though the detailed fishing positions are not available; therefore, spawning bluefin density was assumed to be spatially homogeneous.

Independent variables considered for the GLM are fishing year, month, size of vessel and two-way interaction between month and size of vessel. The dependent variable is the logarithm of CPUE assuming a Gaussian error distribution. To avoid zero CPUE when taking the natural logarithmic transformation, a positive constant was added to all CPUEs, while maintaining or achieving normality of the transformed data.⁷ Test runs with different values of the constant were carried out to see which yielded results that are close to the normally distributed residuals. The assumption of a GLM is that the relationship between the expected $\ln(\text{CPUE})$ and the independent variables is linear. The full model is given by equation 1:

$$\ln(\text{CPUE}_{ijk} + c) = \mu + Y_i + M_j + S_k + M_j \times S_k + \varepsilon_{ijk}, \quad (1)$$

where μ is overall mean, c is a constant that is decided in test runs, Y_i is the effect of year i , M_j is the effect of month j , S_k is the effect of size of vessel k , $M_j \times S_k$ is the two-way interaction term between month j and size of vessel k , and ε_{ijk} is an error term with $N(0, \sigma^2)$. Due to the difficulty of explaining interaction between year factor and other factors, only the interaction between month and size of vessel was considered.

A stepwise analysis of deviance was performed to determine the set of systematic factors and interactions that significantly explained most of the observed CPUE variability. The χ^2 statistic was used to test the significance of an additional factor in the model.⁸ Final selection of explanatory factors was conditional on significance of the χ^2 test and per cent change in deviance as each factor is added to the model. The $\ln(\text{CPUE} + c)$ was esti-

mated as the least-squares mean of the factors selected and then back-transformed to derive the standardized CPUE. The analyses were run with GENMOD and GLM procedures (SAS Institute, Cary, NC, USA).

The normality of residuals from the transformed data by adding different constants was visually diagnosed by comparing quantile of residuals with the 45° reference line on the Q–Q plot (data not shown), indicating that the plot derived by adding either 1 or 0.01 as a constant departed from the line more than that by adding 0.1 or 10% of overall mean. These data suggest that both 0.1 and 10% of overall mean as a constant capture the normality of residuals, but the value of 0.1 shows better fit of data than 10% of overall mean.

Results of deviance estimated from stepwise regression are presented in Table 1 indicating that factors of year, month and the size of the vessel were significant for the χ^2 test ($P < 0.0001$). Among these factors, year, month or size of vessel explained more than 1% of deviance. Therefore, factors of year, month and size of vessel were selected into the GLM. The analysis of variance (ANOVA) results are shown in Table 2.

CPUE estimated by the GLM is shown in Figure 1. The annual abundance index sharply declined from 0.46 fish per 1000 hooks in 1999 to 0.14 fish per 1000 hooks in 2002, and remained constant at 0.2 fish per 1000 hooks in 2003 and 2004.

The process attempts to remove most of the annual variations in the data that are not attributed to changes in abundance and the annual index reflects population abundance. In this study, the selected factors explained approximately 20% of variance of the data (Table 1) and the explanatory power of the model (r^2) was 0.2 (Table 2). Maunder and Punt⁹ indicated that the explanatory power is not always satisfactory and it can be increased by involving more explanatory variables. Accordingly, the explained variation is not the absolute quantity to judge the reliability of the index of abundance. Instead, it is more important to consider whether

Table 2 Analysis of variance (ANOVA) table for selection model in generalized linear model

Source	d.f.	Type III sum of squares	Mean square	F-value	P(F)
Model	8	561.19	70.15	102.01	<0.0001
Error	3181	2187.51	0.69		
Corrected total	3189	2748.70			

r^2 , explanatory power = 0.2042.
d.f., degrees of freedom.

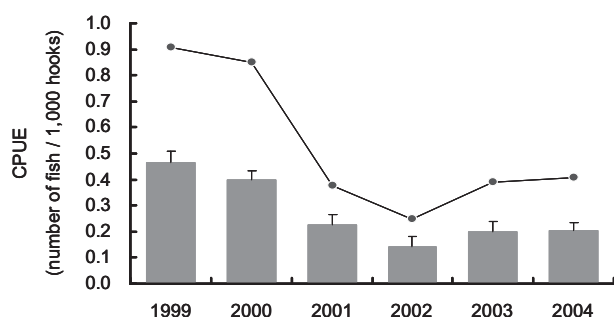


Fig. 1 Estimated (bars) and observed (●) catch per unit effort (CPUE) of Pacific bluefin tuna targeted by Taiwanese longline fishery. Bars, standard error.

the time series of abundance index accurately reflects changes in catchability and fisheries. First, decreases in catches from the longline fisheries² are consistent with our result shown in Figure 1, which is low abundance of bluefin tuna in 2002. Second, abundance indices of spawning fish caught by Japanese coastal longliners also decreased from 1999 to 2002.² Third, decreased abundance is consistent with falling spawning stock biomass after the mid-1990s.² Therefore, it was concluded that the standardized CPUE in this study is a useful abundance index for spawning bluefin tuna targeted by the Taiwanese small-scale longline fishery.

The rapid development of the Taiwanese small-scale longline fishery targeting spawning stock brought about high fishing pressure on the bluefin in recent 10 years. Taking into account the size-specific seasonality of the fishery, the index of

abundance estimated in the present study could provide important information to advance future stock assessment.

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