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Chin-Cheng Wu

Department of Fisheries Production and Management, National Koahsiung Marine University, Nantzu, Koahsiung 811, Taiwan, R.O.C. Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung 202, Taiwan, R.O.C.

Ching-Hsiewn Ou

Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung 202, Taiwan, R.O.C.

Wen-Pei Tsai

Institute of Oceanography, National Taiwan University, Taipei 106, Taiwan, R.O.C.

Kwang-Ming Liu

Institute of Marine Affairs and Resource Management, National Taiwan Ocean University, Keelung 202, Taiwan, R.O.C., kmliu@mail.ntou.edu.tw

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ESTIMATE OF THE MAXIMUM SUSTAINABLE YIELD OF SERGESTID SHRIMP IN THE WATERS OFF SOUTHWESTERN TAIWAN

Chin-Cheng Wu^{* **}, Ching-Hsiewn Ou^{**}, Wen-Pei Tsai^{***}, and Kwang-Ming Liu^{****}

Key words: sergestid shrimp, surplus production model, maximum sustainable yield, total allowable catch.

ABSTRACT

The sergestid shrimp, *Sergia lucens* is one of the major marine resources in the waters off southwestern Taiwan. The maximum sustainable yield (MSY), total allowable catch (TAC) and fishing effort at MSY (E_{MSY}) of the sergestid shrimp in this area were estimated to be 1008 tons, 907 tons and 11292 vessel-day, respectively by using the surplus production model with deterministic observation-error estimator approach based on a catch and effort series from 1997-2008. Furthermore, the mean MSY, TAC, and E_{MSY} with 95% CI were estimated to be 1011 (842-1243) tons, 910 (758-1119) tons, and 11296 (10758-11807) vessel-day, respectively from the stochastic models. The estimated biomass showed a slightly decreasing trend during the period of 1997-2008 suggesting that the TAC should be included in current management measure to ensure a long-term sustainable utilization of this stock in spite of no overfish and overfished occurrence.

I. INTRODUCTION

The sergestid shrimp, *Sergia lucens* is a macrozooplankton and distributes in the waters of Japan and Taiwan. It was used to be only fished commercially in the Suruga Bay, Japan [18, 19]. Starting from 1982, this species was also harvested commercially in the southwestern Taiwan waters from Tongkang to Fangshan (Fig. 1) [18, 19]. Currently, this species has become one of the major marine resources in Tongkang. The middle-water trawling fishery in Tongkang targets on the sergestid shrimp from November to May next year and switches to Taiwan maushia shrimp (*Actes intermedius*) from June to October. They are the only two existing fisheries targeting on macrozooplanktons in Taiwan [12]. Due to the promotion by fishermen association and local government, these two fisheries have become famous coastal fisheries in Taiwan. Historical production of the sergestid shrimp fishery in Tongkang was listed in Table 1. Annual yield peaked in 2008 of 1918 tons, followed by 1203 tons in 2000 and the remaining years ranged 697-1166 tons in the past 10 years.

The development and management of the sergestid shrimp in Tongkang waters can be categorized into four phases (1) Sergestid shrimp was regarded as trash fish (1950-1980), (2) The initiative of sergestid shrimp fishery management (1981-1992), (3) Community-based management (1993-2000), (4) Construction of co-management (2001-) [28]. The self-management organization was set up in 1993 and the fishing activities were regulated by the operation convention [28]. However, both the community-based and co-management fishery management measure were based on fishermen's experience rather than scientific evidences.

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Paper submitted 04/13/09; revised 07/27/09; accepted 08/31/09. Author for correspondence: Kwang-Ming Liu (e-mail: kmliu@mail.ntou.edu.tw).

*Department of Fisheries Production and Management, National Kaohsiung Marine University, Nantzu, Kaohsiung 811, Taiwan, R.O.C.

**Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung 202, Taiwan, R.O.C.

***Institute of Oceanography, National Taiwan University, Taipei 106, Taiwan, R.O.C.

****Institute of Marine Affairs and Resource Management, National Taiwan Ocean University, Keelung 202, Taiwan, R.O.C.

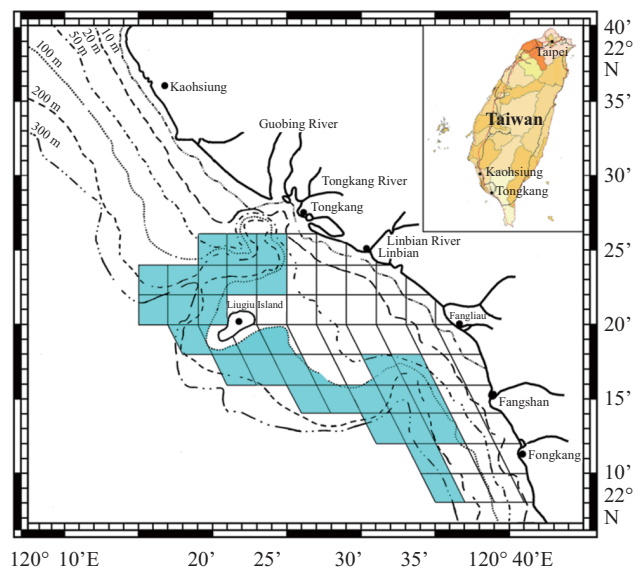


Fig. 1. Sampling area of the sergestid shrimp in the waters off Southwestern Taiwan.

Table 1. Annual fishing effort, yield and CPUE of the sergestid shrimp fishery in the waters off Southwestern Taiwan from 1997 to 2008.

Year	Effort (vessel-day)	Yield (ton)	CPUE (tons/vessel-day)
1997	9276	1166	0.126
1998	7136	1092	0.153
1999	6799	717	0.105
2000	8315	1203	0.145
2001	5160	717	0.139
2002	10065	1093	0.109
2003	10900	697	0.064
2004	11616	1071	0.092
2005	6706	1111	0.166
2006	8604	938	0.109
2007	11287	750	0.066
2008	13351	1918	0.144

Some aspects of *S. lucens* have been well documented such as fishing condition in relation to environmental factors [9] and fishery biology [10]. However, the stock status is still little known although several attempts have been made to estimate the maximum sustainable yield (MSY) or total allowable catch (TAC) of this species. Chen [2] estimated the TAC to be 840 tons with the Fox model based on the data from 1992-1996. Jong [11] reported the MSY and TAC to be 720 and 576 tons, respectively based on Schaefer's surplus production model. Miao *et al.* [17] suggested a TAC of 591 tons with the Leslie's method based on a data set from 1999 to 2000. Hong [8] proposed a management measure of 748 and 711 tons for MSY and TAC, respectively based on the Pella-Tomlinson model using a catch and effort series of 1998-2007. However, none of these studies has even considered the uncertainty in their analyses. Thus, the present study is to estimate the MSY, fishing effort at MSY (E_{MSY}), and TAC of the sergestid shrimp in southwestern Taiwan waters with the surplus production model by using both deterministic and stochastic observation-error estimators approaches. The results obtained in the present study can be used as a reference of setting management measure for this stock.

II. MATERIALS AND METHODS

1. Data Source

The data used in estimating catch per unit effort (CPUE) were from the daily sale records of sergestid shrimp self-management organization from 1997 to 2008 (Table 1). These data include fishing effort and catch (in box). Since the sweeping area of the trawl net used by the sergestid shrimp fishing vessels in Tongkang were almost the same [3, 4, 26], no standardization was taken. Annual catch per unit effort (CPUE) was estimated from the total catch (20 kg*number of box) divided by total fishing effort (vessel*day) during an operation

year (from November to May next year).

2. Model

The surplus production model [24] was used to estimate the sustainable yield of sergestid shrimp in the southwestern Taiwan based on an assumption of a unit stock. A discrete deterministic form of stock dynamics is expressed as:

$$B_{t+1} = B_t + rB_t \left(1 - \frac{B_t}{K}\right) \quad (1)$$

where B_t is the biomass for year t , r is intrinsic population growth rate, K is carrying capacity. Extending the model to include catch becomes Schaefer's model:

$$B_{t+1} = B_t + rB_t \left(1 - \frac{B_t}{K}\right) - C_t \quad (2)$$

Schaefer model can be connected the catch rates to the stock biomass and catchability coefficient (q).

$$I_t = qB_t = \frac{C_t}{E_t} \quad (3)$$

where I_t is the index (CPUE) of relative abundance for year t , C_t is the catch during year t , E_t is the fishing effort during year t .

Maximum sustainable yield (MSY), fishing effort for achieving MSY (E_{MSY}) and biomass at MSY (B_{MSY}) level were estimated by assuming that the rate of change of biomass is zero ($\frac{dB}{dt} = 0$) for all years. Solving C_t by substituting $B_t = C_t/(qE_t)$, gives

$$C_t = \frac{rC_t}{qE_t} \left(1 - \frac{C_t}{qE_t K}\right) \quad (4)$$

This equation can be solved for C_t/E_t

$$I_t = \frac{C_t}{E_t} = qK - \frac{q^2 K E_t}{r} \quad (5)$$

The parameters q , K , and r can be obtained by minimizing the quantity

$$\sum (I_t - \hat{I}_t)^2 \quad (6)$$

where I_t is the observed CPUE for year t and \hat{I}_t is the estimated CPUE for year t .

Estimates of MSY, B_{MSY} and E_{MSY} can be obtained by the formulae below:

$$\begin{cases} E_{MSY} = \frac{r}{2q} \\ B_{MSY} = \frac{K}{2} \\ MSY = \frac{rK}{4} \end{cases} \quad (7)$$

In addition, the TAC was assumed to be 90% of the MSY. The fishing mortality rate can be estimated by the formula:

$$F_t = -\ln\left(1 - \frac{C_t}{(B_t + B_{t+1})/2}\right) \quad (8)$$

where F_t is the instantaneous fishing mortality rate in year t and $(B_t + B_{t+1})/2$ is the mid-year biomass for year t . The instantaneous fishing mortality rate at MSY, F_{MSY} can be expressed as:

$$F_{MSY} = qE_{MSY} = q\frac{r}{2q} = \frac{r}{2} \quad (9)$$

Two biological reference points B_t/B_{MSY} which implies overfished or not and F_t/F_{MSY} which implies overfishing or not [16] were calculated in present study. For a more detailed inference on the surplus production models, please refer to Haddon [6, chap. 10].

3. Deterministic Observation-Error Estimator

There are three methods widely used to fit the surplus production model: (a) effort-averaging methods [5], (b) process-error estimators [25] and (c) observation-error estimators [13, 15, 20, 21]. In the present study, only observed errors were considered in the model which assumed that all of the errors occurred in the relationship between stock biomass and the CPUE. The stock biomass time series is estimated by projecting the biomass at the start of the catch series (B_0) forward under historic catches. An observation-error estimator is constructed by assuming the biomass is deterministic and that all the error occurs in the relationship between biomass and CPUE (zero process error) [21].

The stock biomass was estimated by projecting the initial biomass (B_0) forward under the historic annual catches. Assuming B_t has a log-normal error term and with a constant coefficient of variation (CV). Then, the CPUE can be estimated by the equation below.

$$\hat{I}_t = \frac{\hat{C}_t}{E_t} = qB_t e^\varepsilon \quad (10)$$

where \hat{I}_t is the estimated CPUE at year t , \hat{C}_t is the estimated catch at year t , e^ε ($\varepsilon \sim N(0; \sigma^2)$) indicates that the residual errors which are assumed to be log-normally distributed.

The estimates of the model parameters (B_0 , r , q and K) are

obtained by minimizing the negative log-likelihood function.

$$-\ln L = \frac{n}{2}(\ln(2\pi) + 2\ln(\hat{\sigma}) + 1) \quad (11)$$

where L is the likelihood, n is the number of observed CPUE, and $\hat{\sigma}$ is defined in (12). More detailed inference for this equation can be found in Polacheck *et al.* [21].

The maximum likelihood estimator of the variance is

$$\hat{\sigma}^2 = \frac{\sum_t (\ln I_t - \ln \hat{I}_t)^2}{n} \quad (12)$$

where n is the number of observations.

The value of \hat{q} is given by the geometric average of the time series of individual q estimates

$$\hat{q} = e^{-\frac{\sum_t \ln\left(\frac{I_t}{B_t}\right)}{n}} \quad (13)$$

4. Stochastic Observation-Error Estimator

Biomass is one of the factors that may affect the results of surplus production model. Therefore, it is a necessity to take into account the influence of this uncertainty on estimation of MSY or TAC due to the difficulty in estimating biomass which may result in high uncertainty. In the present study, in addition to using a fixed observation error, we applied a stochastic approach in the simulations.

To take into account the uncertainty in parameter estimation, the most common way to calculate the quality of an estimator, Monte-Carlo simulation, was applied in the present study. The Monte Carlo simulations consisted of randomly drawing values of the biomass (\hat{B}_0) from the statistical distributions described earlier.

$$\hat{B}_0 = B_0 \times e^\varepsilon \quad (14)$$

where B_0 is the estimated initial biomass from deterministic model and ε represents observation error of the initial biomass, $\varepsilon \sim N(0; \sigma^2)$. The standard deviation (σ) is set to be 0.01 which is equal to incorporate 1% random error of CV into the model.

The expected values of parameters approximated to the corresponding means obtained from the Monte Carlo simulations. The distributions for the model outputs such as the biomass, MSY and E_{MSY} were based on 10,000 replications for each year and the 2.5th and 97.5th percentiles were used as approximate 95% confidence intervals.

III. RESULTS

1. Deterministic Approach

The observed CPUE fluctuated in the period of 1997-2008,

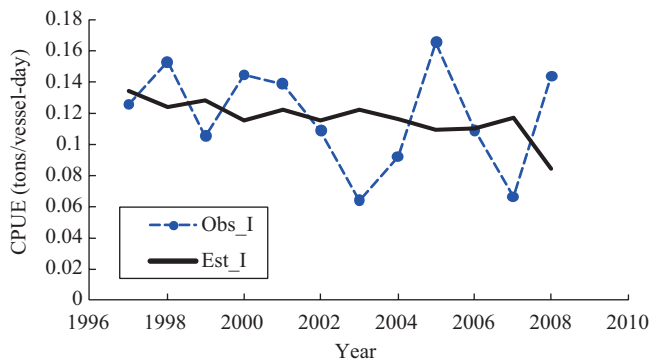


Fig. 2. The observed and estimated CPUE of the sergestid shrimp fishery in the waters off Southwestern Taiwan (1997-2008).

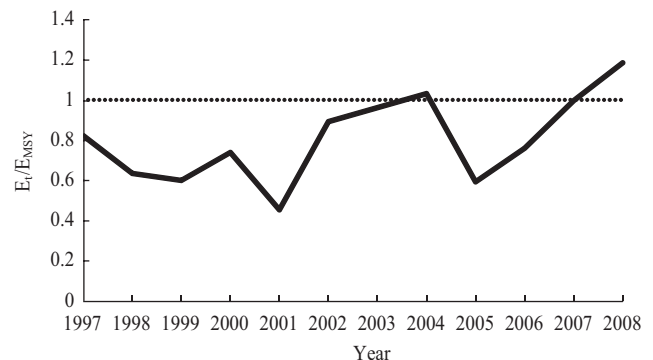


Fig. 4. The ratio of estimated fishing effort (E_t) and the effort of MSY (E_{MSY}) of the sergestid shrimp fishery in the waters off Southwestern Taiwan (1997-2008).

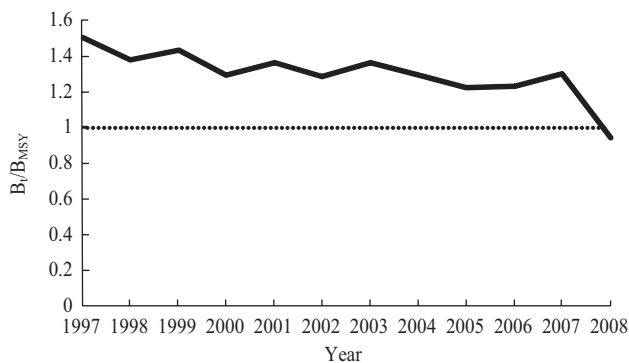


Fig. 3. The ratio of estimated biomass (B_t) and the biomass of MSY (B_{MSY}) of the sergestid shrimp in the waters off Southwestern Taiwan (1997-2008).

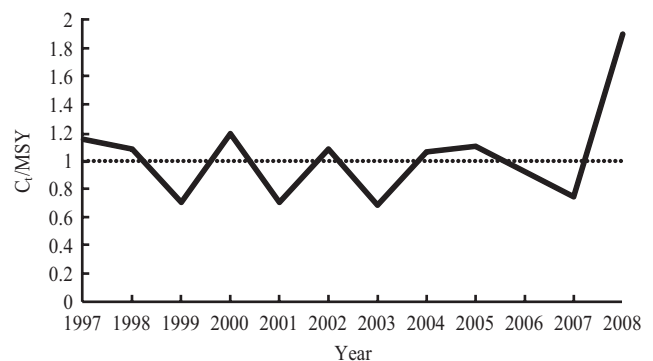


Fig. 5. The ratio of annual yield (C_t) and MSY of the sergestid shrimp fishery in the waters off Southwestern Taiwan (1997-2008).

ranged from the peak of 0.166 in 2005 to the lowest of 0.064 in 2003. The estimated CPUE decreased slightly from the highest of 0.135 in 1997 to the lowest of 0.084 in 2008 (Fig. 2). The discrepancy between these two series was probably due to the measurement and sampling error (observation error). Similar trend was found for the ratio of estimated biomass and the biomass of MSY (B_{MSY}) ranging from 1.51 in 1997 to 0.95 in 2008 (the only one year below 1) (Fig. 3) suggesting the sergestid shrimp stock is not overfished ($B_t/B_{MSY} > 1$).

The ratio of estimated fishing effort and E_{MSY} was below 1 during the period of 1997-2008 with the exception of 2004 and 2008 suggesting that fishing effort was under sustainable level (Fig. 4). The estimated ratio of annual yield (C_t) and MSY indicated only four of the 12 years were less than 1 (Fig. 5). The ratio of F_t and F_{MSY} showed only one year (2008) greater than 1 (Fig. 6) suggesting that the stock is not overfishing ($F_t/F_{MSY} < 1$). The MSY was estimated to be 1008 tons and E_{MSY} was 11292 vessel-day based on the deterministic model.

The above findings suggested that the sergestid shrimp fishery in Tongkang waters is at a reasonable exploitation level (experience no overfished and overfishing).

2. Stochastic Approach

The percentile confidence intervals and distributions of the

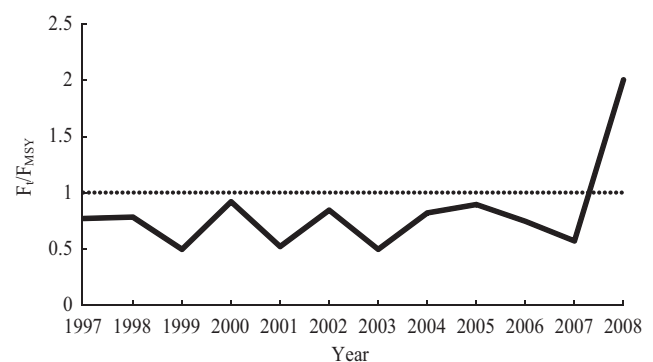
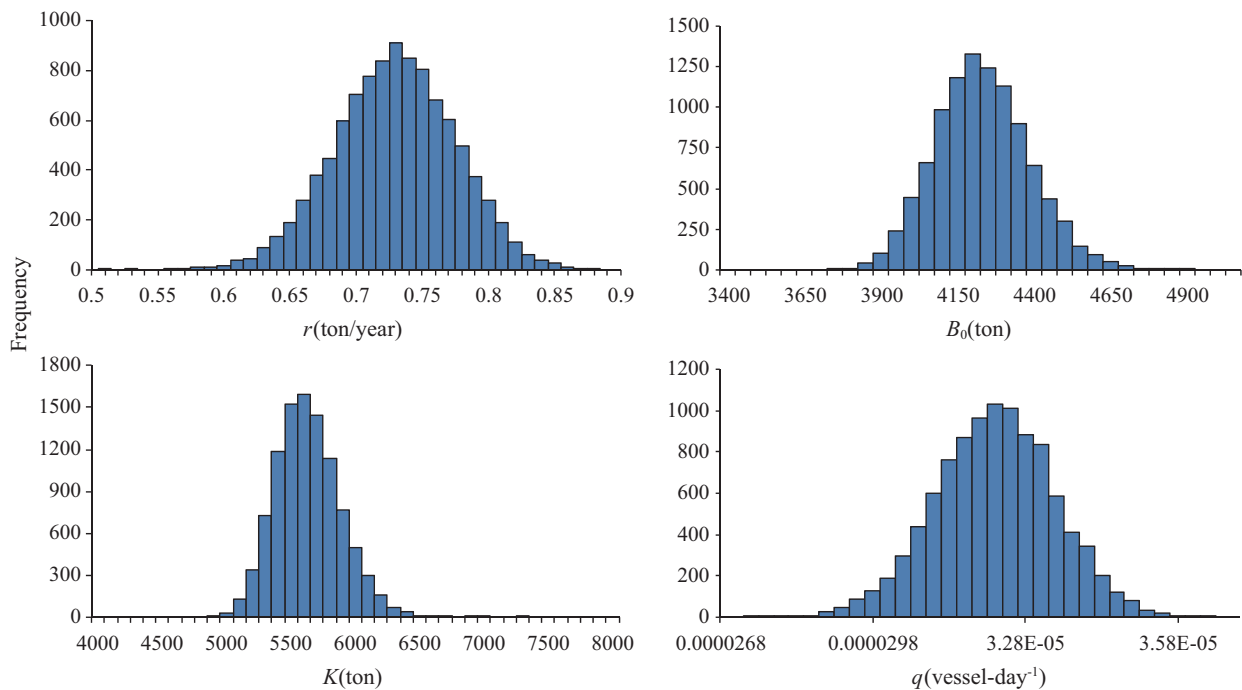
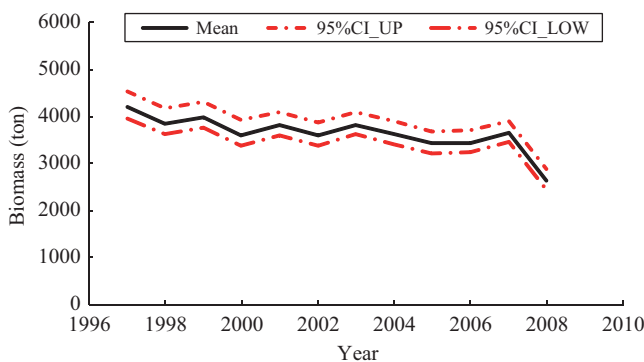


Fig. 6. The ratio of estimated fishing mortality (F_t) and fishing mortality at MSY (F_{MSY}) of the sergestid shrimp fishery in the waters off Southwestern Taiwan (1997-2008).

four parameters estimated based on the stochastic model were showed in Table 2 and Fig. 7. The mean intrinsic population growth rate (r) was estimated to be 0.724 (95% CI = 0.648-0.811). The mean carrying capacity (K) was estimated to be 5585 tons (95% CI = 5199-6133) and the mean catchability (q) was calculated to be 3.21×10^{-5} vessel-day $^{-1}$ (95% CI = 3.01×10^{-5} - 3.43×10^{-5}). The mean MSY, TAC, and E_{MSY} with 95% CI were estimated to be 1011 (842-1243) tons, 910 (758-1119)

Table 2. Summary of output derived from Monte Carlo simulations for the sergestid shrimp fishery in the waters off Southwestern Taiwan.

	r (ton/year)	K (ton)	B_0 (ton)	q (vessel-day ⁻¹)	MSY (ton)	E_{MSY} (vessel-day)	TAC (ton)
Mean	0.724	5585	4207	3.21×10^{-5}	1011	11296	910
95%CI_UP	0.811	6133	4528	3.43×10^{-5}	1243	11807	1119
95%CI_LOW	0.648	5199	3963	3.01×10^{-5}	842	10758	758

**Fig. 7. The frequency distributions of r , K , B_0 , and q obtained from Monte-Carlo simulations with 10,000 iterations.****Fig. 8. The estimated mean biomass (with 95% CI) of the sergestid shrimp in the waters off Southwestern Taiwan (1997-2008).**

tons, and 11296 (10758-11807) vessel-day, respectively from the stochastic models (Table 2). These results were comparable with those adjusted values estimated by Chen [2] and Hong [8]. Furthermore, a slightly declining trend was found for the estimated biomass. The estimated biomass ranged from 4207 tons (95% CI = 3963-4528 tons) in 1997 to 2640

tons in 2008 (95% CI = 2456-2888 tons) (Fig. 8). This decreasing trend implied that the sergestid shrimp population is declining and close monitoring on this species is needed to ensure sustainable utilization of the stock.

IV. DISCUSSION

The analysis in the present study was based on the assumption that the sergestid shrimp in the southwestern Taiwan is a unit stock. However, no evidence can either accept or reject this hypothesis. To clarify this problem, a suitable stock identification study with molecular technique such as DNA analysis is needed in the future. Similar estimates of MSY and TAC were found from the deterministic and stochastic methods (Table 3). However, the deterministic model assumed all parameters remain constant. In reality, the true parameter values of the fisheries estimators are generally unknown [6], such as biomass that is poorly known and is difficult to estimate. Therefore, simulation model would tend to favor stochastic model because at least the uncertainty of some of the variables or parameters can be taken into account. Although

Table 3. Summary of the MSY and TAC of the sergestid shrimp in southwestern Taiwan waters estimated by different authors. Values in parentheses are adjusted MSY and TAC or 95% confidence interval. The yields were estimated based on the unit of 15 kg per box in the past but actually the unit should be 20 kg/box. Therefore, the MSY and TAC of previous studies were adjusted accordingly.

Studies	Methods	Data (year)	MSY (ton)	TAC (ton)
Chen (1999)	Fox model	1992-1996	865 (1153)	840 (1120)
Jong (2001)	Schaefer model	1996-2000	720 (960)	576 (768)
Miao <i>et al.</i> (2006)	Leslie model	1999-2000	-	591 (788)
Hong (2008)	Fox model	1998-2007	732 (976)	-
Hong (2008)	Schaefer model	1998-2007	749 (999)	-
Hong (2008)	Pella-Tomlinson model	1998-2007	748 (997)	711 (948)
Present study	Schaefer model with deterministic observation-error	1997-2008	1008	907
Present study	Schaefer model with stochastic observation-error	1997-2008	1011 (842-1243)	910 (758-1119)

several studies have proposed the MSY or TAC for this stock by using different methods, discrepancy was found among them and the present study (Table 3). None of those studies has even considered the uncertainty in their analyses. In addition, the present study used a longer catch and effort series than previous studies. Thus, we believe the present study will provide a more realistic and better view of the population dynamics for this stock.

In the present study, only observation error has been taken into account in our analysis but the processing error has not been included. The process error assumes that the observations used to fit the model are made without error. In fact, it is not easy to work with both types of error simultaneously in the model. Furthermore, it has been found to be more appropriate to assume only the existence of observation error [14]. Thus, we believe our approach in the present study is a reasonable practice.

The method of observation error estimation is the most recommended approach because simulations have demonstrated that it can more closely reflect the real condition of observations [7, 21-23]. Nevertheless, all of these approaches only consider the variability existed in the sampling data (such as CPUE or biomass), but ignoring other sources of variability. Besides, due to the short time series of fisheries data, the full range of environmental variation cannot be incorporated in the model.

In addition to the fishing activities, many factors may affect the dynamic of sergestid shrimp population. As this species is a short life span shrimp the population size may be affected the environmental factors such as precipitation, salinity and water

temperature [9]. Moreover, most biomass dynamics (or production) models assume that natural mortality is not very high. Although this assumption may not be suitable for the short-lived species, the production models are commonly applied to the shellfish [1, 27]. Chen [2] documented that the high catch of sergestid shrimp was associated with precipitation. Miao *et al.* [17] estimated B_0 of the sergestid shrimp stock to be 2015 tons in 1999. Furthermore, Chen [2] reported a biomass of 1560 tons for the sergestid shrimp in 1993 based on the Leslie method. However, the biomass obtained by our methods (Table 2) is larger than those estimated by previous studies. The discrepancy may be resulted from different data series were used in different studies. To examine the sensitivity of B_0 on estimation of MSY, E_{MSY} and TAC, 1% random error of CV was incorporated into the model. Even with only 1% random error of B_0 , the results of simulations showed that the confidence intervals are relatively wide around MSY, E_{MSY} and TAC, which would be typical of the uncertainty surrounding these parameters (Table 2). Therefore, it is a necessity to incorporate the uncertainty on estimation of MSY, E_{MSY} and TAC. In addition, two biological reference points B_i/B_{MSY} and F_i/F_{MSY} which implies overfished and overfishing, respectively were applied in the present study. Furthermore, the catch-effort time series used in the present study are much longer than previous studies. Thus, our estimation is believed to be more robust and reasonable.

In conclusion, in addition to current management measures, the TAC should be included in current management measure to ensure a long-term sustainable utilization of this stock in spite of no overfishing and overfished occurrence.

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