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Sustainable Management of Shrimp Trawl Fishery in Tonkin Gulf, Vietnam*

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This study investigates the sustainability of shrimp stock in the trawl fishery in the Tonkin Gulf, Vietnam. It is a small scale and multi-species fishery. The Verhulst-Schaefer and Gompertz-Fox surplus production models are applied. There are two shrimp spawning seasons in a year in the Gulf. Therefore, in this study, the surplus production models, associated to catch calendar and effort data, are applied for a half-year time interval. The results indicate that the fishing effort should be reduced by roughly 12-44% to achieve the maximum sustainable yield and 46-61% to reach the maximum economic yield. With a social discount rate of 10%, the effort should decrease by around 45-56% to achieve the optimal yield. The entry tax should be 92-279 USD/month/boat to achieve the maximum sustainable yield and 160-314 USD/month/boat to attain the maximum economic yield.

Keywords: bioeconomic analysis, shrimp trawl fishery, fishery management, Vietnam

JEL Classification: D24, H41, Q22

Introduction

The Tonkin Gulf is a shallow, semi-closed gulf in the northwest South China Sea with an average depth of around 38 m and a total area of about 128,000 km^2, and Vietnam's marine water measures about 67,000 km^2 in the western part of the gulf (Chinh *et al.*, 2005; Xue, 2005). The Gulf is one of the most important fishing grounds in Vietnam's marine water. It annually contributes around 16% of Vietnam's marine resources, 30% of its total fishing boats, and about 20% of its total marine landings (Chinh, 2005). The Gulf has small-scale, multi-species and multi-gear fisheries. In 2003, about 26,000 fishing boats fished in the Gulf using 25 different types of gear; 86% of these boats had an engine of less than 45 HP (Chinh, 2005). There are 166 species from 74 different families that have

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been identified by bottom trawl surveys in the offshore water of the Gulf (Son, 2001). Some studies have shown that the maximum sustainable yield (MSY) in its coastal areas was reached in 1994, and fishing activities have had low economic returns due to overfishing problems (Long, 2001; Long, 2003). The catch per unit of effort (CPUE) of the fisheries in the Gulf has declined from 1.34 to 0.34 ton/HP/year between 1985 and 1997 (Son, 2003). Meanwhile, shrimp is the most important commercial species in Vietnam. In 2003, shrimp landings contributed around 5.5% in volume and 17% in value for marine capture fisheries in Vietnam (Huong and Quan, 2007; www.fistenet.gov.vn). In the Tonkin Gulf, shrimp landings mostly from the shrimp trawl fishery were around 11,445 tones; this was about 4.6% of the total catch in 2003 (Chinh, 2005).

Some management tools have been applied for the shrimp trawl fishery such as licensing, minimum legal length restrictions, minimum mesh size restrictions, and tax regulations, but compliance with these regulations is questionable. The license regulation stands in contrast to an open access system in which a limited number of boats or boat owners are given licenses (King, 1995). In Vietnam, fishing licenses are imposed, but many fishermen appear to ignore them. Licenses are granted on the basis of submitting a number of supporting documents such as vessel inspection, registration papers and paying a small license fee proportional to engine size. A license application generally leads to a license being issued, and the shrimp trawl fishery as well as other marine capture fisheries effectively operate under the open access system (FAO, 2005). The minimum legal length restriction seems to be inefficient in the shrimp trawl fishery. In a 2003 survey, some shrimp species (namely, *Metapenaeus intermedius* and *Metapenaeus affinis*) were caught with an equal mean length of around one third of the minimum legal length. The data from the Assessment of Living Marine Resources in Vietnam (ALRMV project) during 2000-2004 indicated that almost all shrimp trawlers had been seriously violating the minimum mesh size regulation (Thanh, 2006). This implies that the minimum mesh size was also an inefficient regulatory tool in the shrimp trawl fishery. Under the Government Degree no. 68/1998/ND-CP dated 3 September 1998, to regulate and guide the implementation of the natural resources tax ordinance, a tax on landing is imposed. The rate of taxation was stipulated at 2% of the catch value, and it was to be collected based on trawler landings. However, landing and/or output control had not been applied to the shrimp trawl fishery. In practice, an entry tax was annually collected of around 0.66% of the fixed cost for the otter trawler with 20-45 HP engines and about 3.98% of the fixed cost for the beam trawler with 20-45 HP engines. Although taxation is an indirect management tool, it seems to be more efficient than the direct management tools such as the minimum size and mesh size regulations.

The sustainability of the shrimp stock in the trawl fishery in the Tonkin Gulf is investigated in this study. Two questions will be addressed: What are the sustainable optimal stock level and the associated harvest? and how should the optimal stock level be approached? The bioeconomic analysis of historical data is applied. The models are presented in the next section, followed by a description of the demand data. The study concludes with a discussion of the model results, the reference points and some recommendations on fishery management.

Models

The shrimp trawl fishery is typical of a small-scale and multi-species fishery. For such fisheries, surplus production models often have shown to be appropriate analytical tools when catch and effort data are available. Hilborn and Walters (1992: 298) argues that "It is quite difficult to age many fishes, particularly tropical ones, and age-structured analysis is often not practical in these fisheries. Moreover, in the tropical fisheries, the catch consists of many species, and the catch data are difficult if not impossible to collect by species. Management regulations are also difficult to make species specific. In these cases, treating the entire catch as a biomass dynamics pool may be more appropriate than trying to look at single species dynamics". Garcia (1988: 237) also argues that surplus production models might be more appropriate than other models for shrimp fisheries because of the short life span of the species, which means that equilibrium conditions may be attained at any time within a biological year, starting at the point of main recruitment. With respect to the Tonkin Gulf, there are two shrimp spawning seasons per year (i.e. February-March and June-July), implying that it is appropriate to divide the time scale by half-year in accordance with the biological period of the stock. Surplus production models are generally applicable to calendar-year data. (see e.g. Ahmed *et al.*, 2007; Grafton *et al.*, 2010; Kompas *et al.*, 2010). However, this study uses data with half-year intervals. It is assumed that the stock reaches equilibrium within a period of six months. The models use steady state (equilibrium) conditions to formulate reference points and equilibrium assumptions to estimate parameters.

A discrete-time model for exploited stock can be expressed as follows (e.g. Clark, 1990; Conrad, 1999):

$$X_{t+1} - X_t = F(X_t) - H(E_t, X_t) \tag{1}$$

where X_t and X_{t+1} indicate stock biomass in year t and $t+1$, $F(X_t)$ indicates the biological growth of the stock, and $H(E_t, X_t)$ indicates the harvest function, which depends on fishing effort (E_t) and stock biomass (X_t).

In equilibrium $X_{t+1} - X_t = 0$, the stock remains at a constant level.[1] In other words, the biological growth F(X) equals the sustainable yield that can be harvested $(H(E, X))$ while maintaining a fixed stock level X (Schaefer, 1954; Clark, 1990; Clark, 2010). Hence,

[1] For simplicity, the *t* subscript can be dropped.

at the steady state conditions (equilibrium), the sustainable yield can be derived from the function:

$$F(X) \equiv H(E, X)$$

The harvest function of a fishery is often assumed to be a Cobb-Douglas function (Clark and Munro, 1975; Clark, 1990; Eide *et al*., 2003):

$$H = H(E, X) = qE^{\alpha} X^{\beta}$$

where q is gear and stock specific constant, referred to as the catchability coefficient; α, β are positive constants. In case $\alpha = \beta = 1$ the harvest function simplifies to:

$$H(E, X) = qEX$$

Fishing effort is aggregated from a number of different harvesting activities and measured by towing hours, and the biomass variable consists of number of harvested shrimp species (to be measured in tons).

In the Verhulst-Schaefer model (Schaefer, 1954)[2] , it is assumed that the biological growth follows the logistic growth function. Therefore, exploited stock can be expressed as follows:

$$X_{t+1} - X_t = rX_t\left(1 - \frac{X_t}{K}\right) - qE_tX_t \tag{2}$$

where r indicates the intrinsic growth rate, and K is environmental carrying capacity. In equilibrium, the model implies that:

$$qEX = rX(1 - \frac{X}{K}) \Leftrightarrow X = K - \frac{KqE}{r}$$

The sustainable yield for a given level of effort:

$$H_1(E) = qKE - \frac{q^2K}{r}E^2$$

The relationship between catch per unit effort (CPUE) and effort is linear as derived from the sustainable yield equation:

$$CPUE_1 = \frac{H_1(E)}{E} = qK - \frac{q^2K}{r}E$$

Let $\gamma = qK$ and $\gamma_1 = -\frac{q^2K}{r}$,then obtain:

$$CPUE_1 = \gamma + \gamma_1 E \text{ and } H_1 = \gamma E + \gamma_1 E^2 \tag{3}$$

Since shrimp is internationally traded, it is assumed that shrimp trawl fishery has a perfectly elastic demand curve. The total revenue (TR) and total cost (TC) of the fishery are defined (Schaefer, 1954; Clark, 1990) as follows:

$$TR(t) = p * H(E(t), X(t)) \tag{4}$$

$$TC(t) = c * E(t) \tag{5}$$

[2] The model was proposed by Gordon and Schaefer in 1954 and 1957, and it uses the logistic growth equation proposed by P. F. Verhulst in 1838.

where *p* indicates the constant price per unit of harvested biomass, and *c* indicates the constant cost per unit of effort.

The *profit* of the fishery is:

$$\prod(t) = TR(t) - TC(t) = p * H(E(t), X(t)) - c * E(t) \qquad (6)$$

Substituting equation (3) into (6), then obtain the profit of the fishery in the Verhulst-Schaefer model as follows:

$$\Pi_1 = pH_1 - cE = (p\gamma - c)E + p\gamma_1 E^2$$

In the Gompertz-Fox model (Fox, 1970)[3] , it is assumed that the biological growth follows the Gompertz growth function. Therefore, exploited stock can be expressed as follows:

$$X_{t+1} - X_t = rX_t \ln\ln\left(\frac{K}{X_t}\right) - qE_t X_t \qquad (7)$$

In equilibrium, the model implies that:

$$qEX = rX\ln\left(\frac{K}{X}\right) \Leftrightarrow X = \frac{K}{e^{\frac{qE}{r}}}$$

The sustainable yield for a given level of effort:

$$H_2(E) = \frac{qKE}{e^{\frac{qE}{r}}} = qKEe^{-\frac{qE}{r}}$$

The relationship between Log (CPUE) and effort is linear as derived from the sustainable yield equation:

$$CPUE_2 = \frac{H_2(E)}{E} = qKe^{-\frac{qE}{r}}$$

Taking natural logarithm of both sides:

$$Ln(CPUE_2) = Ln(qK) - \frac{q}{r}E$$

Let $\gamma = Ln(qK)$ and $\gamma_1 = -\frac{q}{r}$, then

$$Ln(CPUE_2) = \gamma + \gamma_1 E \text{ and } H_2 = Ee^{\gamma + \gamma_1 E} \qquad (8)$$

Substitute equation (8) into (6) to obtain the profit of the fishery in the Gompertz-Fox model as follows:

$$\Pi_2 = pH_2 - cE = E(pe^{\gamma + \gamma_1 E} - c)$$

In the open access situation (OA), fishermen will join in the fishery until marginal cost (MC) is equal to average revenue (AR). In this case, the open access stock biomass

[3] The model was proposed by Fox in 1970 and uses the growth equation proposed by Gompertz in 1825.

(XOA) is defined by cost per unit effort, price and the catchability coefficient:

$$MC = AR \Leftrightarrow c = \frac{p * H}{E} = pqX_{OA} \Rightarrow X_{OA} = \frac{c}{pq}$$

The effort and yield formulae in the open access situation of Verhulst-Schaefer and Gompertz-Fox models are shown in Table 1.

Table 1 Effort and yield formulae in open access situation of Verhulst-Schaefer and Gompertz-Fox models

Models	Effort	Yield
Verhulst-Schaefer	$E_{OA1} = \frac{c - p\gamma}{p\gamma_1} = \frac{r}{q}\left(1 - \frac{c}{pqK}\right)$	$Y_{OA1} = \frac{c^2 - pc\gamma}{p^2\gamma_1} = \frac{rc}{pq}\left(1 - \frac{c}{pqK}\right)$
Gompertz-Fox	$E_{OA2} = \frac{\ln c - \ln p - \gamma}{\gamma_1} = \frac{r}{q}\ln\frac{pqK}{c}$	$Y_{OA2} = \frac{c(\ln c - \ln p - \gamma)}{p\gamma_1} = \frac{cr}{pq}\ln\frac{pqK}{c}$

The fishing effort that produces the maximum sustainable yield is derived by differentiating equations H_1 and H_2 with respect to *E*. The MSY and effort used at MSY are shown in Table 2.

Table 2 Yield and effort formulae at MSY situation of Verhulst-Schaefer and Gompertz-Fox models

Models	Effort	Yield
Verhulst-Schaefer	$E_{MSY1} = -\frac{\gamma}{2\gamma_1} = \frac{r}{2q}$	$MSY_1 = -\frac{\gamma^2}{4\gamma_1} = \frac{rK}{4}$
Gompertz-Fox	$E_{MSY2} = -\frac{1}{\gamma_1} = \frac{r}{q}$	$MSY_2 = -\frac{1}{\gamma_1}e^{\gamma - 1} = \frac{rK}{e}$

The fishing effort that produces the maximum economic yield (MEY) is derived by differentiating equations Π_1 and Π_2 with respect to *E*. The results are presented in Table 3.

Table 3 Yield and effort formulae at MEY of Verhulst-Schaefer and Gompertz-Fox models

Models	Effort	Yield
Verhulst-Schaefer	$E_{MEY1} = \frac{c - p\gamma}{2p\gamma_1} = \frac{r(pqK - c)}{2pq^2K}$	$MEY_1 = \frac{c^2 - p^2\gamma^2}{4p^2\gamma_1} = \frac{r(p^2q^2K^2 - c^2)}{4p^2q^2K}$
Gompertz-Fox	$E_{MEY2} = \frac{-1 + w}{\gamma_1}$	$E_{MEY2} = \frac{-e^{-1+\gamma+w} + \frac{c}{p}}{\gamma_1}$

Note: $we^w = \frac{ce^{1-\gamma}}{p} = \frac{ce^{1-\ln qK}}{p}$

The equation that maximizes the present value (PV) of the fishery can be expressed as follows:

$$\max_{0 \le H_t \le H_{max}} \max_{0 \le H_t \le H_{max}} \sum_{t=\infty}^{t=0} \rho^t \pi(t) \tag{9}$$

$$subject: X_{t+1} - X_t = F(X_t) - H_t$$

where ρ indicates the discount factor. The current-value Lagrangian (see e.g. Conrad and Clark, 1995) is:

$$L = \sum_{t=\infty}^{t=0} \rho^t \{\pi(t) + \rho_{t+1}[X_t + F(X_t) - H_t - X_{t+1}]\}$$

The necessary conditions are:

$$\frac{\partial L}{\partial H} = \rho\{\pi - \rho\lambda\} = 0$$

$$\frac{\partial L}{\partial X} = \rho\left\{\pi \mp \rho\left[1 + F(X)\right]\right\} - \rho\lambda$$

In equilibrium, these conditions imply that:

$$\pi'_H = \rho\lambda$$

$$\rho\lambda\left[1 + F'(X) - (1+\delta)\right] = -\pi'_X$$

where δ indicates the discount rate. Assuming the prices are constant, π,*(X, H)* = *p*H- c*E* and *H = q*E*X,* therefore,

$$\pi(X,H) = pH - \frac{cH}{qX}$$

Substituting into the necessary conditions, then obtain:

$$F'(X) + \frac{cF(X)}{X(pqX - c)} = \delta \tag{10}$$

The optimal biomass can be determined for the Verhulst-Schaefer model from equation (10) (Clark, 1990; Conrad, 1999; Clark, 2010):

$$X^* = \frac{K}{4}\left(\left(\frac{c}{pqK} + 1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{c}{pqK} + 1 - \frac{\delta}{r}\right)^2 + \frac{8c\delta}{pqKr}}\right) \tag{11}$$

And the optimal biomass for the Gompertz-Fox model can be determined as follows (Clarke, Yoshimoto, and Pooley, 1992):

$$ln\left(\frac{K}{X^*}\right) - \left(1 + \frac{\delta}{r}\right)\left(1 - \frac{c}{pqX^*}\right) = 0 \tag{12}$$

Optimal yield (*F[X*]*) can be computed by the equation (7) and optimal effort (*E**) can be determined by the following equation:

$$E^{*} = \frac{F\left[X^{*}\right]}{qX^{*}} \tag{13}$$

Data

The demand data were obtained from the ALRMV project supported by DANIDA and carried out in Vietnam from 2000 to 2004 (Thanh, 2006). The fleet was divided into groups based on the fishing gears and horsepower of the main engines. In the project, interviews were conducted monthly at local harbors. Data from the interviews were used to estimate indicators for differences across shrimp trawler groups. These monthly indicators include the average CPUE in kg/towing hour, average effort in towing hours/boat, the average percentage of shrimp per catch, the average price of shrimp in 1,000 VND, and the average variable cost per towing hour in 1,000 VND. Other relevant data such as the number of boats were collected from both the ALRMV project and the Ministry of Fisheries (MOFI).[4]

In this study, the shrimp trawlers with engines less than 45 HP are divided into three groups. The first group is the otter trawlers with 20-45 HP engines. This is the largest group representing the standard group for aggregating fishery efforts. The second group is the otter trawlers and beam trawlers with engines of lower than 20 HP. It is assumed to form a single and homogeneous group. The third group is the beam trawlers with 20-45 HP engines.

To apply bioeconomic models to the shrimp trawl fishery, monthly catch and effort according to the different shrimp trawler groups must be standardized. For this purpose, the standardized CPUE for shrimp is computed by multiplying the average CPUE for mixed landings with the shrimp proportion. The effort from different trawler groups are then standardized based on relative fishing power, defined as the ratio of the standardized CPUE of each group to that of the group taken as a standard and fishing for the same density of fish on the same type of ground (Beverton and Holt, 1993). As such, each group can be allotted a power factor that is used to compute a standardized effort. The catch of each group is estimated by multiplying the standardized CPUE by the average effort and the number of boats in the group. The total catch of the fishery is computed by summing the catch of different shrimp trawler groups. The fixed price is calculated as the weighted average price of the catch for the period of study from 2000 to 2004 as follows:

$$p = \frac{\sum_{F=1}^{k} \sum_{j=2000}^{2004} \sum_{i=1}^{m} p_{Fji} H_{Fji}^{Month}}{\sum_{F=1}^{k} \sum_{j=2000}^{2004} \sum_{i=1}^{m} H_{Fji}^{Month}} \tag{14}$$

[4] This is now the Ministry of Agriculture and Rural Development (MARD)

where p_{Fji} indicates the average price of 1 kg shrimp in month *i* of year *j* that fleet *F* caught, and H_{Fji}^{Month} indicates the catch in month *i*, year *j* of fleet *F*.

The cost per unit of effort per month for one boat in one group (c_F) is computed by summing the variable cost (c_{vc}) and the fixed cost (c_{fc}):

$$c_F = c_{vc} + c_{fc} \tag{15}$$

The cost per unit of the standardized effort is computed as the weighted average cost of effort for the period of study from 2000 to 2004 by the following equation:

$$c = \frac{\sum_{F=1}^{k}\sum_{j=2000}^{2004}\sum_{i=1}^{m} c_{Fji} E_{Fji}^{Month}}{\sum_{F=1}^{k}\sum_{j=2000}^{2004}\sum_{i=1}^{m} E_{Fji}^{Month}} \tag{16}$$

where c_{Fji} indicates the cost per unit of effort in month *i*, year *j* of fleet *F*, and E_{Fji}^{Month} indicates effort in month *i*, year *j* of fleet *F*.

Table 4 show the standardized data of catch, effort and CPUE to be used in the bioeconomic models. The standardized data of shrimp price is 1.584 USD/kg and the cost per unit of effort is 2.270 USD/hour. The data of the shrimp stock biomass in 2003 of 4,165*10^{-4} ton in southwest monsoon season and 6,687*10^{-9} ton in northeast monsoon season (Thi *et al.*, 2004) were used to estimate the catchability (*q*).

Table 4 Standardized catch, effort and CPUE of the fishery by half-year

Year	Half-year	Catch (10^{-3} ton)	Effort (h)	CPUE (10^{-3} ton/h)
2000	1	7,522,878	4,158,473	1.81
2001	2	7,906,749	4,686,582	1.69
	3	7,476,235	3,581,219	2.09
2002	4	5,887,093	3,619,525	1.63
	5	7,218,815	4,226,861	1.71
2003	6	5,699,222	4,124,319	1.38
	7	3,877,434	5,627,033	0.69
2004	8	5,494,582	3,544,291	1.55
	9	4,065,578	4,708,158	0.86

Source: Thanh (2006)

Results

The estimated coefficients (γ, $\gamma 1$) using OLS (n=9) for each model are shown in Table 5. The slope coefficients equal -5.056*10^{-7} and -4.302*10^{-7} for Verhulst-Schaefer and Gompertz-Fox models, respectively. The results indicate an expected negative relationship between CPUE and effort. Their P-values indicate that the slope coefficients are different from zero with a significance level of 95%. The R^2 values indicate that 58.1% and 63.5% of CPUE variations were explained by the explanatory variable effort in the Verhulst-Schaefer and Gompertz-Fox models, respectively. The observed R^2 values shows that the two models gave reasonable fit to the data. The Gompertz-Fox model was slightly better than the Verhulst-Schaefer model. The Durbin-Watson (DW) statistic for both models is between the 5% upper (1.32) and lower (0.824) limits, so it was inconclusive about serial autocorrelation in residuals. However, the Durbin's alternative test (durbinalt) for serial correlation and Breusch-Godfrey test for higher-order serial correlation show that there was no autocorrelation in residuals for both models.

Table 5 The estimated coefficients for Verhulst-Schaefer and Gompertz-Fox models

Parameters	Verhulst-Schaefer model		Gompertz-Fox model	
	Coefficients	t-value	Coefficient	t-value
γ	3.640	5.212*	2.176	4.106*
γ_1	-5.056×10^{-7}	-3.114*	-4.302×10^{-7}	-3.491*
	R^2	0.581	R^2	0.635
	F	9.696	F	12.187
	DW statistic	0.87	DW statistic	0.84

Note: * Statistical significance at 95% level

The results of predicted catchability, *q*, computed from the estimated biomass derived from independent surveys in 2003[5] . They were $3.31779*10^{-7}$ ton/hour for southwest monsoon season, $1.03047*10^{-7}$ ton/hour for northeast monsoon season, and $2.17413*10^{-7}$ ton/hour in average.

The intrinsic growth rate per half-year, *r*, and the carrying capacity in 1,000 tons, *K*, are calculated based on the estimated coefficients derived from the two models. The estimated results of *r* and *K* are 1.564950 and 16.740900 for the Verhulst-Schaefer model and 0.505324 and 40.528400 for Gompertz-Fox model, respectively.

The sustainable yield as a function of fishing effort, $H_1(E)$ and $H_2(E)$, derived from the two models are plotted against effort as shown in Figure 1. The figure shows a static or equilibrium view of the fishery. The yield refers to the annual catch that can be sustained over a long run if a fixed level of annual fishing effort is maintained. Figure 2 shows total revenue and total cost as a function of fishing effort given the sustainable yield (presented in Figure 1), fixed price and fixed unit cost of fishing effort derived from equation (14) and (16).

[5] Catchability is calculated from the equation *h=qEX*, given *h, E*, and *X* in 2003.

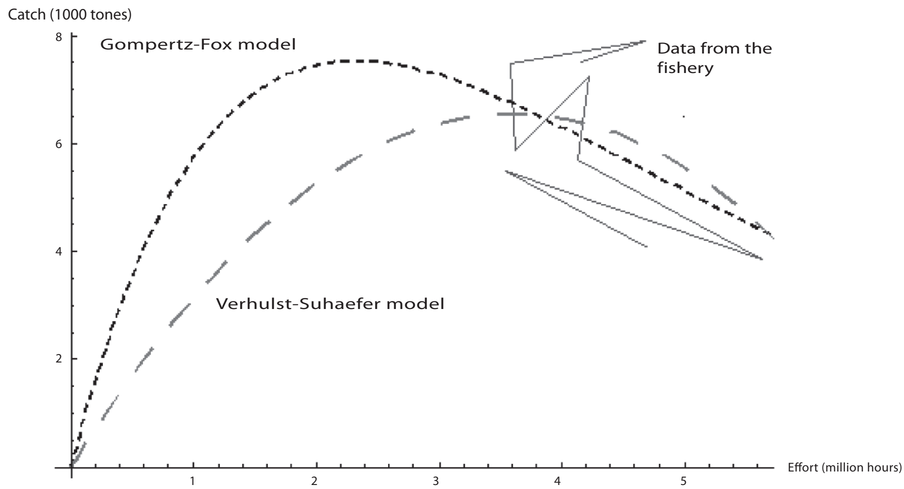

Figure 1 The relationship between catch and effort of Verhulst-Schaefer and Gompertz-Fox models

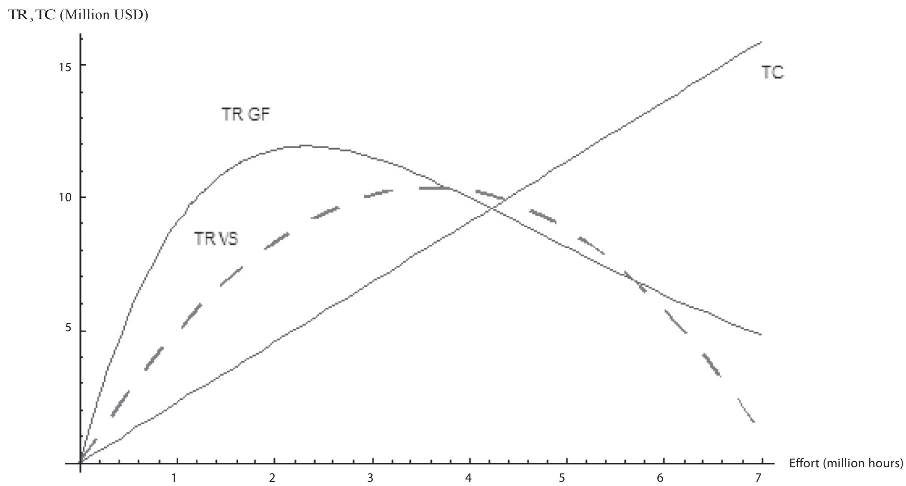

Figure 2 Total revenue, total cost and effort relationships in Verhulst-Schaefer and Gompertz-Fox models

Table 6 shows reference points derived from two models. The two models show considerable differences in predicted reference points. The Gompertz-Fox model shows that the MSY of the shrimp fishery was 15% higher than that from the Verhulst-Schaefer model. The Gompertz-Fox model shows 35% lower in the effort level at MSY than that of the Verhulst-Schaefer model. The estimated profits at MSY ($p*MSY-c*E_{MSY}$) were higher in the Gompertz-Fox model due to the differences in predicted efforts. The Gompertz-Fox model also shows that the stock was heavily exploited, while the Verhulst-Schaefer model predicts that the stock was fully exploited.

Table 6 Catch and effort reference points

Reference points	OA		MSY		MEY	
	Verhulst-Schaefer	Gompertz-Fox	Verhulst-Schaefer	Gompertz-Fox	Verhulst-Schaefer	Gompertz-Fox
Catch (1,000 tons)	6.25477	6.05070	6.54969	7.53417	5.53345	7.05241
Effort (10^6 hours)	4.36275	4.22040	3.59904	2.32426	2.18137	1.57845

The discounted optimal values for *Y*, E*, X*, CPUE** and the estimated profits are shown in Table 7. The discount rates indicate biological considerations (5%), social accounting (10%), and private interest rates compounded by risk (20%) (Clark, 1990; Clarke, Yoshimoto, and Pooley, 1992). The results at 0% (i.e. no discounting) as well as those tending toward infinity (∞) confirm the values estimated for the static MEY and OA. The two models show the same trends in optimal reference points over the range of discount rates (i.e. δ between 0% and 20%), although absolute values varied. In terms of percentages, estimated optimal effort values varied the most over various discount rates within a given model (6.37-10.91%), while estimated profits varied the least (0.05-0.56%). Optimal yield varied at the same, low level, for the two models (1.17-2.10%). Optimal biomass and optimal CPUE varied by 0.98-1.88% for the Verhulst-Schaefer model and 4.82-8.11% for the Gompertz-Fox model. According to the two models, the MEY varied by 27% while corresponding effort varied by 28% (Table 6). The profit at the MEY varied by 100% for the two models (Table 7).

Table 7 Optimal reference points

Models	δ (%)	*Y** (1,000 tons)	*E** (10^6 hour)	*X** (1,000 tons)	π^* (Million USD)	*CPUE** (10^{-3} ton/hour)
Verhulst-Schaefer	0	5.53345	2.18137	11.66760	3.810	2.536686
	5	5.60297	2.23073	11.55280	3.808	2.511720
	10	5.66832	2.27880	11.44100	3.803	2.487414
	20	5.78732	2.37115	11.22620	3.782	2.440723
	∞	6.25477	4.36275	6.59427	0	1.433676
Gompertz-Fox	0	7.05241	1.57845	20.55050	7.585	4.467934
	5	7.20065	1.69317	19.56080	7.559	4.252763
	10	7.31203	1.80103	18.67380	7.491	4.059916
	20	7.45235	1.99751	17.16010	7.267	3.730820
	∞	6.05070	4.22040	6.59427	0	1.433679

Based on the results above, the policy implications on taxation can be drawn. In the open access scenario, the amount of landing tax, effort tax and entry tax to be imposed at MSY and MEY are shown in Table 8.

Table 8 Tax policies to achieve MSY

Model	Landing tax (USD/ton)	Effort tax (USD/hour)	Entry tax (USD/boat/month)
MSY			
- Verhulst-Schaefer	336	0.612	92.379
- Gompertz-Fox	883	2.863	279.293
MEY			
- Verhulst-Schaefer	689	1.747	159.926
- Gompertz-Fox	1076	4.805	318.343

Table 9 shows that on a percentage basis, estimated effort tax values varied the most over varying discount rates within the Gompertz model (7.09-12.53%), while estimated entry tax values varied the least within the Verhulst-Schaefer model (0.05-0.56%). The estimated tax on landing values varied by 1.29-2.60% for the Verhulst-Schaefer model and 2.39-4.82% for the Gompertz-Fox model.

Table 9 Tax policies to achieve optimal reference points

Model	δ (%)	Landing tax (USD/ton)	Effort tax (USD/hour)	Entry tax (USD/boat/month)
Verhulst-	0	689	1.747	159.926
Schaefer	5	680	1.707	159.844
	10	671	1.669	159.607
	20	653	1.595	158.716
	∞	0	0	0
Gompertz-Fox	0	1076	4.805	318.343
	5	1050	4.464	317.265
	10	1024	4.159	314.389
	20	975	3.638	304.993
	∞	0	0	0

Discussion

Previous studies indicate that fisheries seem to be overexploited. Long (2001; 2003) argued that shrimp trawler fleets were decreasing in size and number due to overfishing. Chinh (2005) showed that the density of penaeid stock had been reduced by half over a thirty-year period from 1975 to 2002. The Verhulst-Schaefer model, including a logistic growth function, showed the current multi-species shrimp biomass to be closer to the MSY level than did the Gompertz-Fox model. The Verhulst-Schaefer model predicted the intrinsic growth rate of the shrimp stock to be 1.5-fold per a half year, three times higher than that of the Gompertz-Fox model. However, the data used in the models are short time series data, which means that the results may not globally describe fishery developments. Indeed, the reference points derived from the models may be just local reference points. In this study, a range of reference points were derived from the two models to take these uncertainties into consideration.

This study demonstrates that the surplus production models are not necessarily restricted to annual periods. These models can be applied flexibly to take into account the biological characteristics of the stock. In contrast, for a fast-growing species with a high turnover rate (that is, short lifespan) in tropical areas, as is the case of shrimp in this study, using data from an enumerator program may be an alternative to reduce problems related to insufficient statistical data. In addition, a range of reference points was chosen for the fishery in this study because it is difficult to choose a priority model, and the time series covers a short time span. This may also be one way to deal with uncertainties due to insufficient statistical data.

The results from the two models show that the open access yield of the fishery was around 6,000 tons per half-year or 12,000 tons per year while the official catch statistics was around 11,445 tons for 2003 (Chinh, 2005). This open access yield figure may also be appropriate for measuring shrimp biomass, estimated to be about 4,165 tons in the southwest monsoon season and 6,687 tons in the northeast monsoon season (Thi, Ha, and Kien, 2004) because the penaeid shrimps, a short-lifespan species, have a high annual turnover growth rate. It is common for the shrimp population to have an annual growth that, in biomass terms, exceeds the population size at some points during the year. Fox (1970) argued that the commercial exploitation of the marine fish population is usually directed toward mature individuals, and if spawning occurs during the year, the survival of the population may be ensured, even at 100% annual fishing mortality. Other arguments could be applied to multi-species problems. The species composition probably changes over time, typically toward less valuable species. This could change the MSY value dynamically over time. The possible depletion of one species may be reduced by the increase in another species (Gulland and Rothschild, 1984).

It is unlikely that any single management measure will produce the desired results; moreover, a combination of several regulations may be needed (King, 1995). The entry tax was applied effectively to the shrimp trawl fishery. However, the current tax is 6.67 USD/boat/month. It should be increased to achieve the reference points of the fishery. An entry tax should be between 92-279 USD/boat/month to achieve the MSY. At the social discounted rate of 10%, an entry tax of 160-314 USD/month/boat should be imposed to attain the MEY. The current tax should thus be increased 14-47 fold to achieve the selected reference points.

Previous studies show that the legal length and the minimum mesh size regulations were inefficient means of managing the shrimp trawl fishery (Thanh, 2006). A closed season regulation may be an alternative. The current fishing season should be reduced 12-44% per half-year to achieve the targeted MSY and 45-56% per half-year to achieve the targeted MEY. The appropriate timing and duration of closed fishing seasons depend on the shrimp spawning seasons, the specific fishing areas and the fishing communities.

Conclusions

In this study, two surplus production models (i.e. the Verhulst-Schaefer and Gompertz-Fox models) are presented and parameterized to analyze catch and effort data from a Vietnamese shrimp fishery. The data were aggregated in half-year periods in accordance with the biological year of the shrimp stock in the Tonkin Gulf. The results derived from the models are then compared with the data from independent surveys and official statistics.

The two models indicate that the fishery is fully exploited both in terms of maximizing yield and maximizing profits. The E_{MSY} and E_{MEY} values of the fishery from the Verhulst-Schaefer model were 3.6 and 2.2 millions fishing hours, respectively. The E_{MSY} and E_{MEY} values of the fishery from the Gompertz-Fox model were 2.3 and 1.6 millions fishing hours, respectively. The effort of the fishery in 2004 (i.e. the average effort per half-year) was estimated to be 4.1 millions fishing hours indicating that the harvest of the shrimp stock is not sustainable with respect to the reference points. The fishing effort should be strongly reduced to achieve optimal reference points. Based on Verhulst-Schaefer model and Gompert-Fox model, the current effort (in 2004) should have been reduced by 12% and 44% to achieve the MSY and by 46% and 61% to reach the MEY, respectively. At the social discount rate of 10%, the current effort should have been reduced by around 45-56% to achieve the optimal yield.

The entry tax rates should be increased. However, the recommended rates may be too high for poor fishers such that only the most efficient boats would be able to comply. The government should directly invest tax revenues on improving the poor fishing communities' livelihood.

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