BIOECONOMIC ANALYSIS OF THE ARTISANAL SHRIMP TRAWL FISHERY IN THE TONKIN GULF, VIETNAM

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ABSTRACT

The objective of this study is to investigate the sustainability properties of the stock of the shrimp trawl fishery in the Tonkin Gulf, Vietnam. Surplus production models of Verhulst-Schaefer and Gompertz-Fox are applied to the shrimp trawl fishery, which is a typical tropical fishery with the characteristic properties of small scale and multi-species fisheries. There are two shrimp spawning seasons per year in the Gulf. This implies that it is appropriate to divide the time scale into a half year in accordance with the biological year of the stock. The surplus production models which are usually associated to calendar year catch and effort data, in this study are applied for a half year time interval data. From 2000 to 2004, the total catch of the fishery fluctuated between 3.8 thousand tons and 7.9 thousand tons for a half year time interval. The range of the effort was about 3.5 to around 5.6 million towing hours respectively. The results indicated that the effort of the fishery should be reduced roughly 12% to 44% to archive the MSY and about 46% to 61% to reach the MEY. Under social discount rate, the effort should be decreased around 45% to 56% to archive the optimal yield.

Keywords: Bioeconomic analysis, shrimp trawl fishery, fisheries management, Vietnam

INTRODUCTION

The Tonkin Gulf is a semi-closed gulf in the Northwest of the South China Sea with total area about 126,250 km^2 (Vietnam's sea water-the Western part: 67,203 km^2 or 53.23%). It is a shallow Gulf, the average depth around 38 m and maximum depth lower than 100 m. The Gulf is one of the most important fishing grounds in Vietnam's sea water. It contributed around 16% to Vietnamese marine resources, 30% to total fishing boats and about 20% to total marine landing annually (Chinh, 2005). Fisheries in the Gulf are small scale, multi-species and multi-gears. In 2003, there were about 26,000 fishing boats using 25 different types of gears in the Gulf; 86% of these boats had the engine lower than 45 HP (Chinh, 2005). There were 166 species of 74 different families identified by bottom trawl surveys in the offshore water of the Gulf (Son, 2001). Some studies showed that the maximum sustainable yield (MSY) in the coastal areas of the Tonkin Gulf was reached since 1994 and fishing activities had low economic returns due to overfishing problems (Long, 2001; Long, 2003). The catch per unit of effort (CPUE) of fisheries in the Gulf globally declined from 1.34 to 0.34 ton/HP/year between 1985 and 1997 (Son, 2003). However, there has not been any quantitative analysis of the local fisheries. Meanwhile, shrimps are the most important commercial species in Vietnam. In 2003, shrimp landing contributed around 17 % in monetary value of the marine capture fisheries in Vietnam (MOFI, 2006). In the Tonkin Gulf, shrimp landing which mainly derived from the shrimp trawl fishery, was estimated around 11,445 tones, occupied about 4.6 % of the total catch in 2003 (Chinh, 2005).

The objective of this study is to investigate the sustainability properties of the stock of the shrimp trawl fishery in the Tonkin Gulf by using bio-economic analysis of historical data. The basis assumption is that the management objectives are to sustain development and to maximize economic yield. The major questions that arise in this case include:

(1) What is the sustainable harvest of selected reference points?
(2) Must the fishing effort be reduced in order to reach the reference points?

The shrimp trawl fishery is a typical tropical fishery with all characteristic properties of small scale and multi-species tropical fisheries. In such cases, surplus production models often have shown to be an appropriate analysis tool when catch and effort data are available. This is supported by Hilborn & Walters:

"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" (Hilborn & Walters, 1992:298).

Garcia (1988: 237) also argues that surplus production models might be more appropriate than other in shrimp fisheries because of short life span of species, which means that equilibrium conditions are close to exist at any time within a biological year, which starting with the main recruitment. With respect to the Tonkin Gulf, there are two shrimp spawning seasons per year (February-March and June-July). This implies that it is appropriate to divide the time scale into a half year in accordance with the biological year of the stock. Surplus production models which are generally applicable to a calendar year data, in this study, are applied for a half year time interval data. It is assumed that the stock will reach an equilibrium situation within a period of six months. The models use steady state (equilibrium) conditions to formulate reference points and equilibrium assumptions to estimate parameters.

First the models are presented, followed by describing the demand data. The study will finish off by a discussion on results of the models, reference points and some recommendations concerning management of the fishery.

MODELS

A general growth model for an exploited stock can be expressed (Clark, 1990)

$$\frac{dX}{dt} = F(X) - H(E, X) \qquad \text{(Eq.1)}$$

Where

F (X) biological growth of the stock
H (E, X) harvest function, depends on fishing effort (E) and stock biomass(X).

The Verhulst-Schaefer model [a]: $$\frac{dX}{dt} = rX(1-\frac{X}{K}) - qEX \qquad \text{(Eq.2)}$$

The Gompertz-Fox model [b]: $$\frac{dX}{dt} = rX\ln\frac{K}{X} - qEX \qquad \text{(Eq.3)}$$

Where

r intrinsic growth rate
q gear and stock specific constant, referred to as the catchability coefficient K environmental carrying capacity

Total sustainable revenue (TR) and total cost (TC) of the fishery are defined (Clark, 1990; Schaefer, 1954):

$$TR(t) = p * H(E(t), X(t)) \qquad \text{(Eq.4)}$$
$$TC(t) = c * E(t) \qquad \text{(Eq.5)}$$

Where

p	constant price per unit of harvested biomass
c	constant cost per unit of effort

The difference between total sustainable revenue TR and total cost TC is called *the sustainable economic rent* provided by the fishery resource at each given level of effort E:

$$\prod(t) = TR(t) - TC(t) = p * H(E(t), X(t)) - c * E(t) \qquad \text{(Eq.6)}$$

The equation that maximize the present value (PV) of the fishery can be expressed

$$\max PV = \max \int_{t=0}^{\infty} e^{-\delta t} \prod(t)dt \qquad \text{(Eq.7)}$$

Subject to $\dfrac{dX}{dt} = F(X) - H(E, X)$

The equation to solve for optimal biomass under discounting is (Clark, 1985; Clark, 1990; Clark & Munro, 1975):

$$F'(X) - \frac{a'(X)F(X)}{p - a(X)} = \delta \qquad \text{(Eq.8)}$$

Where

δ	Discount rate
$F(X)$	Growth rate of the stock
$a(X)$	Cost per unit of harvest

Optimal biomass can be determined for the Verhulst-Schaefer model from Eq.8_(Clark, 1990; Clark & Munro, 1975):

$$X^* = \frac{K}{4}\left(\left(\frac{c}{pqK} + 1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{c}{pqK} + 1 - \frac{\delta}{r}\right)^2 + \frac{8c\delta}{pqKr}}\right) \qquad \text{(Eq.9)}$$

Optimal biomass for the Gompertz-Fox model can be determined (Clarke, Yoshimoto & Pooley, 1992):

$$\ln\left(\frac{K}{X^*}\right) - \left(1 + \frac{\delta}{r}\right)\left(1 - \frac{c}{pqX^*}\right) = 0 \qquad \text{(Eq.10)}$$

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

$$E^* = \frac{F\left[X^*\right]}{qX^*} \qquad \text{(Eq.11)}$$

DATA

Demand data for the models are derived from the ALRMV project, which was supported by DANIDA and carried out in Vietnam from 2000 to 2004 (see (Thanh, 2006)). The fleet was divided into groups based on the fishing gears and horse power of the main engines. In the project, interviews were monthly conducted at local harbors. Data from the interviews were used to estimate indicators for difference shrimp trawler groups. These monthly indicators include average CPUE to be measured in kg/towing hour; average effort to be measured in towing hours/boat; average percentage of shrimp in catch; average price of shrimp to be measured in 1000 VND; average variable cost per towing hour to be measured in 1000 VND. Other relevant data such as the number boats were collected from both the ALRMV project and departments of the Ministry of Fishery (MOFI).

In this study, shrimp trawlers (with engine lower than 45 HP) are divided into three groups. Otter trawlers with the engine from 20-45 HP, the biggest group, are chosen as the standard group for aggregating effort of the fishery. Otter trawlers and beam trawlers with the engine lower than 20 HP are assumed homogeneous and will be consider as one group. The third group is the beam trawlers with the engine from 20-45 HP.

In order to apply the bioeconomic models for the shrimp trawl fishery, monthly catch and effort of different shrimp trawler groups need to be standardized. For this purpose, first, the standardized CPUE (for shrimp) is computed by multiplying the average CPUE (for mixed landing) together with the shrimp's proportion. Efforts of the different trawler groups are then standardized based on their *relative fishing powers*. Which is defined, and can be measured as the ratio of the standardized CPUE of the group to that of another group taken as a standard and fishing on the same density of fish on the same type of ground (Beverton & Holt, 1993). In this way each group can be allotted a *power factor* which is used to compute its standardized effort. Catch of each group is estimated by multiplying the standardized CPUE together with the average effort and the number of boats in the group. Total catch of the fishery is computed by summing the catch of different shrimp trawler groups. The equations to estimate the standardized CPUE, catch and effort are shown in appendix 1.

The fixed price is calculated as the weighted average price (of catch) for the period of study (2000-2004)

$$p = \frac{\sum_{F=1}^{k} \sum_{j=2000}^{2004} \sum_{i=1}^{m} p_{Fji} H_{Fji}^{Month}}{\sum_{F=1}^{k} \sum_{j=2000}^{2004} \sum_{i=1}^{m} H_{Fji}^{Month}} \qquad \text{(Eq.12)}$$

Where:

p_{Fji} Average price of 1 kg shrimp in month i of year j that fleet F caught

H_{Fji}^{Month} Catch in month i, year j of fleet F

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

$$c_F = c_{vc} + c_{fc} \qquad \text{(Eq.13)}$$

Cost per unit of standardized effort of the fishery is computed as the weighted average cost (of effort) for the period of study (2000-2004) by the following equation:

$$c = \frac{\sum_{F=1}^{k}\sum_{j=2000}^{2004}\sum_{i=1}^{m} c_{Fji} E_{Fji}^{Month}}{\sum_{F=1}^{k}\sum_{j=2000}^{2004}\sum_{i=1}^{m} E_{Fji}^{Month}} \qquad \text{(Eq.14)}$$

Where:

c_{Fji} Cost per unit of effort in month i, year j of fleet F

E_{Fji}^{Month} Effort in month i, year j of fleet F

Table 1, 2 show standardized catch, effort, price and cost per unit of effort that are used for the bioeconomic models. Table 3 shows biomass of the shrimp stock in 2003, which is used to estimate the catchability (q).

Table 1 Standardized catch, effort, CPUE of the fishery by half years

Year	*Half year*	*Catch (kg)*	*Effort (h)*	*CPUE (kg/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

Table 2 Standardized cost and price of shrimps in the shrimp trawl fishery

Average price (1000 VND)	*Cost per unit of effort (1000 VND/hour)*
23.755	34.057

Table 3 The shrimp stock biomass in 2003

Southwest monsoon season *(10^3 kg)-4/2003*	**Northeast monsoon season** *(10^3 kg)-9/2003*
4165	6687

Source:(Thi, Ha & Kien, 2004)

RESULTS

Parameters

Table 4, 5 shows predicted catchability (*q*), intrinsic growth rate *(r)* and the carrying capacity (*K*) from the models for the fishery. The catchability is computed from the estimated biomass, which derived from independent surveys in 2003. Afterward, intrinsic growth rate and the carrying capacity are calculated based on estimated coefficients, which derived from the two models. Verhulst-Schaefer model predicts intrinsic growth rate almost three times that of the Gompertz-Fox model. In case of the carrying capacity, it is vice versa for the two models.

Table 4 The catchability (q) in 2003

Southwest monsoon season (10^{-7} hour^{-1})	*Northeast monsoon season* (10^{-7} hour^{-1})	*The average catchability*(10^{-7} hour^{-1})
3.31779	1.03047	2.17413

Table 5 Estimated r, K parameters

Parameters	Models	
	Verhulst-Schaefer	**Gompertz-Fox**
r	1.564950	0.505324
K	16.740900	40.528400

r = intrinsic growth in a half year^{-1}
K = carrying capacity in 10^6 kg

Reference points

The graph of the equilibrium yields derived from the two models against effort are shown in figure 1. The two models show considerable differences in predicted reference points. The Gompertz-Fox model shows that the MSY of the shrimp fishery is 15% higher than that of the Verhulst-Schaefer model (table 7). If this comparison is extended to the effort level at MSY, it is shown that the Gompertz-Fox model is 35 % lower than the one of the Verhulst-Schaefer model. While estimated profits at MSY ($p*MSY-c*E_{MSY}$) shows the Gompertz-Fox model with a higher profit of 200% because of differences in predicted effort. The Gompertz-Fox model predicts the stock is heavily exploited, while the Verhulst-Schaefer model predicts the stock is fully exploited.

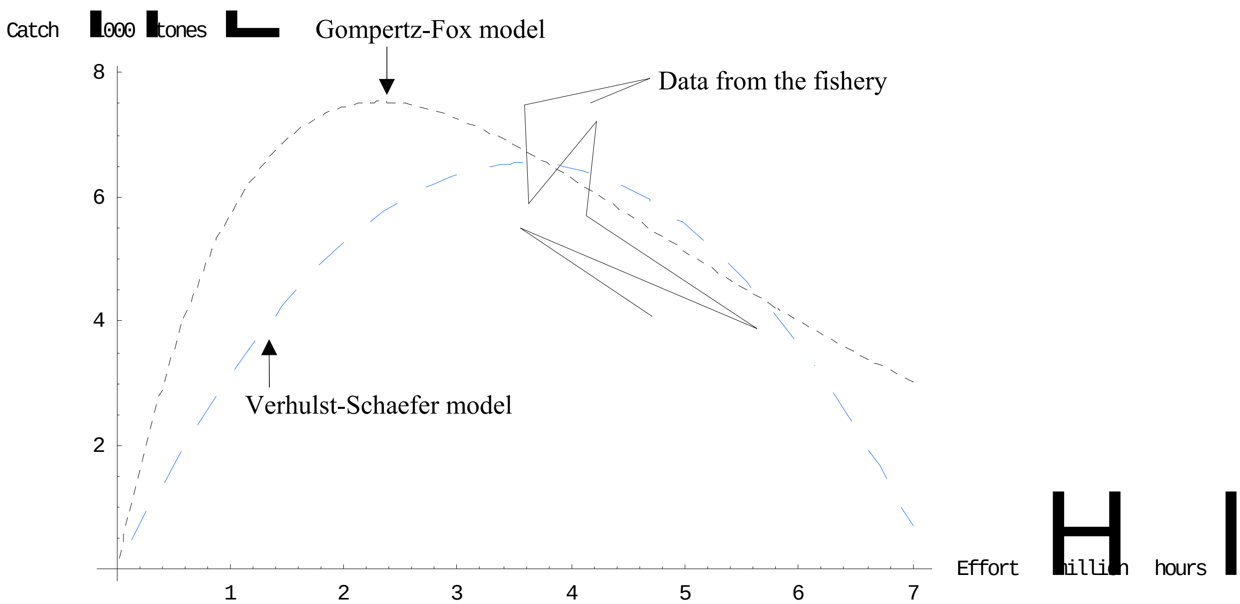

Figure 1 Catch versus effort

Figure 2 shows TC and TR derived from the two models against effort. The two models show the MEY varies by 27% while corresponding effort varies by 28% (table 7, 8). The profit at MEY varies by 100% for the two models. The Verhulst-Schaefer models show the break even point is closer the MSY than that of Gompertz-Fox model.

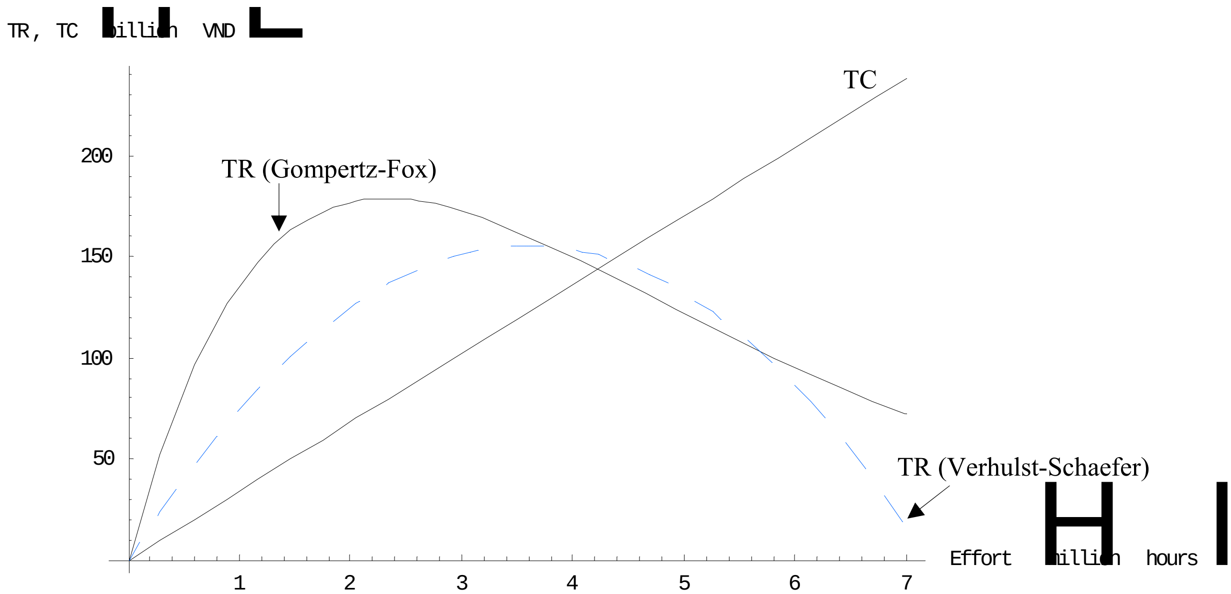

Figure 2 TR, TC versus effort

Table 6 Catch and effort reference points

	OA		*MSY*		*MEY*	
	Verhulst-Schaefer	**Gompertz-Fox**	**Verhulst-Schaefer**	**Gompertz-Fox**	**Verhulst-Schaefer**	**Gompertz-Fox**
Catch (10^6 kg)	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

Table 7 Optimal reference points

Models	δ *(%)*	Y^* *(10^6kg)*	E^* *(10^6hour)*	X^* *(10^6kg)*	π^* *(10^9VND)*	*CPUE** *(kg/hour)*
Verhulst-Schaefer	0	5.53345	2.18137	11.66760	57.156187	2.536686
	5	5.60297	2.23073	11.55280	57.126581	2.511720
	10	5.66832	2.27880	11.44100	57.041850	2.487414
	20	5.78732	2.37115	11.22620	56.723531	2.440723
	∞	6.25477	4.36275	6.59427	0	1.433676
Gompertz-Fox	0	7.05241	1.57845	20.55050	113.772728	4.467934
	5	7.20065	1.69317	19.56080	113.387150	4.252763
	10	7.31203	1.80103	18.67380	112.359594	4.059916
	20	7.45235	1.99751	17.16010	109.001376	3.730820
	∞	6.05070	4.22040	6.59427	0	1.433679

Discounted optimal values for Y^*, E^*, X^*, $CPUE^*$ and estimated resource rent are shown in table 9. The discount rates are representative of biological considerations (5%), social accounting (10%), and private interest rates compounded by risk (20%)_(Clark, 1990; Clarke et al., 1992). Models results at 0% (no discounting rate) and ∞ confirm values estimated for static MEY and OA (table 7, 8). The two models show the same trends optimal reference points over the range of the discount rate (δ between 0% and 20%) although absolute value values vary. On a percentage basis, estimated optimal effort values vary the most over alternative discount rates within a model (6.37-10.91%), while estimated resource rents vary the least (0.05-0.56%). Optimal yield varies at the same low level for the two models (1.17-2.10%). Optimal biomass and optimal CPUE vary by 0.98-1.88% for the Verhulst-Schaefer model and by 4.82-8.11% for the Gompertz-Fox model.

DISCUSSION

The two models, Verhulst-Schaefer and Gompertz-Fox, appear to estimate valid biological parameters and reasonable economic results for the shrimp trawl fishery in the Tonkin Gulf. The two models also have statistically significant coefficients, which may make their results be acceptable. The relevant studies indicate the fishery seems to be in a situation of overexploitation. Long (2001; 2003) argued that shrimp trawler fleet are shorten both in size and number due to overfishing problems. Chinh (2005) showed that the density of penaeids stock had been reduced by a half over the last thirty year (1975-2002). That the fish stock is overexploited means present shrimp biomass is below the MSY biomass level.

The Verhulst-Schaefer model, which used the logistic growth function, showed the current multi species shrimp biomass closer to the MSY level than the Gompertz-Fox model did. In addition, the Verhulst-Schaefer model predicts the intrinsic growth rate of the shrimp stock around 1.5 per a half year, which is three times higher than that of Gompertz-Fox model. However, the data which used for the models are the short time series data. It implies that the results may not globally describe the development of the fishery. The reference points derived from the models may be just local reference points. In this study, a range of reference points, which derived from the two models are chosen in order to take consideration of uncertainty in practice.

The results from the two models show the open access yield of the fishery is around 6,000 tones for a half year (12,000 tones per year). This yield may be accordance to the official catch statistic, which was around 11,445 tones for the year 2003 (Chinh, 2005). The open access yield figure may also be appropriate to the figure of the shrimp biomass, which was estimated about 4,165 tones in the southwest monsoon season and approximately 6,687 tones in the northeast monsoon season (Thi et al., 2004). Since the penaeid shrimps, which are short life span species, have high turn-over growth rate annually. It is quite common for the shrimp population to have an annual growth which in biomass terms exceeds the population size at some points during the year. Fox (1970) argues that commercial exploitation of marine fish population is usually directed towards mature individuals and, if spawning occurs during the year, survival of the population may be ensured – even at 100% annual fishing mortality. Other arguments could be derived from multispecies problems. The species composition probably is changed over time, typically towards less valuable species. This could change the MSY value dynamically over time. The possibility depletion of one species may be reduced by the increase of other species (Guland & Rothschild, 1984).

The two models show that the fishery is at least fully exploited both in terms of maximizing yield and maximizing resource rent. The E_{MSY} and E_{MEY} of the fishery from the Verhulst-Schaefer model are about 3.6 and 2.2 millions fishing hours respectively. The E_{MSY} and E_{MEY} of the fishery from the Gompertz-Fox model are around 2.3 and 1.6 millions fishing hours correspondingly (table 6). The effort of the fishery in

2004 (average effort for a half year) was estimated around 4.1 millions fishing hours (table 1), indicating that the harvest of the shrimp stock is not sustainable regarding to the referent points. The effort of the fishery should be strongly reduced to achieve optimal reference points. The current effort of the fishery (2004) should be reduced roughly 12 % (Verhulst-Schaefer model) to 44 % (Gompert-Fox model) to archive the MSY and about 46 % to 61% to reach the MEY. Under social discount rate (δ = 10%), the current effort should be reduced around 45% to 56% to achieve the optimal yield.

CONCLUSION

In this study, two surplus production models (Verhulst-Schaefer and Gompertz-Fox) have been presented and parameterized when applying catch and effort data from a Vietnamese shrimp fishery. The data is aggregated in time periods of half year in accordance with the biological year of the shrimp stock in the Tonkin Gulf. Results derived from the models are reasonable compared with the independent surveys and official statistics.

It demonstrates that surplus production models are not necessarily restricted to cover annual periods. The models should be applied in a flexible way regarding the biological characteristics of the stock. On the other hand, for the fast growing species with a high turn-over rate (short life span) in tropical areas such as for these shrimps, using data from the enumerator program could be an alternative method and may reduce the problems of insufficient statistical data.

In addition, a range of reference points was chosen for the fishery in this study since 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 uncertainty in practice in case of insufficient statistical data.

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ENDNOTES:

a. The model was proposed by Gordon and Schaefer in 1954, 1957 which uses the Logistic growth equation of P.F. Verhulst in 1838
b. The model was proposed by Fox in 1970 which uses the growth equation of Gompertz in 1825

Appendix 1 Equations to estimated the standardized catch and effort

The standardized CPUE of trawler groups is defined

$$CPUE_F = MeanCPUE * ps_F$$

Where:

$CPUE_F$	standardized CPUE of fleet F in a month, to be measured in kg shrimp/towing hour
$MeanCPUE$	average CPUE of fleet F in that month, to be measured in kg (mixed fish)/towing hour;
ps_F	average percentage of shrimp in the catch of fleet F in that month;

Effort per month of fleet F is estimated

$$E_F^{month} = e_F * n_F * pf_F$$

Where:

E_F^{month}	total effort per month of fleet F, to be measured in towing hours
e_F	average effort per month of one boat in fleet F, to be measured in towing hours;
n_F	number of boats in fleet F for the period of study;
$pf_F = \dfrac{CPUE_F}{CPUE_S}$	power factor of fleet F to the standard fleet (S) in that month;

Effort per a half year of fleet F is estimated

$$E_F^{Halfyear} = \frac{\sum_{i=1}^{m} E_{iF}^{month}}{m} * 6$$

($m \leq 6$) where m- number of months that fleet F were observed in that half year

Total effort per a half year of the fishery is estimated

$$E = \sum_{F=1}^{k} E_F^{HalfYear}$$

Where k- number of fleet (or boat groups)

Catch per month of fleet F is estimated by an equation

$$H_F^{month} = CPUE_F * e_F * n_F$$

Where:

H_F^{month}	landing shrimp (catch) per month of fleet F, to be measured in kg

Catch per a half year of fleet F is estimated

$$H_F^{Halfyear} = \frac{\sum_i^m H_{iF}^{month}}{m} * 6$$

(m ≤ 6) where m- number of months that fleet F were observed in that half year

Total catch per a half year of the fishery is estimated

$$H = \sum_{F=1}^{k} H_F^{HalfYear}$$

Where k- number of fleet

Appendix 2 Average fixed costs of different trawler groups in 2001

Fixed cost (million VND)	***Beam & otter trawlers <20HP***		***Beam trawlers 20-45 HP***		***Otter trawlers 20-45 HP***	
	Year	***Month***	***Year***	***Month***	***Year***	***Month***
Boat repairs	5.7	0.4750	4.378943	0.3649	9.704839	0.8087
Interest	0.9627	0.0802	8.236421	0.6864	1.98629	0.1655
Tax	-	-	1.196842	0.0997	0.1487097	0.0124
Depreciation	4.72099	0.3934	16.24765	1.3540	10.72156	0.8935
Total	***11.3837***	***0.9486***	***30.0599***	***2.5050***	***22.5614***	***1.8801***

Source: *Data from the ALRMV project and IFEP, 2005*

Shrimp trawl fleet in 2003

Groups	**Beam trawl**	**Otter trawl**	***Total***
< 20 HP	203	1749	1952
20 HP to 45 HP	211	1808	2019
Total	**414**	**3557**	**3971**

Source: NADAREP, MOFI, 2005