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Optimal Stock, Harvest and Effort Level of Bangladesh Trawl Shrimp Fishery – A Nonlinear Dynamic Approach

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ABSTRACT

The purpose of this paper is to develop a non-linear dynamic model for Bangladesh trawl shrimp fishery for optimal control in discrete-time frame. The model has been developed on the concept of optimal resource management based on the criterion of maximization of present values of net economic revenues. The results of the optimal steady state solutions (i.e. optimal stock, harvest and effort level) for ensuring long run sustainability of the resource through the model are presented. Results reveal that Bangladesh marine shrimp fishery is not managed and utilized optimally. Present condition of high effort level, less harvest amount and less shrimp stock indicates that the danger of depletion of the resource cannot be ruled out.

Key words: Bangladesh marine shrimp fishery, optimal management, non-linear dynamic model.

INTRODUCTION

International experience has shown that overfishing, as a result of improper management of fishing, may cause extinction or near extinction of different species of fishes, like Antarctic blue whales (FAO, 1979), Antarctic fin whales (FAO, 1979), Hokkaido herring (Murphy, 1977), Peruvian anchoveta (Johnston and Suiten, 1996), Southwest African pilchard (Butterworth, 1980), North Sea herring (Saville, 1980), California sardine (Murphy, 1977), Georges Bank herring (Sinderman, 1979), Japanese sardine (Murphy, 1977), and Canadian cod fishery (Ruitenbeck, 1996) etc. However, many other factors other than mismanaged fishery may also have contributed to the collapse of these species, like - change in temperature and salinity, reduced food abundance etc. But over estimation of biomass, high levels of juvenile catch, underestimation of fish mortality etc. that led to overexploitation of a species and its collapse are manifestation of mismanaged fishing scenario.

The practice of the management of renewable resources has generally been relied on the concept of Maximum Sustainable Yield (MSY). The concept of MSY suggests exploiting the surplus production on the basis of biological growth model. Several objections have been raised against the use of MSY on both biological and socioeconomic grounds. One of such serious objections is obviously the non-recognition of cost-factor. Recognition of the inadequacy of MSY concept has resulted in a trend to replace it with a concept of optimal resource management based on criterion of maximization of present values of net economic revenues. However, Bangladesh Marine Trawl shrimp fishery is managed at present on the basis of MSY concept.

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Bangladesh has a land area of 1,47,570 sq. km. and has declared an Exclusive Economic Zone (EEZ) from her base line to 200 nautical miles seaward in 1974. As a result along with 710 km. (coast line) an area of about 1,66,000 sq. km., which is greater than actual land of Bangladesh, is now under the economic jurisdiction of the country for exploitation, exploration, conservation, and management of its living and non-living resources (DOF, 1999). At present the marine fisheries sector contributes about 22% of the country's total fish production. Several surveys have been conducted in Bangladesh marine waters to assess, particularly the demersal fish/shrimp resources. Result of these surveys differs significantly estimation-to-estimation starting from 1,550 metric tons shrimp to 11,400 metric tons shrimp (West, 1973; Saetre, 1981; Penn, 1983; Rashid, 1983; Khan *et al,* 1983; White and Khan, 1985; VanZalinge, 1986; and Lamboeuf, 1987).

Bangladesh Marine fishery has two sub sectors, such as artisanal fishery and industrial (trawl) fishery. Trawl shrimp fishing is one of the most important sectors in marine fishing in Bangladesh with respect to foreign exchange earnings, employment etc. Bangladesh started with a fleet of 10 trawlers after liberation i.e. 1972-1973. The numbers of trawlers more than doubled to 21 in a year and then jumped to 26 two years later. The current number of trawlers is 119 of which 41 are shrimp trawlers and the remaining are fish trawlers (BBS, 1999; MFSMUC, 2007). The trawlers operate in the shelf area beyond the depth of 40 meters in the EEZ. The effort in the trawl fishery during the last two decades have been rotated around 5,000–6,000 standard fishing days to produce 3,500-6,000 metric tons of shrimp. This is, however, no agreement on MSY of penaeid shrimp of Bangladesh. The MSY of penaeid shrimp is estimated as 7,000 - 8,000 metric tons and the optimum effort for producing the said amount is 7,000-8,000 standard days (BOBP, 1997). Other estimations of MSY of penaeid shrimp are 4145 metric tons (using Schaefer model) and 4329 metric tons (using Fox model) (Khan and Hoque, 2000). Because of an unplanned and irrational increase in fishing efforts, many species of the marine fish and shrimp stocks have already been declined (Khan and Hoque, 2000a; Khan, 2000). As a result, coastal fishing has become non-remunerative and fisher folk are becoming poorer. Their fruitless endeavor for survival is thus putting more and more damaging pressure on the resources.

In this paper, we have attempted to formulate a non-linear dynamic model of Bangladesh trawl shrimp fishery for optimal control with discrete-time. We have also attempted to estimate the optimal steady state solution (i.e. optimal stock, harvest and effort level) through the model that ensures the long run sustainability of the resource, maximum benefit and excludes the possibility of depletion due to overexploitation.

MATERIALS AND METHODS

Sources of Data and Methodology

We have used published data of (i) BOBP (1993; 1997), (ii) Department of Fisheries (DOF, 2000), (iii) Marine Fisheries Survey Management Unit Chittagong (MFSMUC, 2007), Bangladesh, for the time series data of harvest and effort for the period 1981-1982 to 2005-2006. Due to unavailability of time series data on dock-price of commercially exploited trawl shrimp, we have used published data of Export Promotion Bureau of Bangladesh (EPBB, 2000) for time-series data of exported shrimp price. The data from sample survey made by Khan and Hoque (2000) are used for estimation of cost parameters. We have solved the nonlinear dynamic optimization model with discrete time through Microsoft Excel.

The Model

We assume that one of the objectives of the shrimp fishery is that it should be managed to maximize the discounted present value of net benefit over time. In case of Bangladesh trawl shrimp fishery we propose the following non-linear dynamic programming problem, which maximizes the objective function of present value of net benefit (PVNB) over the time period (0,T) with discrete uniform time interval, subject to usual constraint of growth function.

Maximize

$$\left.\begin{aligned}
&PVNB = \sum_{t=0}^{T} \beta^t .\ \Pi\,(x_t, h_t) \\
&\text{Subject to,} \\
&\qquad x_{t+1} - x_t = f\,(x_t) - h_t \\
&\qquad f\,(x_t) = \frac{dx}{dt} = r\,x_t\,(1 - \frac{x_t}{K}) \\
&\qquad x_0 \text{ (given)} \\
&\quad \text{and } x_t, h_t \geq 0
\end{aligned}\right\} \qquad (1)$$

Here Π (.) is a concave profit function expressed in terms of harvest, stock level, $\beta = \frac{1}{1+\delta}$ is a social discount factor and 'δ' is social discount rate; '**r**' denotes the intrinsic growth rate; '**K**' denotes the saturation level or carrying capacity; and '$\mathbf{h_t}$' denotes the harvest level at period '**t**'. Symbol '$\mathbf{x_t}$' denotes biomass level at period '**t**', which follows logistic growth function or surplus production function.

Net benefit ∏(.) is calculated as total revenue less total operating cost. We have assumed that cost function is an increasing function of harvest and decreasing function of biomass. Thus,

$$\Pi(x, h) = p\,(h).\,h - C\,(x, h) \qquad (2)$$

where p(h) is demand function and C (x, h) is total effort cost.

Solution of the Model for Optimum Allocation

The dynamic formulation of our problem defined in (1), takes the form following the procedure suggested by Conard (1999):

Maximize

$$\left.\begin{aligned}
&PVNB = \Sigma\beta^t .\ \Pi\ \ (x_t, h_t) + \frac{\beta^t \Pi\ (x_{t+1},\ f(x_{t+1})}{\delta} \\
&\text{Subject to} \\
&\qquad x_{t+1} - x_t = f\,(x_t) - h_t \\
&\qquad x_0 \text{ (given)}
\end{aligned}\right\} \qquad (3)$$

Following are additional characteristics of above system:

(i) In each period, escapement stock or what remains after harvest enters the growth schedule. The value of intrinsic growth rate (**r**) and carrying capacity or saturation level (**K**) which are estimated by Ray and Khan (2003) are given by **r** = 1.330818 and **K** = 11400 metric tons.

(ii) The model assumes deterministic logistic growth function of a single species (penaeid shrimp).

(iii) We assume that demand is linear in price and stationary, the inverse demand or willing to pay (WTP) function of harvest **h** is **p**(**h**) = $\mathbf{d_1}$ + $\mathbf{d_2}$. **h**. We estimate inverse demand function by using price and harvest data through ordinary least squares method and get estimates $\mathbf{d_1}$ = 10,759.389 and $\mathbf{d_2}$ = -0.69602.

(iv) The harvest cost varies with harvestable stock (measured prior to harvest) and harvest. The cost function is as $c(x,h) = \frac{c_2\,h}{q\,x^u}$,

where the values of $\mathbf{c_2}$ = 1156.76, estimated by Khan and Hoque (2000) on the basis of sample survey during 1999. We have used **q** = 0.0000977332, estimated by Ray and Khan (2003), and **u** is assumed to be unity.

(v) The social discount rate (δ) is assumed to be 0.1

(vi) Producers are competitive.

We, therefore, try to solve dynamic allocation problem objective of which is to find approach path which maximizes objective function (PVNB). Hence industry's profit in period '**t**' is given by the explicit function,

$$\pi (x_t, h_t) = p (h_t).\, h_t - C (x_t, h_t)$$

$$= d_1 h_t - d_2 . h_t^2 - \frac{c_2 h_t}{q x_t} \qquad (4)$$

Substituting this explicit profit function in the objective function of (3), we obtain,

$$\sum_{t=0}^{t} \beta^t (d_1 h_t - d_2 h_t^2 - \frac{c_2 h_t}{q x_t}) + \frac{\beta^t}{\delta}[d_1 r\, x_t (1 - \frac{x_t}{K})$$

$$- d_2 r^2 x_t^2 (1 - \frac{x_t}{K})^2 - \frac{c_2 r\, x_t}{q x_t}(1 - \frac{x_t}{K})] \qquad (5)$$

Using the objective function (5), optimal steady state or optimal levels of harvest and stock are determined by solving the problem (3). The optimal level of stock (**x***) and harvest (**h***) in each year gives optimal level of effort and shadow price for each year of our study period by using following standard equations (Clark, 1990; Conard, 1999):

Effort, $E^* = h^*/q\, x^*$, where q = catchability co-efficient,
and shadow price, $\lambda^* = (1+\delta)[p - c_2/qx^*]$, where p = price of shrimp.

These calculated values are given in Table 1. Actual and optimal level of harvests, stocks, and efforts for the period 1981-1982 to 2005-2006 are shown respectively in Figures 1, 2, and 3.

Table 1. Actual and Optimal Stock, Harvest & Effort Levels of Bangladesh Trawl Shrimp Fishery

Year	Actual Stock (tons)	Optimal Stock (tons)	Actual Harvest (tons)	Optimal Harvest (tons)	Actual Effort (days)	Optimal Effort (days)
1981-82	4592.00	4,592.00	1697	2,480.81	3782	5527.76
1982-83	4545.81	5,760.71	3120	3,327.98	7024	5911.02
1983-84	5784.25	6,225.13	5461	3,594.88	9662	5908.73
1984-85	6921.28	6,390.89	5518	3,681.55	8159	5894.23
1985-86	6406.52	6,446.44	4034	3,709.63	6444	5888.01
1986-87	6629.59	6,464.60	4488	3,718.70	6928	5885.83
1987-88	5476.84	6,470.49	3523	3,721.63	6583	5885.10
1988-89	7210.16	6,472.39	4893	3,722.57	6945	5884.86
1989-90	5783.10	6,473.00	3134	3,722.88	5546	5884.80
1990-91	7802.25	6,473.20	3430	3,722.98	4499	5884.77
1991-92	4851.17	6,473.26	2902	3,723.01	6122	5884.76
1992-93	6066.48	6,473.28	4188	3,723.02	7065	5884.76
1993-94	4967.78	6,473.29	3480	3,723.02	7169	5884.75
1994-95	3657.02	6,473.29	2416	3,723.02	6761	5884.75
1995-96	4966.09	6,473.29	3588	3,723.02	7394	5884.75
1996-97	5091.76	6,473.29	3536	3,723.02	7107	5884.75
1997-98	3338.90	6,473.29	2444	3,723.02	7491	5884.75
1998-99	4666.32	6,473.29	3764	3,723.02	8255	5884.75
1999-00	3795.30	6,473.29	2919	3,723.02	7871	5884.75
2000-01	3854.63	6,473.29	3162	3,723.02	8395	5884.75
2001-02	4674.99	6,473.29	3168	3,723.02	6935	5884.75
2002-03	3119.85	6,473.29	2487	3,723.02	8158	5884.75
2003-04	3767.85	6,473.29	3076	3,723.02	8357	5884.75
2004-05	3941.16	6,473.29	3310	3,723.02	8595	5884.75
2005-06	4258.77	6,473.29	3444	3,723.02	8276	5884.75

Source: Actual values are presented from Ray and Khan (2003) & MFSMUC (2007) and optimal values are calculated by the author using the model.

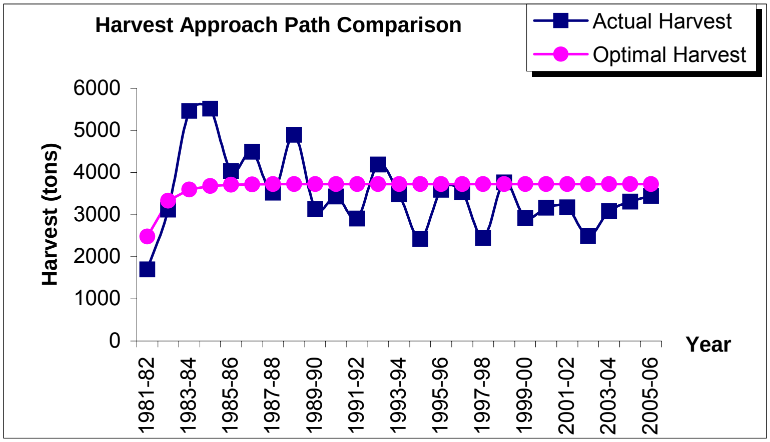

Figure 1. Harvest Approach Path Comparison

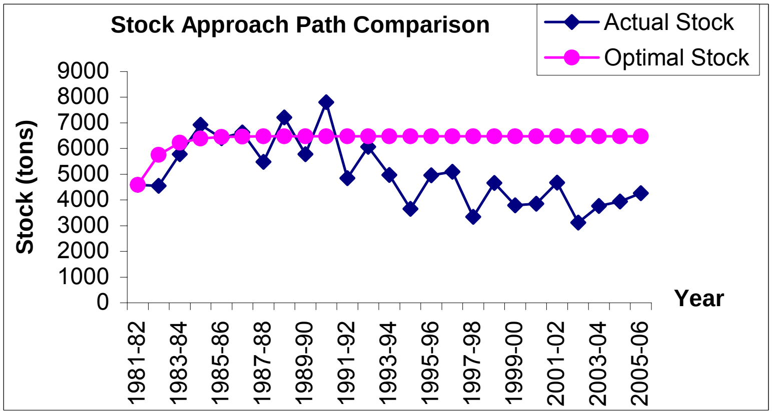

Figure 2. Stock Approach Path Comparison

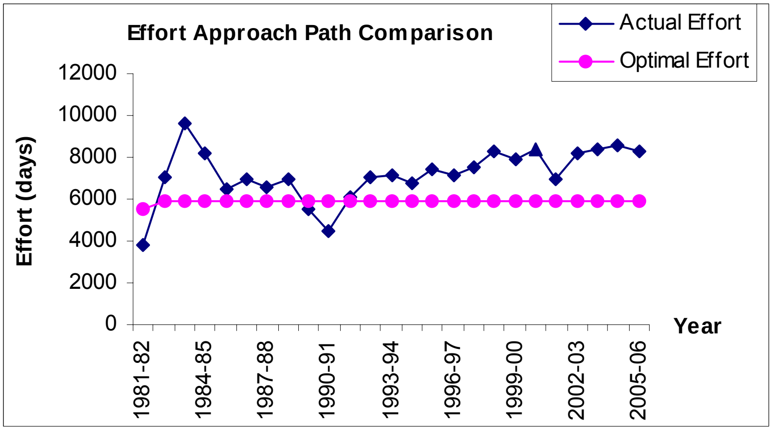

Figure 3: Effort Approach Path Comparisons

RESULTS AND DISCUSSION

With actual shrimp stock (1981-82) and an initial guess, the solver optimizes the sum of PVNB over the period when cost parameters, demand parameters, intrinsic growth rate, carrying capacity, discount factors are given as constant. Results of Non-linear dynamic optimization model are provided in Table-1.

We find from Table-1 that system reaches at steady state very quickly. It takes only nine (9) years. Similar studies on Northern Anchovy Fishery of California (Kolberg, 1993), Canadian Northern Cod Fishery (Grafton *et al*, 2000) show that the system takes much longer time for reaching steady state. It implies that the Bangladesh shrimp fishery system is under favourable condition in the sense that it would require much less time to recover stock by implementing corrective measures.

The optimal stock and harvest level attained steady state in the year 1991-92 at 6473 metric tons and 3723 metric tons respectively. But comparison with the actual and current harvests during the period of study indicates the fact that current harvest level is much lower than the level of optimal harvest. Lower level of actual harvest may be explained by the fact that overfishing during the period 1983-84 to 1986-87 may have had some consequences on population dynamics of the species.

Approach paths of harvest, stock and effort, are depicted in Figures-1 to 3. Harvests and stocks are initially higher than the steady state situation, but gradually decline below the optimum steady state level. Not only that, it also clearly reveals that the gap between actual and optimal values keeps increasing. On the contrary, in case of effort, it is much higher both in the initial and later phases but around steady state level in between. It clearly implies that the higher level of effort causes overfishing which, in turn, causes lower stock. As a consequence, even higher level of effort in later years does not get adequate quantity of catch. This is obviously alarming and demands immediate attention of policy makers and administrations. In order to protect the resource from depletion or other catastrophic collapse, immediate measures must be taken. Scientific approach must be adopted for managing this resource.

CONCLUSION

The results of the study presented in this paper conclude the following:

(a) Bangladesh marine shrimp fishery is not managed and utilized optimally.

(b) Present condition of high effort, less harvest and less biomass stock indicates that the danger of depletion of the resource cannot be ruled out.

(c) Steady state is found to be attained by the system very quickly. It implies that marine shrimp fishing of Bangladesh would take less time and cost to recover from the sub-optimal level if corrective measures are taken.

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