Chapter 4

Optimal Control:
Non-Linear Dynamic Optimization Model in Bangladesh Trawl Shrimp Fishery
-Discrete Time Analysis

A part of this work was presented at the 8th University Level Workshop On Research Methodology In Economics (22-23 March, 2002), titled *"Issues in the Solution Procedure of Non-linear Dynamic Optimization Problem in Renewable Resource Economics"* in Department of Economics, University of North Bengal, Darjeeling, India.

4.1. Introduction:

Management of renewable resource attracts attention of economists, biologists and planners in recent years. Non-linear dynamic optimization techniques are extensively used for the optimal solution of such class of problems. The application of Non-linear Dynamic Optimization techniques in optimal control of renewable resource poses several difficulties. However, difficulties lie not in the formulation of the problem but for the solution of it.

In this chapter, we have suggested a formulation of non-linear system of Bangladesh trawl shrimp fishery under a discrete time horizon (Section 4.2). Initially we will try to have an optimal solution by applying classical method of constrained extrema. Obviously, the optimal allocation given by the solution will be static in nature. Hence, it would be Static Optimal Allocation solution of the system (Section 4.2.1).

However, because of the very nature of the renewability, it is natural that the growth function of the resource is to be incorporated as one of the constraints in any renewable resource optimization model. Since the problem of such class has always been a dynamic characteristic this static solution can only be viewed as a special case of the formulated dynamic optimization model. Moreover, static solution gives only single optimal value of the decision variables, whereas dynamic optimization solution, if exists and feasible to obtain, gives us optimal values at different point of time over the time horizon (0, T). Hence, we also try to have a non-linear dynamic steady state solution of the model developed for the system (Section 4.2.2) over the discrete time horizon.

4.2. The General 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 the usual constraint of growth function.

Maximize

$$pvNB = \pounds_{t=0}^{T} / r\text{-}n(x_t, h_t) \quad 1$$

Subject to ,

$$x_w - x, = f(x,) - h \quad , \qquad (4\ 1)$$

$$f(x,) = f = r\,x_{l(1} - i)$$

x_0 (given)

and x_t, h, > 0

n (.) is a concave profit function expressed in terms of harvest and the stock level, p = **1/(1+8)** is a social discount factor and 'S' is the social discount rate; Y denotes the intrinsic growth rate; 'K' denotes the saturation level or carrying capacity; and 'h_t' denotes the harvest level at period *1'.* 'x_t' denotes the biomass level at period 't' and follows the logistic growth function or surplus production function given in equation (3.4) of the previous chapter.

Net Benefit *Tl{.)* is calculated as total revenue less total operating cost. We have already assumed and discussed in 3.3:2 that the cost function is an increasing function of harvest and decreasing function of the biomass. Thus, -

$$H(x, h) = p(h). h - C(x, h) \quad ' \qquad (4.2)$$

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

4.2.1. Static Solution of **the Model for Optimum Allocation:**

For the solution of the system 4.1, we follow the classical method of constraint optima. This requires to obtain the Lagrangian function which is given by

$$L = 2p'\{n(x_t, h_t) + p;Mx, + f(x,)-h,-Xt_+,]\} \qquad (4.3)$$

Now, for necessary conditions, all first order partial derivatives of the Lagrangian function with respect to x_{tl} h_t and \^ can be obtained and set these equal to zero, Lagrangian multiplier *QCj* represents shadow prices which. measure marginal values of the resource. After appropriate simplification the following equations from first order necessary conditions are obtained (Conard, 1999):

$$?4 = 9\ 7T(.)/3\ X_t + PXt_{+1}\ [1 + f.\ (.)]) \qquad (4.4)$$

$$97t(.)/3h_t = pli+i \qquad (4.5)$$

$$Xt+i= Xt + f(x,)-h[\qquad (4.6)$$

The purpose of solving this problem is to have a set of controlling variables necessary for managing the marine shrimp resource of Bangladesh optimally. Firstly, for optimum harvesting decision we should know the marginal value of an additional unit of marine shrimp in period t' and how this additional value be allocated among current period harvest and unharvest. The current period unharvested resource will transmit the value in the next period **(t+1).** Secondly, we must know what is the marginal net benefit if an additional unit of marine shrimp is trawled in period 't'? Because, for an optimal harvest strategy, this marginal net benefit of trawl shrimp must equal the opportunity cost. Thirdly, we also require to have a relation between shrimp stock and associated resource stock so that steady state conditions can be obtained by equating *present* value discount factor with the resource's internal rate of return.

Equation (4.4) implies that when marine shrimp is optimally managed, the marginal value of an additional unit of the marine shrimp in period T equals the current period marginal net benefit, (9n/3xt) plus the marginal benefit that an unharvested unit will convey in the next period [pVi {1 + f (x_t }]. The equation (4.5) shows that the marginal net benefit of an additional unit of the resource harvested in period 't' must be equal to the discounted value of an additional unit of the resource in period **(t+1).** Thus $p\hat{}_{t1}$ represents opportunity cost in accordance to our 2nd requirement. Thus equation (4.5) implies that two types of costs, the standard marginal cost of harvest in the current period and the future cost that results from the decision to harvest an additional unit of the resource today i. e. p?n+1 must be balanced. Equation (4.6) gives the difference equation for the associated state variable of Bangladesh trawl shrimp fishery.

The optimal levels of the variables x_t, h_t and *7** can be obtained by solving the set of equations 4.4 to 4.6 either in transition or at a steady state, if exists. We assume that the steady state exists. It implies that at steady state x_t, h_t and *h* are unchanging and the time subscript T can be removed. Then we get the following system of three equations with three unknown variables:

pa.=a*(.y3h (4.7)

' *pi* [1 +f» M - (1 +5)] = - 3 7t(.)/3x (4.8)

$h = f(x)$ (4.9)

It is now possible to solve the system 4.7 to 4.9 which will provide steady state optimum. The variables or system will reach at steady state when

$x_{t+}i = Xt = x^*$; $h_{t+}i = ht = h^*$ and A4+i = *h* = *X**.

Algebraic manipulation of the equation 4.8 gives the social discount rate '8' given by the relation (4.10). In the literature, this is known as the 'fundamental equation of renewable resource':

an

f" (4.10)

By using this 'fundamental equation of renewable resource' given by 4.10 we can calculate the rate of social discount '8' which also implies the internal rate of return of marine shrimp resource of Bangladesh at steady state optimal biomass stock (x*) and optimal harvest (h*). For optimal biomass stock (x*) and optimal harvest (h*) we can employ the equations 3.4, 3.9 and 3.10 of the previous chapter. These equations are:

$$f(x) = rx(l-\frac{f}{k})$$

$$h(x, h) = q. E. x$$

and $c = C2. E$

The ratio of the partial derivatives with respect to x and h of the profit function 4.2 after appropriately substituting 3.9 and 3.10 along with the derivative of equation 3.4, the equation 4.10 will give a single equation in x having an explicit solution of the form given below (Conard, 1999):

x* = K[1 + ^ _ 5 + { (1 + ^ _ 5) 2 + 8 c ^ } X] (411)

4 pqK r pqK r pqKr

At steady state, equations 3.4, 3.9 and 4.8 assume the following form:

$$h^* = rx^*(1-x7K) \quad (4.12)$$

$$E^* = h7qx^* \quad (4.13)$$

$$\text{And} \quad V = (1 + 8)\ [p - c_2/qx^*] \quad (4.14)$$

Derivatives with respect to different parameter of equation 4.11 show that dx7dr>0, dx7dK>0, dx7dc>0, dx7dp<0, dx7dq<0 and dx7d5<0.

These relations imply that with increasing values of r, K and c the optimal stock increases and with increasing values of p, q, and 5 the optimal stock decreases. Thus, obtaining the optimal stock level x* from 4.11, we can obtain the optimal values of all unknown variables from above three equations.

We have calculated in chapter-3 that K = 11,400, r = 1.330818, q = 0.0000977332 and c_2 = 1156.76. The dollar prices (p) of marine shrimp in Bangladesh for the period 1981-82 to 1997-98 are given in Table 3.4 and the average dollar price (p) is obtained as $8,226.30 per ton. The social discount rate 8 is assumed to be 0.1. Substituting these values in equation 4.11, we get the optimal stock (x*). This x* when substituted in equations 4.12 to 4.14, we get the optimal values of other three parameters. Optimal values for Bangladesh trawl shrimp fishery as a static solution are given in Table 4.1.

Table 4.1
The Optimal Steady State of Bangladesh Trawl Shrimp Fishery
(Static Model)

Optimal Stock (x*)	Optimal Harvest (h*)	• Optimal Effort (E*)	Optimal Shadow Price *(X*)*
6092.24	3774.87	6339.91	6911.87

Source: Estimated by the author

4.2.2. Dynamic Solution of the Model for Optimum Allocation:

It is known that there are three different approaches in solving dynamic optimization problem, namely, calculus of variation, dynamic programming and optimal control theory. Among these three approaches, the numerical dynamic programming which was first developed by Bellman (1957), is applicable for discrete-time dynamic solution. It involves a search algorithm based on backward and forward recursion. The backward or forward recursion method helps to limit the field of search and is suitable for the problems which can be formulated according to Bellman's Principle of Optimality. The numerical dynamic programming is an important tool that can be used to solve such problems those *are* nonlinear in control as well as containing stochastic elements and discontinuous functions. John Kennedy (1986) reviews the applications of the numerical dynamic programming of the above approach to a variety of natural resource problems.

Most common objective of renewable resource economics is to find out the optimal time path of resource exploitation over a period of time. It is, therefore, a resource allocation problem in a dynamic system. There are two quite different strategies for the solution of numerical dynamic programming problem. The first method of linear quadratic analytical dynamic programming necessitates a quadratic objective function and a linear stock transformation constraint (Chow, 1975).

The other approach is one of the most popular methods for obtaining approximately optimal solutions to complex stochastic models (Spulber, 1985; Koenig, 1984). They derived an optimal rule which they called current period decision rule (CPDR). They obtained it by Taylor's Series approximation of the value function and, therefore, CPDR is optimal but approximate.

Kolberg (1992) showed that Taylor's series expansion approach (Burt and Cumming, 1977) gave better approximation of the optimal solution than the solution of the problem formulated as linear quadratic analytical dynamic programming (Chow, 1975), though the latter approach is used more often than the former (Spulber, 1985 ; Koenig 1984). Quick and easy optimal approach path by Perturbation method suggested by Kolberg (1993) provides a solution which can also be obtained in a much easier way by the procedure suggested by Rowse (1995). He showed that GAMS and optimization subroutine MINOS can be employed with appropriate procedure in solving dynamic allocation problem in the resource economics. He obtained exactly the same result of Koiberg's problem. But, Conard (1999) suggested the simplest solution procedure of such class of Non-linear Dynamic problem by using EXCEL solver. However, Conard's procedure to obtain steady-state solution for renewable resource like fishery is subject to initial guess and time period (Ray and Khan, 2002).

Variation in the result depending on the initial giiess is understandable and the explanation is available in the existing literature on Non-linear Optimization. But why this suggested procedure for optimization depends on time-period and does fail to provide optimal solution of any system which reaches at steady state around time-period twenty or more is not explainable. However, we have adopted the Conard's procedure for the dynamic but discrete-time solution of the problem. Since, the steady state of the marine shrimp of Bangladesh is attained well within the time period less than twenty, it does not deter the solution procedure. So far the initial guess is concerned, the trial and error of searching reveals a non-significant variation at steady state of Bangladesh trawl shrimp.

The dynamic formulation of our problem defined in (4.1) will take the form following the procedure suggested by Conard (1999; 28) given below:

Maximize

$$PVNB = \sum \rho^t \pi(x_t, h_t) + \rho^T \pi(x_{t+1}, f(x_{t+1}))$$

Subject to (4.15)

$$x_{t+1} - x_t = f(x_t) - h_t$$

$$x_0 \text{ (given)}$$

Following are the additional characteristics of the 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 discussed and estimated in section 3.2.3 and 3.2.2 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) explained in section 2.3 and provided in the equation 3.4.

(iii) The harvest cost varies with harvestable stock (measured prior to harvest) and harvest. The cost function is as already given by the equation 3.11,

$$c(x, h) = \frac{\quad}{qx} >$$

where the estimated values of c_2 = 1156.76, q = 0.0000977332 (section 3.3) and u is assumed to be unity (section 3.3.2).

(iv) The social discount rate (S) is assumed to be 0.1

(v) Producers are competitive.

We, therefore, try to solve the dynamic allocation problem objective of which is to find the approach path which maximizes the objective function (PVNB). We adopt the dynamic analysis of optimization of Bangladesh trawl shrimp fishery under non-linear exponential demand situation as discussed in Chapter 3.

PVNB of the Model: When demand is non-linear exponential, as we have shown in (3.7), then willing to pay (WTP) function of harvest h is p (h) = pi + (p2 - pi). e^{-bh}; where pi= 6,083.97729, p_2 = 13,977.93881 and b = 0.0004682 in accordance to our computation and estimation presented in Table 3.5. Hence, the industry's profit in period T is given by the explicit function,

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

$$= p_1 . h_t + (p_2 - p_1) . e^{-b} - \backslash h_t - . \wedge\wedge \qquad (4.16)$$

Substituting this explicit profit function in the objective function of 4.15, we obtain,

$$jjfbA \sum_{t=0} +(p_2 - p_1)e^{bh}.h_t \ " \wedge_{<l^x t}) + \%^{\circ} \ rx_t(1-\wedge_{-k-}) +$$

$$(p_2 - p_1)e^{-brx,a-\wedge_K o} -- * \frac{c_{,,}r\ x.}{qx_t} S\text{-}C1-- \frac{x.}{K}.)]^n \qquad (4.17)$$

Using objective function 4.17 and the growth function 3.4, the optimal steady state or optimal harvest and stock levels are determined by solving the problem (4.15). The optimal level of stock (x*) and harvest (h*) in each year gives the optimal level of effort and shadow price for each year by using equations 4.13 and 4.14 for the period of our study. These calculated values are given in Table 4.2.

Table 4.2
Optimal Stock and harvest levels of Bangladesh Trawl Shrimp Fishery (Non-linear exponential demand function)

Year	Optimal Stock (tons) (x*)	Optimal Harvest (tons) (h*)	Optimal Effort (E*)	Optimal Shadow Priced*)
1981-1982	4,592.00	2,087.72	4651.88	7124.34
1982-1983	6,153.79	3,296.25	5480.69	6432.09
1983-1984	6,626.34	3,731.76	5762.33	6240.72
1984-1985	6,587.23	3,694.47	5738.62	6255.71
1985-1986	6,593.70	3,700.63	5742.54	6253.21
1986-1987	6,592.66	3,699.64	5741.91	6253.61
1987-1988	6,592.83	3,699.80	5742.01	6253.55
1988-1989	6,592.81	3,699.77	5741.99	6253.57
1989-1990	6,592.81	3,699.78	5742.00	6253.56
1990-1991	6,592.81.	3,699.78	5742.00	6253.56
1991-1992	6,592.81	3,699.78	5742.00	6253.56
1992-1993	6,592.81	3,699.78	5742.00	6253.56
1993-1994	6,592.81	3,699.78	5742.00	6253.56
1994-1995	6,592.81	3,699.78	5742.00	6253.56
1995-1996	6,592.81	3,699.78	5742.00	6253.56
1996-1997	6,592.81	3,699.78	5742.00	6253.56
1997-1998	6,592.81	3,699.78	5742.00	6253.56

Actual harvests and optimal harvests for the period 1981-82 to 1997-98 are shown graphically by the harvest approach path in Figure 4.1. Actual stocks and optimal stocks for the period of study are shown graphically by the stock approach path in Figure 4.2. Similarly, actual level of efforts and optimal level of efforts are shown for the same period by the effort approach path in Figure 4.3.

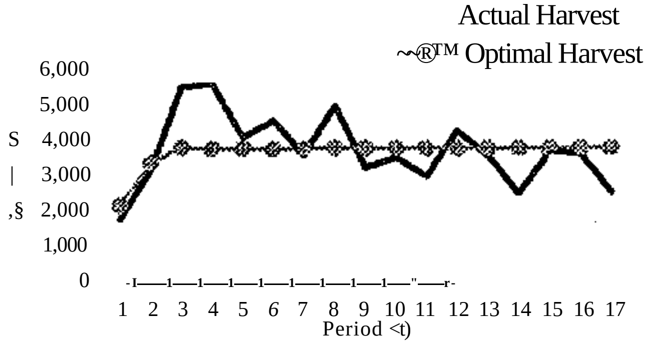

Figure 4.1: Harvest Approach Path Comparison

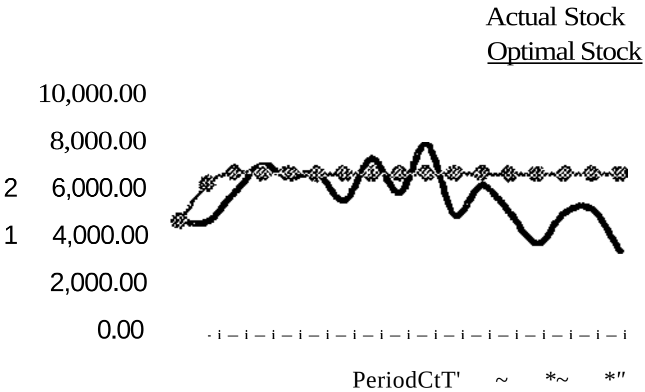

Figure 4.2: Stock Approach Path Comparison

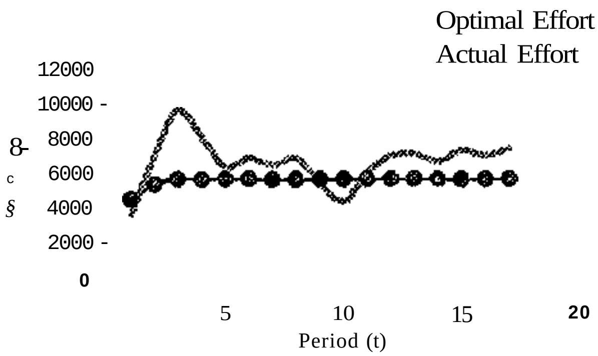

Figure 4.3: Effort Approach Path Comparison

4.3. 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 static optimization, provided in Table 4.1, and dynamic optimization, provided in Table 4.2 indicate marginal variations between static and dynamic situation. The levels of optimal stock under dynamic analysis show a marginally higher value than the static one. Optimal stock under static analysis, shown in Table 4.1, is 6092.24 metric tons where as under dynamic analysis is 6592.81 metric tons. The difference appears to be small but shows marginally significant rise of stock by 8% as given below in Table 4.3. But, in case of optimal harvest, result shows that the system appears to be less insensitive to static or dynamic analysis. In case of dynamic analysis, decline of optimal harvest is by 2.78 % as given below.

Table 4.3
Summary of Optimal Values of Stock and Harvest

Model Used	Stock optimal (x*)	% increase	Harvest optimal (h*)	% decrease
Static	6092.24	-	3774.87	-
Dynamic	6592.81	8.22	3669.78	-2.78

However, in case of optimal effort and optimal shadow price, if we summarize the results for the comparison of static and dynamic analysis, we find that dynamic analysis shows lower values at the steady state than the static analysis and the extent of decreases is not marginally insignificant. Summary Table 4.4 given below shows that changes are around 10%. Thus, on the whole, as the test of sensitivity shows that the dynamic analysis exhibits significant variation in the optimal values of the parameters and the system itself is dynamic in nature, it is better to rely more on dynamic analysis.

Table 4.4
Summary of Optimal Values of Efforts and Shadow Prices

Model Used	Optimal Effort (E*)	(%) increase/ decrease	Optimal shadow price (X*)	(%) increase/ decrease
Static	6339.91	-	6911.87	-
Dynamic	5742.00	-9.44	6253.56	-9.52

We find from the tables that system reaches at steady state very quickly. It takes only six (6) 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 harvest level attained steady state in the year 1989-90 at 3699.78 metric tons. But comparison with the actual harvests during the period of study shown in Table 3.8, indicate 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 the overfishing during the period of 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 Figure 4.1 to 4.30. Harvests and biomass 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 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 amount of catch. This is obviously alarming and demands immediate attention of the 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.,

However, as the results show that marine shrimp of Bangladesh is not being utilized optimally it implies that there must be consequential adverse effect also in terms of benefit due to non-optimal utilization of resources - be it over-utilization or under-utilization. We try to measure ,it quantitatively under static and dynamic situation as under.

(a) Static optimization: Results of static optimization analysis of Bangladesh trawl shrimp fishery (Table 4.1) show that had the resource been managed optimally, the present level of stock, harvest and effort could have been better. The estimated present stock of trawl shrimp of Bangladesh (Table 3.1) is 3338.899 metric tons, whereas the static analysts shows that the optimal present stock could have been 6092.24 metric tons. Similarly, actual harvest data (Table 3.8) show that the present level of harvest is only 2444 metric tons (1997-98), whereas the optimal harvest could be 3774.87 metric tons and that also with less effort. The result reveals that the optimal effort level that could have been required for catching the level of optimal harvest 3774.87 metric tons is 6339.91 fishing days as against the actual effort of 7491 fishing days (1997-98) to catch 2444 metric tons of fish.' In short, though in optimum situation we require less effort but higher level of catch, we actually employing higher level of effort for the less amount of harvest.

Results of the static analysis seem to imply that the Bangladesh marine shrimp is not optimally managed. If it is managed optimally then the following three distinctively exhibited notional loss could be avoided:

(i) Notional loss due to lower harvest - a higher amount of shrimp catch could be harvested every year

(ii) Notional loss due to present higher effort ~ a lesser amount of effort would be required to catch the harvesting amount of fish

(iii) Notional loss due to lower level of stock - a greater level of shrimp stock could be maintained in the marine shrimp zone of Bangladesh

If we convert these benefits or gains into monetary terms, then the relative advantage of optimal management would be quantitatively understandable. We convert those gains/benefits into monetary values on the basis of the result of the last year of our period of analysis i.e. 1997-98:

(i) Notional loss due *lo* lower harvest = (optimal harvest - present actual harvest) X market price of shrimp.

= $ (3774.87-2444) X 8226.30 '

= $1,10,27,988.08

(ii) Notional loss due to present higher effort = (present actual effort - optimal effort) X unit cost of effort.

= $ (7491-6339.91) X 1156.76

= $13,31534.87

(iii) Notional loss due to lower level of stock: Computing the quantitative values of the inherent benefits due to higher level of biomass stock is difficult and problematic as ecological factors are involved. Monetary values of this, enhanced biomass stock is bound to be partial. However, as we also get the optimal shadow price which makes the sense of incremental cost of making one more unit of resource, we assume that the cost of reproducing one unit of lost biomass stock would be well approximated by this shadow price. Therefore, Notional loss due to lower level of stock = (optimal stock- present level of stock) X shadow price

= $ (6092.24-3338.90) X 6911.87

= $1,90,30,535.41

Total annual notional loss due to non-optimal management of marine shrimp of . Bangladesh = sum of above three different losses.

= $ (11027988.08+1331534.87+19030535.41)

= $3,13,90,058.36

Hence, our findings emphatically reveal that a substantial amount of loss of 3,13,90,058.36 could have been avoided annually by managing the shrimp stock optimally,

(b) Dynamic optimization: Results of dynamic optimization analysis (discrete-time) of Bangladesh trawl shrimp fishery show, like static analysis, that the present level of stock, harvest and effort could have been much better, had this renewable resource been managed optimally. As we find[1] in static analysis, the dynamic analysis also shows that industry as well as country accepts huge notional loss annually due to non-optimal management of this resource. Following the same procedure of calculating notional loss of static analysis, we calculate notional loss for each year during the period of our study on the basis of the optimal values of different parameters (presented in Table 4.2) given by the dynamic optimization analysis. These calculated values of notional loss are presented in Table 4.5. However, in case of dynamic analysis over the period of study, there are some years where actual stocks are higher than the optimal stock. Thus the notional loss due to lower level of stock does not exist in that year and is not taken into account. Though there must be a loss due to non-utilization of resources upto optimal level, we do not account that for avoiding complexities in valuation. Proper valuation technique may be employed to quantify this loss due to underutilization of resources in future. There *are* some complexities in case of valuation when actual harvest is higher than the optimal harvest. This loss is more damaging and has a permanent effect over the resource stock. We also do not try to account for this loss. But, in case of effort, where actual effort is less than the optimal, it does not, imply any loss and therefore, notional loss due to higher effort is not included in our computation of losses in those years where it is applicable. The cumulative loss over the whole period, as shown in Table 4.5, is almost $ 180 million.

Table 4.5
Annual Notional Loss Calculated on the Basis of dynamic Optimization Analysis

Year	Loss ($)
1981-1982	3537646.19
1982-1983	13502717,40
1983-1984	9767797.75
1984-1985	2799802.89
1985-1986	1985144.00
1986-1987	1372017.06
1987-1988	9279490.60
1988-1989	1391599.72
1989-1990	9296413.27
1990-1991	2018042.48
1991-1992	17299733.80
1992-1993	4824830.09
1993-1994	13461820.00
1994-1995	29141090.90
1995-1996	12920469.30
1996-1997	12195761.40
1997-1998	31770961.70
Total loss	17,65,65,338.40

This, however, does not represent true picture of the total loss. The actual loss would be the present value of annual losses i.e. the sum total of annual losses compounded upto present time with appropriate compounding factor. The amount of such losses after compounding are given in Table 4.6.

Table 4.6
Annually Compounded Loss Upto the Year 2003 on the Basis of Dynamic Optimization Analysis

Year	Loss ($)
1981-1982	8383934.18
1982-1983	30769561.25
1983-1984	21402447.71
1984-1985	5898762.41
1985-1986	4021537.50
1986-1987	2672552.71
1987-1988	17380311.86
1988-1989	2506192.48
1989-1990	16098379.91
1990-1991	3360189.07
1991-1992	27697431.19
1992-1993	7427604.25
1993-1994	19926782.12
1994-1995	41476858.90
1995-1996	17682554.40
1996-1997	16048790.00
1997.1998	40200402.07
Total loss	282954292.00

Note: Compounded @ 4 percent interest rate

The losses are shown compounded at 4% annual interest upto the current year 2003. Table shows that $ 282 million is cumulative compound losses upto the current period. If the measures are not adopted to manage the marine shrimp scientifically and optimally, then the losses would be going on increasing over the years.

Moreover, we should keep in mind that these estimates are approximation of the actual losses in the sense that some of the losses due to adverse ecological impacts are not taken into account. Thus both in terms of annual loss* or in terms of cumulative compounded loss, the amounts are substantial. The present management policy did fail to adopt scientific approach which could optimize the utilization of the resource is revealed by this astonishing amount of loss.

4.4. Concluding Remarks:

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

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

(b) This revelation holds true for both static and dynamic discrete time situation. The result does not vary significantly for static and dynamic condition.

(c) The country bears loss due to non-optima! allocation of marine shrimp resource and both the cumulative loss over the years or annual loss are substantial.

(d) Present condition of high effort, less harvest and less biomass stock indicates that the danger of depletion of the resource cannot be ruled out. Thus, the study of both (i) the population dynamics of Bangladesh marine shrimp under chaos and, (ii) the possibility of catastrophic discontinuities may be helpful.

(e) 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.