Chapter 1

Introduction

1.1 Prologue:

Inefficiency in resource allocation and utilization is a major concern of present day economic order. Inefficiency in micro-economic level is even strongly viewed as responsible for macro-economic crisis. It is argued that micro-economic inefficiencies distort the structure of incentives to producers for which degenerated motivation in investment leads to macro-economic crisis (Bhagwati and Srinivasan, 1993). In a positive sense, we know, at an aggregate level of economy, any acceleration in growth requires some combination of an increase in gross domestic fixed capital formation and an increase in efficiency of resource uses.

The necessity to improve efficiency both 'macro level" and 'sector level' for third world countries, is urgent. Gunnar Myrdal in "Asian Drama" wrote long time back, 'All south Asian Countries face the challenge of a largely unskilled labour force and a small and inexperienced managerial force. This adds plausibility to the argument that large and highly mechanized industries are better suited to the maximum use of what skills and technical education do exist. This policy appears to be rational, provided there is also a policy to encourage the rapid increase of skills and to overcome the social restraints on their effective use' (Myrdal, 1968: 250).

Advantage of economies of large scale may also be frustrated if the ability of using resources optimally is not being achieved. From the management point of view, it implies right decision at the right time. Decisions under complex and competitive situation cannot be taken optimally by applying judgement and intuition. If the decision is not optimum, it implies that the organization operates at sub-optima! level and as a consequence of it, makes wastage of scarce resources. Level of managerial efficiency in decision-making may be best conceived by the level of use of Operations Research (OR) techniques. The use of OR-techniques can improve the competitive edge substantially by minimizing the cost and wastages of resources. There are several studies, which show the applicability of OR-techniques in variety of organizations and the extent of savings in a developed country [Appendix-A]. Other than financial benefits the application of OR also makes an organization able to establish better managerial control over the process of activities.

Managerial efficiency is not only required at firm level but also even more urgent in case of exploitation of natural resources at the national level. If not managed optimally, the obvious consequence may be a world unsuitable for human existence. Operations Research is a subject that deals with the techniques that could be applied to determine the optimum level of operation. As we have already mentioned how developed countries had derived benefits of application of OR-techniques in industry level, the same is true for conservation and utilization of natural resources. In this respect, any third world country has become a technological and psychological laggard leading to either over-exploitation or under-exploitation of resources. Both the situations - over or under exploitation of resources - makes a sense of some kind of loss. In case of over-exploitation the loss may be of the nature of permanent damage leading to ecological imbalance, and for under-exploitation it may be the loss of revenue or may be slowing down of economic development and progress of the country.

Thus the absence of optimum decision-making process in natural resource management may prove to be disastrous both for economy and ecology, Bangladesh is not oniy an underdeveloped country of small geographical size but with less natural resources and population burden. General awareness of application of optimization techniques in different sectors of the economy does not only help to improve managerial efficiency in general but it also creates a conducive environment to manage resources optimally with the objective of long run sustainability. It is, therefore, imperative to study the present practices of exploitation of resources in order to understand the scope and problems of application of optimization' techniques. However, it is to be noted that any resource, which is under long-scale commercial exploitation, satisfies a[[pre-conditions for such application of optimization techniques.

The economy of human society consumes two distinct kinds of natural resources: (a) resources capable of self-regeneration such as, fish, timber and agricultural product etc., and (b) resources without having capacity of self-regeneration, such as petroleum, natural gas and innumerable products of mines. The first category of resources being capable of self-regeneration, as man consumes, is called renewable resource and can provide man with an essentially endless supply of goods or services, while the second is called non-renewable resource as it represents a fixed stock whose inventory can only be depleted with the use over time. It is the second category, which is specifically called 'exhaustible resource', although man possesses capacities both for the conservation and for the destruction of the renewable resource base as well (Clark, 1973). Thus, both types of resources are capable of exhaustion (Smith, 1968).

Renewable resources, however, are different from exhaustible resources because of its regenerative property. Harvesting a fish or cutting a tree does reduce the stock of fish population or tree in any period but, unless and until the stock has already declined to the minimum viable level, natural growth will replenish the loss of biomass due to harvest within a relatively short period of time. The flow of the renewable resources over time is a natural phenomenon but its continuity over time and over generations is subject to the optimum rate of resource use.

From the capital-theoretic point of view, the renewable resource is viewed as an asset, which under optimal management will yield a rate of return comparable to that of other capital assets. Since, prudent use and proper management of renewable resources are necessary and essential conditions for deriving benefits of endless supply of goods and services, the interest in management of renewable resources has increased greatly in recent years.

In Bangladesh, like other underdeveloped countries, renewable resources play a vital role in the national economy. Renewable resources contribute nearly 25% to the national GDP, while the nonrenewable resources contribute to it only around 1% (Table 1.1). Among the renewable resources in Bangladesh, in most of the recent years, crops and horticulture contributes around 15%, animal farming's contributes 3%, forest and related services contributes 1.9% and fishery (inland and marine) contributes marginally above 5% to the national GDP (Table 1.2 and Table 1.3). Except crops and horticulture, fishery is, therefore, one of the major contributing sectors in Bangladesh's economy. In the agrobased economy of Bangladesh, fishery sector plays an.important role in terms of foreign exchange earnings, income generation, employment, and providing nutrition. It contributes 5.16% of the country's total export earnings. This sector provides full-time employment for 1.2 million professional fishermen and 11 million part-time fisher folks, which is about 10% of the total population. The fisheries sector provides about 80% of the animal protein consumed in Bangladesh. (Khan *et al,* 1997).

This fishery'sector in Bangladesh can be classified into two major sectors, viz. inland fishery and marine fishery. Inland fishery subdivided into two sub sectors, one is capture fishery (rivers & estuaries, beels, lake, flood-lands etc.) and other is closed water fishery (ponds, baors, etc.); Again, marine fishery has two sub sectors, such as artisanal fishery and industrial (trawl) fishery. We undertake a detailed discussion on fishery (including marine) and shrimp fishery (including trawl) in chapter-2 (sections 2.1 & 2.2).

Table 1.1

Renewable and Non-Renewable Resources' Share in GDP

Sector	1994/95	*1995/96*	1996/97	1997/98	*1998/99*
Natural Resource:	**27.01**	**26.73**	**26.90**	**26.37**	**16.28**
Renewable	26.00	25.68	25.87	25.34	25.28
Non-Renewable	1.01	1.05	1.03	1.03	1.00
Other than Natural Resource	**72.99**	**73.27**	**73.10**	**73.63**	**73.72**
Total	**100**	**100**	**100**	**100**	**100**

Source: Bangladesh Bureau of Statistics, 2000

Table 1.2

Sectoral Shares in GDP

Sector	1994/95	1995/96	1996/97	1997/98	1998/99
Agriculture:	**26.00**	**25.68**	**25.87**	**25.34**	**25.28**
Crop & Horticulture	15.42	15.03	• 15.21	14.59	14.33
Animal Farming	3.42	3.36	3.27	3.19	3.12
Forestry & Related Activities	1.95	1.93	1.91	1.89	1.90
Fishing	5.21.	5.36	5.48	5.67	5.93
Industry	**24.27**	**24.87**	**25.02**	**25.71**	**25.69**
Services	**49.73**	**49.45**	**49.11**	**48.95**	**49.03**
Total	**100**	**100**	**100**	**100**	**100**

Source: Bangladesh Bureau of Statistics, 2000

Table 1.3
Sectoral Growth Rates of GDP

Sector	Average 90/91-94/95	1995/96	1996/97	1997/98	1998/99
Agriculture	1.55	3.10	6.00	3.19	4.77
Crop &Horticulture	-0.43	. 1.74	6.44	1.05.	3.11
Aniinal Farming	2.38	2.51	2.58	2.64	2.69
Forestry & Related Activities	2.82	3.46	4.03	4.51	5.16
Fishing	7.86	7.39	7.60	8.98	9.96
Industry	7.47	6.98	5.80	8.32	4.92
Services	4.63	4.29	.4.91	4.77	4.90
GDP	4.39	4.62	5.39	5.23	4.88

Source: Bangladesh Bureau of Statistics, 2000

1.2. Problem of The Study:

Bangladesh's commercial trawl shrimp fishing commenced during the period 1972-1973. Bangladesh started with a fleet of 10 trawlers and 200 motorized boats. The numbers of trawlers more than doubled to 21 in a year and then jumped to 26 two years later. It seems to imply as we described earlier, that the sufficient economic rent was left for attracting more and more entrepreneurs in the industry. The number of trawlers changed abruptly in the early eighties and reached a maximum of'73 in 1984. It probably reflects the situation when the revenue did not cover the cost of effort. The number then falls gradually and stabilizes at a little more than 50. The current number of trawlers is 54 of which 41 are shrimp trawlers and the remaining are fish trawlers. The number of motorized boats also experienced three abrupt changes. It increased from 276 in 1974 to 1,000 in 1975, growing more than three times in a year. The number of motorized boats increased again from 1,300 to 2,000 between 1980-1981 and from 2,100 to 3,374 between 1983-1984. After some fluctuations, it finally settled at the current number of 3,317. Commercial trawl shrimp fishing in Bangladesh is confined to the marine area beyond 40 meter and within 200-meter depth. Motorized boats, however, do not participate in trawl fishing zone and operate only within the area of 40-meter depth.

The present practice of controlling the shrimp harvest in Bangladesh is guided by the Marine Fishing Ordinance (MFO) 1983, which encompasses the scope of management, development and conservation of marine resource. Under the provisions of MFO all mechanically propelled vessels require a license for fishing. Normally, a vessel is required to obtain a certificate of inspection, which is a precondition for registration. A registered vessel can then apply and receive a license from DOF. Type of fishing gear, method of fishing, and location of fishing or the fishing ground are specified in the license.

Effective management, however, require bioeconomic approach and the study of the system under dynamic situation. The objective of resource utilization is to optimize the long-run net social benefit function. System being dynamic and this social net benefit function being non-linear, the situation, therefore, depicts a non-linear dynamic optimization problem.

Present practice of management of trawl shrimp in Bangladesh is in all sense simplistic and that also heuristic without considering the bioeconomic as well as dynamic elements.

If the objective is to manage this resource optimally then it must be viewed as a non-linear dynamic system. Managing this resource with the objective of optimizing a non-linear dynamic system requires that some bioeconomic parameters like, intrinsic growth rate (r), carrying capacity (K), social discount rate (8), catchability co-efficient (q), demand and cost parameters are to be available. At present except MSY, which does not consider any economic implications, none of the above parameters are available.

The social discount rate (8) plays a very important role in resource economics. The basic proposition, that an increase in the'social discount rate leads to a faster depletion or a reduction in the social discount rate leads to greater conservation of a resource (both renewable and non-renewable) under dynamic system, is widely accepted in economic literature. In this context, the social discount rate (5) becomes very relevant with relation to a poor country. In an underdeveloped country like Bangladesh where the social discount rate is presumably high due to acute poverty, there always lies a possibility of overexploitation of any renewable resources like fishery. In this aspect, Bangladesh trawl shrimp fishery urgently demands a scientific probing whether the social discount rate has an influence on its present behaviour like decline in fleet size or reduction in harvest etc.

Nearly all fisheries worldwide display large fluctuations in stock level and harvest level year to year due to presence of uncertainty in fishery. We have already discussed the situation when even a species stock can collapse and gradual depletion eventually results in complete extinction. Bangladesh trawl shrimp fishery is not beyond this dynamic instability leading to chaos and catastrophic situation. The study of the possibility of such eventuality is, therefore, very important for Bangladesh trawl shrimp fishing because present management is dependent on estimated MSY only.

On the whole, Bangladesh, being an underdeveloped and poor country, cannot overlook the need of optimal management of renewable resources like fishery. The detail study of the said resource may reveal a completely different facet of un-satisfactory performance of the present management policy.

The problem of the study, therefore, urges to make a comprehensive analysis of present scenario of Bangladesh trawl shrimp fishery, to estimate different bioeconomic parameters, to formulate nonlinear dynamic (both discrete and continuous time frame) optimization model, to examine the impact of social discount rate on steady state, to study the possibility of chaotic and catastrophic situation and, above all, to suggest a feedback rule for optimal management. However, before this in-depth study of non-linear dynamic situation of trawl shrimp fishery as an optimal control problem, we will present a survey of general level of application of Operations Research techniques i.e. optimization techniques in different sectors of the economy in general. This will reveal the extent of awareness and concern regarding the need of the managerial efficiency in general. Three decades after independence may be considered long enough for the required time as said by Howe (1982), - "this is a long term process of learning to manage the system more productively."

1.3. Rationale of The Study:

Success of the development strategy in Bangladesh is much dependent on prudent and economical use of natural resources. Non-renewable part of natural resources being limited, the judicious, steady and long run mechanism of renewable resources utilization is the only way which may provide the basic structure of long-run sustainability of the development process. Among all the sub sectors of renewable resources, fishery is the most important one. Exploitable marine area being more than the mainland of the country, it gives ample scope in utilizing marine fish resources as a substantial contributing sector in GDP. The present practice of trawl shrimp fishery management, however, is neither scientifically making use of bioeconofnic parameters for decision-making, nor it is optimal in allocating and distributing inputs-outputs. The fishery management agency of Bangladesh has generally relied on the concept of MSY (Maximum Sustainable Yield). 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 as a policy in practice. It is also established that MSY is not an efficient point where the net benefit is optimum.

Thus, in the advent of any adverse eventuality like depletion due to the reason that it is not managed, conserved and utilized properly, Bangladesh will lose huge foreign currency, too many of its fishermen will lose employment, marine environment will lose its biodiversity and, above all, the adverse impact will contribute in abetting social tensions in Bangladesh.

The major problem in implementing the state-of-the-art optimization techniques in trawl shrimp fishery management is the lack of time series data of estimated biomass level in Bangladesh. Moreover, bioeconomic parameters are yet to be calculated or estimated for trawl shrimp of Bangladesh. Studies are, therefore, needed either to have calculated values of all bioeconomic parameters, or to design and suggest the method of estimation of those parameters, which would be reliable up to a reasonable degree/extent.

The fact is that many important aspects of Bangladesh trawl shrimp fishery with respect to dynamic analysis are yet to be understood. All these aspects of Bangladesh trawl shrimp fishery deserve *to be* studied comprehensively.

This present endeavour is, therefore, a humble attempt (i) to make a comprehensive study of the state of application of optimization techniques in general in Bangladesh, (ii) to make a comprehensive and detailed study of the Bangladesh Trawl shrimp fishery for estimating some of the bioeconomic parameters of shrimp, (iii) to obtain a steady state solution under a dynamic framework and (iv) to assess the chaotic dynamics and catastrophic discontinuities and to obtain Consistent Expectation Equilibrium (CEE). The study seems to carry an enormous academic value since no extensive study has been undertaken on this aspect of the problem. It may be helpful to the government, to the researchers, to the national policy makers, who have been making serious endeavour to protect the resource for sustainability.

1.4. An Overview of Literature:

Literature review has been discussed in two parts: in the first part, studies of all theoretical and empirical issues and their development related to optimization and management of renewable resource in general and in the second part, other studies related to Bangladesh Trawl Shrimp Fishery in particular.

(i) Theoretical development of optimization methods/techniques applicable to renewable resource management with special reference to fishery in the last few decades is enormous, wide and multidimensional.

Two important intellectual threads, one from biology and the other one from economics emerged in the 1950's to form a new rationale for renewable resource management. These thoughts emerged in the literature almost simultaneously, with the publication of esteemed papers by Beverton and Holt (1957) and Schaefer (1957) in Biology and by Gordon (1954) and Scott (1955) in Economics. Schaefer used a logistic framework connecting fishing, stock dynamics and various potential long-run equilibria in a lumped parameter model. Beverton and Holt used a dynamic pool model depicting multi-age North Atlantic trawl fisheries. These two studies were certainly important because they established the.conceptual foundations for a biological rationale for renewable resource management. Some familiar other models are given by Ricker (1958), Larkin (1963, 1966), Pella and Tomlinson (1969) and Fox (1970). However, the above models dealt mostly with biological parameters and describe how fisheries change with time under a steady state situation, whereas, in most cases, fisheries operate under complex biotechnological and socioeconomic conditions.

On the other hand, Gordon studied open access resource use and focused on the institutional cause of overfishing. Scott gave a logical and operational foundation to conservation policy that had its roots in dynamics, capital theory and investment. Scott viewed fish population and biomass as a capital stock, capable of yielding a sustainable consumption flow through time, and thus attempted to cast the problem of management of a fishery resource as a problem in capital theory. These two studies thus laid foundations of an economic rationale for renewable resource management.

Unlike biological fishery management models, most of the fisheries economics models dealing with management problems were cast largely in static terms, based on a theory of fisheries management founded by Gordon (Clark and Munro, 1975). Crutchfield and Zellner (1962) formulated a fishery model in terms of a dynamic mathematical problem. Resource economics was given a significant boost by Pontryagin's book on optimal control theory (Pontryagin et al., 1962). Optimal control theory and the maximum principle provided a powerful new way to pose and solve dynamic optimization problems, such as the problem of optimal saving and investment (Dorfman, 1969). Within a short period, control theory approach techniques were brought to the task of describing the optimal control paths for both renewable and non-renewable resources (Clark, 1990).

Several approaches to analyzing the implications of various management schemes are available. Mathematical models of fishery, which include both biological and economic factors, have been found to be useful tools for determining the best regulatory scheme.

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[1] it with a concept of optimal resource management based on criterion of maximization of present values of net economic revenues.

Zellner (1961), Rothschild and Balsiger (1971), Mueller et al. (1979) and Aguero (1987) applied linear Programming (LP) to the economics of fisheries management. Mueller and Vidaeus (1981) developed a quadratic programming model for an optimal fishery management. Nevertheless, LP modeling in fishery management problem, though very common, suffers from limitations in the underlying assumptions of LP itself. The loss of accuracy in solution due to, linear approximation of functional relationship of cost and price with quantity has been proved to be not very serious (McCarl and Onal, 1989), but the disadvantage due to difficulties in incorporating non-linear relationship of Stock-Yield-Effort within static linear framework cannot be ignored. Attempt has been made to incorporate non-linear catch-effort relation with linear approximation while stock has been considered constant and exogenous (Haynes and Pascae, 1988).

Exogenous stock assumption compels management to ignore the dynamic changes in the resource stock, which results from harvest rate and restricts the validity of the decision within single period. Moreover, as the exogenous stock concept fails to consider the characteristics of recruitment, migration and non-homogeneity of stock etc., the management decision would not be realistic.

Simulation is another frequently used method in fishery management analysis. It facilitates to incorporate non-linearity aspect of catch-per-unit-effort (CPUE) or cost function (Griffin et al'., 1988; Grant and Griffin, 1979; Nance and Nichols, 1987). Several studies take resort to this method of simulation to get rid of the problem of lack of biological data. These data when generated by simulating an appropriately parameterized function within the restrictive limit imposed by the number of control variables may then be used to reap the benefit of optimization (Blomo et al., 1978,1982).

The price-endogenous approach models that has been developed in a non-linear dynamic programming format (McCarl and Spreen, 1980), however, of-late, make it possible to include price-responsive demand functions. The biological characteristics of the system and endogenous resource dynamics through stock/effort/catch relations are better represented in these models.

Bellman (1957) first developed the numerical dynamic programming. 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 problems nonlinear in control, and containing stochastic elements and discontinuous functions. Burt (1964) was perhaps the first economist to apply stochastic dynamic programming to resource management. He was initially concerned with the optimal use of groundwater. His approach presumes that resource dynamics are linear in the stock and harvest (extraction). Burt and Cumming (1970) presented' a discrete-time, finite horizon model of harvest and investment in a natural resource industry. Smith (1968) presented to model the dynamics of a resource and the capital stock of the exploiting industry as a system. A simple dynamic approach was used by Rothschild (1971), who optimized the route of a fishing vessel. Quirk and Smith (1970) applied a time dynamic programming model to economic optimization of fishing industry.

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). This approach was one of the most popular methods for obtaining approximately optimal solutions to complex stochastic models (Spulber, 1985; Koenig, 1984). Another approach applied by Burt and Cummings (1977) involves Taylor's series expansion of the value function in the context of a dynamic programming formulation of the problem. They derived an optimal rule which they called current period decision rule (CPDR). Since they obtained it by Taylor's Series approximation of the value function and, therefore, CPDR is approximately optimal. Koiberg (1992; 1993) compares the result of these two methods in the context of a non-linear fishery model and his finding is that Taylor's series approximation approach is better than linear quadratic dynamic programming. He also used a Perturbation Method to illustrate how an optimal discrete-time-path solution set can be generated with backward/forward induction in time from the optimal steady state. Rowse (1995) argued that there is no need for 1st or 2^{nd} order approximations or current period decision rules, such as that derived by Koiberg and he proposed that one could easily use powerful non-linear programming packages to solve for the optimal time path of harvest/extraction. He showed that GAMS and optimization sub-routine MINOS can be employed with appropriate procedure in solving dynamic allocation problem in the resource economics. Conard (1999), however, showed that EXCEL could do the same. Sandal and Steinshamn (1997a), Grafton et al. (2000) and Sandal and Steinshamn (2001) provide a feedback rule for managing any renewable resource optimally. It is being considered as the best way to maintain a resource for long-run sustainability.

Many economists, such as Baumol (1968), Clark (1973) showed that an increase in the discount rate implies a reduction in the optimal standing stock or vice versa for any renewable and non-renewable resources. But most recently, some scholars, such as Farzin (1984), Hannesson (1997), Sandal and Steinshamn (1997) proved that it might not be true if the objective is non-linear concave function.

However, complex dynamics arising from non-linearities in such systems can show chaotic and catastrophic dynamic patterns (Conklin and Kolberg, 1994; Rosser, 2001; Homes and Rosser, 2001). This severely complicates the difficulties facing by the policy makers. It emphasizes adequate attention on determining critical boundaries and threshold levels for the system that must be controlled within permissible limit to avoid catastrophic collapses or as the phenomenon is known, catastrophic discontinuities.

Recent studies focused on understanding the dynamics of fisheries with different approaches departing from the MSY framework (Mangel, 1992). Some authors tried to study the theoretical aspects of mechanism of depletion in general and characteristics of factors responsible for depletion under dynamic situation instead of case study of a particular species in a particular place. They incorporate the inertial factors such as labor and capital in the dynamics of exploitation (Meadows et al, 1992; Weisbuch et al, 2002) based on a very realistic argument that capital and labor (effort) already engaged in economic activity do not change instantly and can only adjust with some inertia. The study, when includes capital inertia, results in dangerous oscillations of resource level and of production at the initial stage till the system stabilizes to equilibrium (Weisbuch et al, 2002).

(ii) Study related to Bangladesh Trawl Shrimp Fishery with reference to optimum management policy is of recent origin in nineties. Although Hossain (1971) highlighted the commercial importance of different types of fish in the Bay of Bengal in his publication at the beginning of the early seventies, the study of its different aspects with respect to systematic and scientific exploitation of this resource could not take place. The first scientific publication came out in 1973 by West. This was actually a report of the marine survey conducted during the period 1968-1971 by West as a project supervised and financed by the FAO, UNO. This publication of systematic and scientific research on the marine resource in Bangladesh is considered a reference point till today in this field of study. West gave an estimation of standing stock of shrimp along with other commercially exploitable fishes in Bay of Bengal. His estimation of huge stock of shrimp in the region substantiated the assertion made two years before by Hossain that shrimp could be an important commercially viable and exploitable resource.

After beginning of commercial trawl fishing, it gradually draws attention of new entrepreneurs as well as marine scholars. As a result of joining newer entrepreneurs, number of trawlers was going on increasing every year and reached at 74 in 1984. Crowding of trawlers made catch per unit effort uneconomic and a few trawlers were compelled to withdraw from the industry. Concerned people realized the importance of scientific stock assessment and four publications came in succession with the estimation of standing biomass of shrimp. These are, chronologically, Saetre (1981), Penn (1983), White and Khan (1985) and Vanzalinge (1986). Their estimations, however, differ widely with each other due to difference in under-lying assumptions and methodologies.

Publications related to serious study on managerial aspect came later, mostly in nineties. Scholars attempted to calculate and assess the MSY level of shrimp in the trawl fishing zone from different approaches and at least three very important report of the study published: Mustafa and Khan (1993), Khan and Latif (1997) and Khan and Hoque (2000a).

Khan and Hoque (2000) undertook a sample survey project during 1999 and estimated the cost function of trawl shrimp fishery. This publication enables the subsequent scholars in this field to have very valuable parameters like average cost and slope of the cost curve for their study.

We have mentioned earlier that the complexities of fishing industry in general in Bangladesh are intermingled with so many socio-economic factors. People employed in the industry at different levels with different capacities caused variety of social problems. Rahman (1993), Islam (1995) and Khan and Hoque (2000b) deserve special mention for their studies in this perspective of human involvement.

However, scholars in renewable resource economics, especially in fishery, know that the fishery is at present considered as a multidimensional optimal control problem. In this regard, classical variational techniques of Euler, Lagrange, Legendre, Weierstrass, Hamilton and Jacob! are as such of no use without technique of 'Optimal Control Theory', which of-course extensions of those earlier classical variational techniques. The famous maximum principle of Pontryagin provides a set of necessary conditions for optimality and makes application of optimization simple through Optimal Control Theory. The advantage of maximum principle is that it possesses a clear economic interpretation, which was not evident in classical formation.

Not a single work has been undertaken for the application of Optimal Control Theory for Bangladesh trawl shrimp fishery.

1.5. Objectives of The Study:

The main objectives of the study are as follows:

(a) To study marine trawl shrimp fishery in Bangladesh - a particular sector of renewable resource - with respect to optimum utilization and sustainability of the resource.

(b) To estimate annual optimum harvestable stocks of marine shrimp in Bangladesh on the basis of the trawler's specification, marine zone characteristics and other relevant data for the period 1981-82 to 1997-98.

(c) To estimate the bioeconomic parameters of Bangladesh TrawJ Shrimp Fishery like intrinsic growth rate (r), carrying capacity (K), catchability co-efficient (q), demand parameters (di and *62*- intercept and slope of demand function) etc.

(d) To identify the optimal control path of exploitable biomass and to estimate the steady state - optimal stock and optimal harvest level of Bangladesh trawl shrimp fishery through non-linear dynamic optimization model - under discrete and continuous time - and to examine the impact of social discount rate on optimal control path.

(e) To determine the limit reference point or minimum viable level of Bangladesh trawl shrimp fishery, where the exploitable biomass of shrimp is at a low enough level such that a harvesting moratorium is bioeconomically optimal.'

(f) To develop and design an optimum feedback rule that would help to formulate management policy and implement it for utilization and conservation of shrimp stock of Bangladesh time to time.

(g) To investigate the existence and stability of equilibria (different types of CEE - steady state, two cycle and chaotic) as well as to study the aspect of catastrophic discontinuities.

1.6. Hypotheses of The Study:

Following are, therefore, hypotheses postulated for this study:

(a) Economy of Bangladesh demands the adoption of sustainable development strategy through optimum allocation of renewable resources in genera! and commercially exploited marine shrimp in particular.

(b) Sophisticated optimizing model incorporating bioeconomic parameters is hardly seemed to be *in use in* exploiting renewable resources in Bangladesh like marine shrimp fishery.

(c) There is serious and far-reaching impact of social discount rate on the sustainability of shrimp stock in the long run and indiscriminate commercial harvesting of shrimp fishing zone of Bangladesh in Bay of Bengal seems to be leading to overfishing.

(d) Optimal control path of steady state solution of the dynamic system can be obtained and a scientific Feedback Rule can be framed for Bangladesh marine shrimp fishery assuming that controllability of multidimensional non-linear system exists.

(e) If not properly managed, the present system and practice of large-scale commercial exploitation of marine shrimp seems heading beyond chaotic boundaries and a catastrophic discontinuity may be the cause of depletion of this renewable resource.

1.7. Sources of Data and Methodology of the Study:

We will use secondary data for our study. Sources of secondary data are mainly published series of Department of Fisheries **(DOF),** Bangladesh; Bay of Bengal Programme **(BOBP),** Chennai, India: and Bangladesh Bureau of Statistics **(BBS).** A few surveys had been done so far in Bangladesh on the shrimp fishery like West (1973), Saetre (1981), Penn (1983), White and Khan (1985), Vanzalinge (1986), Lamboeuf (1987) etc. We will also use these survey data for our study. There are a few published works on shrimp fishery in Bangladesh by different scholars at different point of time and their findings are to be used whenever necessary. The published documents of government and non-government organizations are also to be consulted.

Both theoretical and applied dynamic natural resource models employ discrete-time methods for analysis because of its simplicity and ability to capture complex phenomena that are'either difficult or impossible to resolve using continuous-time methods. Identification of a generalized decision variable and structuralization of a stock transition relation are primary tasks that are to be done. Appropriate solution procedures like Kolberg (1992/1993), Rowse (1995), Conard (1999) etc. are to be employed after developing a generalized discrete-time single stock model of Bangladesh trawl shrimp fishing.

Annual harvestable stocks for the period 1981-82 to 1997-98 on the basis of the trawlers' specification and marine zone characteristics are to be estimated by employing a method suggested by Pauly (1984) for demersal marine resource. Bioeconomic Parameters are to be estimated either by estimating through OLS method or by Simulation.

Assuming then that the objective function of the system fulfills the Mangasarian sufficiency theorem for infinite horizon (Theorem 13 in Seierstad and Sydsaeter [1987]), the model will be extended for continuous time-path and we will formulate a general dynamic optimization problem. Sandal and Steinshamn (2001) method will be applied to have the steady state solution by solving the first- order conditions for the maximization of the current value Hamiltonian of the formulated optimal control problem.

Possibilities of chaos and catastrophic collapse due to harvesting activities in the system are to be studied in order to ascertain Consistent Expectation'Equilibrium (CEE) following Hommes and Sorger (1998).

1.8. Plan of the Study:

The thesis spans over seven chapters including the present one. Chapter-2 contains an account of fishery resources in Bangladesh in general and trawl shrimp fishery in particular.

Chapter-3 deals with the estimation of different bioeconomic parameters of trawl shrimp fishery in Bangladesh.

In chapter-4, we estimate the optimal steady state (biomass level, harvest level etc) by using 10 percent social discount rate under non-linear exponential demand situation with discrete time model. We also derive the notional loss due to non-optimal trawl shrimp harvesting at present in Bangladesh.

Chapter-5 deals with the estimation of optimal biomass levels and optimal harvest levels by using 0, 5 and 10 percent social discount rate under non-linear exponential demand situation with continuous- time model. We also estimate the minimum viable level for Bangladesh trawl shrimp. By using optimal steady state level, the notional loss due to non-optimal utilization of this resource will be calculated.

Chapter-6 concentrates on the possibility of the chaos and catastrophic situation in Bangladesh trawl shrimp fishery with CEE model.

Finally, chapter-7 summarizes the conclusions of the empirical results of the study. The major policy implications that are directly related to the findings will be highlighted.