MANAGERIAL EFFICIENCY- AN EVALUATION OF SCOPE AND PROBLEMS OF APPLICATION OF OPERATIONS RESEARCH:

A STUDY OF TRAWL SHRIMP FISHERY IN BANGLADESH

Thesis submitted in partial fulfillment of requirements for the Degree of Doctor of Philosophy in Commerce of the University of North Bengal

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By

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To whom it may concern

This is to certify that the research work reported in this thesis entitled *"Managerial Efficiency - An Evaluation Of Scope And Problems Of Application Of Operations Research: A Study Of Trawl Shrimp Fishery In Bangladesh"* by Mohammed Shamim Uddin Khan has been carried out by himself under my supervision and guidance. He has fulfilled all the requirements for the submission of the thesis for Ph. D. degree of the university of ' North Bengal. In character and disposition Mohammed Shamim Uddin Khan is fit to submit the thesis for Ph. D. degree.

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(Mohammed Shamim Uddin Khan)

Acronyms

AR	Auto-Regressive
BBS	Bangladesh Bureau of Statistics .
BFDC	Bangladesh Fisheries Development Corporation
BFW	Bangladesh Fishing Water
BOBP	Bay of Bengal Programme
CEE	Consistent Expectations Equilibria
CPDR	Current Period Decision Rule
CPUE	Catch Per Unit Effort
DOF	Department .of Fisheries
EEC	European Economic Council
EU	European Union
EEZ	Exclusive Economic Zone
EPBB	Export Promotion Bureau of Bangladesh
ESBN	Estuarine Set Bagnet
EAO	Food and Agriculture Organization
FCD	• Flood Control and Drainage
FCDI	Flood Control, Drainage and Irrigation
FRI	Fisheries Research Institute
GAMS	General Algebraic Modeling Systems
GDP	Gross Domestic Product
GOB	Government of Bangladesh
GSB	Geological Survey of Bangladesh
HYV	High Yielding Varieties
ICLARM	International Center for Living Aquatic Resources Management
IUCN	International Union for the Conservation of Nature
KGOE	Kilogram of Oil Equivalent
LPP	Linear Programming Problem
MEY	Maximum Economic Yield
MFO	Marine Fisheries Ordinance
MPO	Master Plan Organization
MSBN	Marine Set Bagnet
MSY	Maximum Sustainable Yield
NGO	Non-Government Organization
NLP	Non-Linear Programming
OAE	Open Access Equilibrium
ODE	Ordinary Differential Equation
OLS	Ordinary Least Square
OR	Operations Research
PAP	Passively Adaptive Policies
PVNB	Present Value Net Benefit
REE	Rational Expectations Equilibrium
REH	Rational Expectations Hypothesis
SAC	Sample Auto-Correlation
SCSP	South China Sea Fisheries Development Programme
TCF	Trillion Cubic Feet
UNO	United Nations Organization
WCED	World Commission on Environmental Development
WTP	Willing to Pay

Contents

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 2nd 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.

Chapter 2

Introduction to Trawl Shrimp Fishery in Bangladesh

2.1. Fishery in Bangladesh- An Overview:

Fish is an essential item of food for the people of Bangladesh and is the major source of animal protein. The fisheries sub-sector currently contributes about 6% to GDP and about 8% of the total merchandise export. It ranks third to jute and leather in total export. About 80% of the country's animal protein supply is'contributed by fisheries. Nearly 10% of the population directly or indirectly depends upon fishing and its ancillary industries for their livelihood.

Annual per capita consumption of fish in Bangladesh was 12 kg in 1962-1963 and decreased to 7 kg in 1982-1983. With the introduction of modern fish culture practices in inland waters and captures technology in deep-sea waters, per capita production has risen to 8.80 kg per annum in 1993-1994, but this is far below the Asian average of 25 kg and the world average of 12 kg per annum. But despite continuous increase in fish production, it has not been able to cope with the fast

Table 2.1

Year-wise Fish Production of Bangladesh (1994-95 to 1998-99)

Source	1994-95	1995-96	1996-97	1997-98	1998-99
Inland Fisheries	**9,08,218**	**9,88,238**	**10,85,764**	**11,90,761**	**12,42,620**
Inland Openwater (Capture)	**5,91,145**	**6,09,151**	**5,99,900**	**6,15,949**	**6,49,418**
River and Estuaries	1,52,782 ,	1,65,637	1,59,660	1,56,894	1,51,309
Sundarban	6,951	7,265	9,225	7,031	11,134
Beel	58,298 '	60,768	62,798	67,812	69,850
Kaptai Lake	5,556	6,148	5,764	5,932	6,689
Flood Lands	3,67,558 ..	3,69,333	3,62,453	3,78,280	4,10,436
Inland Closewater (Culture)	3,17,073	3,79,087	4,85,864	5,74,812	5,93,202
Ponds	2,67,282	3,07,974	4,03,830	4,83,416	4,99,590
Baors (Ox-bow Lake)	2,460	2,764	3,014	3,378	3,536
Shrimp Farms	47,331 •	68,349	79,020	88,018	90,076
Marine Fisheries	**2,64,650**	**2,69,702**	**2,74,704**	**2,72,818**	**3,09,797**
Industrial	11,715 ,	11959	13,564	15,273	15,818
Artisanal	2,52,935	2,57,743	2,61,140	2,57,545	2,93,979
Total	**11,72,868**	**12,57,940**	**13,60,468**	**14,63,579**	**15,52,417**

Source: DOF, Bangladesh

growing population. The country's fish production has increased from 6,40,000 metric ton in 1975-1976 to 13,73000 metric ton in 1996-1997, whereas per capita fish consumption has decreased from 33 gm to 20 gm. This has happened simply because fish production increased at an arithmetical rate whereas the human population increased in geometrical proportion.

Fisheries in Bangladesh are broadly categorized as (i) inland and (ii) marine fisheries. Rahman (1989) lists 260 species of fresh water fish belonging to 55 families that abound the fresh waters of Bangladesh. About 56 species of palaemonid and penaeid prawns occur in the fresh water, estuarine water and marine waters (Kibria, 1983). In the marine waters, the species of finfish recorded, so far, are 475, of which only about 65 are commercially exploited (Hussain, 1971).

Bangladesh produced about 15,52,417 metric tons of fish in 1998-1999, of which about 12,42,620 metric tons (80.04%) came from the inland and 3,09,797 metric tons (19.96%) from marine fisheries. Inland openwater capture fishery constituted about 6,49,418 metric tons (52.26%) and ciosedwater culture fishery 5,93,202 metric tons (47.74%) of the total inland fish production. Marine fish catch from artisanal fisheries and industrial (trawl) fisheries were 2,93,979 metric tons (94.89%) and 15,818 metric tons (5.11%) respectively (Table 2.1).

2.1.1. Inland Water Fishery:

Bangladesh is situated in the deltaic plain of the three main river systems - the Padma (Ganges), the Meghna and the Jamuna-Brahmaputra and their tributaries. The size of the riverine (flowing river and estuaries) and other large inland perennial water bodies has been estimated to be about 12,200 square kilometer i.e. over 8% of the area of Bangladesh (Table 2.2). It has vast inland open waters, rich in fisheries resources. The waters of these rivers and their many branches and tributaries have been central to the economic and social lives of both fishers and non-fishers. In addition to riverine and estuarine fisheries, other important categories of inland fisheries are beels (natural depressions), baors (dead rivers), haors (low-lying natural depressions), pukur and dighis (ponds and tanks), floodlands (seasonal floodplains), an artificial lake (Kaptai lake), the Sundarban, shrimp firms and bheries (salt water fish enclosures or farms) (DOF, 1986). Historically, inland open waters were the major source of fish production of the country. According to the World Bank (1989), Bangladesh is the world leader in per unit area fish production in fresh water with an average production of 4,016-kg/square kilometer (China 411 kg/hectare; India 391 kg/hectare; World average 90 kg/hectare). Even the per capita production of 5.5 kg demonstrates Bangladesh's lead compared to other major fresh water fish producers (China 4.2 kg; India 1.8 kg). The inland open water fishery resources contributed about 90% of the country's fish production in the 1960s (BOBP, 1997), but due to man-made causes, such as overfishing in the absence of fisheries management and conservation measures, implementation of flood control and drainage projects, fish production in the inland open water, particularly in the rivers and floodplains, has declined significantly during the last three decades.

Seasonally Flooded Land: The area of floodplains was estimated at 5.5 million hectare (MPO, 1985). The downward trend in the late 1970s saw a 20%-25% decrease in the contribution to production from inland open water sources. This contribution to the country's fish production has continued to drop and is about 51% at present (DOF, 1994). This decline has been comparatively high in the case of important and valued fish like major carp (Rui, Catla, Mrigal, etc.). The major carp, which earlier contributed about 30% of the fish production, has now dropped to 5%-6% (Tsai and Ali, 1987). The species composition in open water has been out of balance because of the disturbance to natural reproduction of the fish by overfishing and other causes. In the open water production system, floodplains play an important role in fish production. Floodplains are the low-lying areas, which are flooded by rivers and rainwater congestion. About one-third of the total area of Bangladesh is flooded every year and remains under water for 4-6 months. The floodplains, naturally rich in nutrients and fish food, are the feeding and grazing grounds of almost all inland fish, and the breeding grounds of many of the aquatic species. During the flood seasons (June-November), fish and shellfish grow in the floodplains and are harvested by the rural people. When the water recedes, fish accumulate in the deeper part of the floodplains, called beels, or they migrate to rivers, which retain water throughout the year. Due to the decline of fish population in inland open water and obstruction in the migration route, recruitment of fish in the floodplains has declined and resources in the floodplains are not fully utilized.

Table 2.2
Inland Water Resources and Its Area

Inland water resources	**Water area (hectare)**
Open water	
River and brackish water	10,31,563
Beel	1,14,161
KaptaiLake	68,800
Floodplain	28,32,792
Total	**40,47,316**
Closed water	
Ponds (12,88,222 in number)	1,46,890
Baor (Ox-bow lake)	5,488
Coastal shrimp farm	1,37,996
Total	**2,90,374**
Grand Total	**43,37,690**

Source: DOF (1999)

Beels, Haors and Baors Fishery: The number of beels in the Northeast Region is between 3,440 (covering 58,500 hectare with a mean size of 7 hectare) and 6,149 (covering 63,500 hectare with a mean size of 10 hectare) (Bernacseket *et. at.,* 1992). About 58% of the beels in the Northeast Region are permanent and the remainder is seasonal. Bernacsek er a/., (1992) also provide a list of the most important fish producing haors in the Northeast Region of the country. They estimate the area of haors is about 1,13,430 hectare. In the other region of the country, the haor-like basins are not seen but beels are seen almost all over the country. All low-lying areas inundated and submerged for a number of months, usually from June to September and becoming dry in the dry season are termed as beels in other regions of the country.

In the southwest region of the country, some of the meandering rivers, becoming old, changed their courses and, in the process, left ox-bow bends, which got cut off from the main stream and become isolated, forming baors or ox-bow lakes. There are 37 large ox-bow lakes, covering an area of about 4000 hectare, and 50 smaller ones in Jessore, Kushtia, Faridpur and Khulna. Most of the larger ox-bow lakes are located in the Jessore region. Ox-bow lakes range in size from about 25 hectare to a maximum of 500 hectare (Hasan, 1990). The total area of baors is about 5,488 hectare. Baor production (1992-1993) was reported to be 1,803 tons with an average annual production rate of 329 kg/hectare (DOF, 1993).

Pond Fish Culture: Bangladesh has got a large number of ponds scattered all over the country. There are over 1.3 million ponds covering an estimated area of 147,000 hectare, representing 3.53% of total inland water resources excluding FCD/FCDI and burrow-pits. The size of the individual ponds varies from 0.02 hectare to 20 hectare. Currently, the average production in fresh water ponds is 1.4 metric ton/hectare and that of brackish water shrimp farms is only 160 kg/hectare (GOB, 1998; BOBP, 1997). Country production figures show that 2,02,167 tons of fish about 19.8% of the total country production are produced in ponds in Bangladesh with an average annual catch of about 1376 kg/hectare from ponds (1992-1993) (DOF, 1993).

FCD/FCDI Areas and Burrow Pits: The total area under FCD/FCDI component is estimated be 0.7 million hectares, of which 7,000-hectare area is now being developed under different projects for integrated aquaculture. Burrow-pits, after implementation of irrigation, drainage and embankment projects, usually lie unused. Poor people catch some fish, which grow naturally in sdme of these pits. These pits could be turned into nursery ponds and could be used for growing of quick-yielding species. Up to 1.25 million fingerlings per hectare can be produced by modifying the size and depth of these pits besides about 1.5 of high-yielding fish, like *Sarpuntiand Tilapia.*

Paddy Fields: It has. been estimated that Bangladesh's paddy fields cover an area of about 8 million hectare. Fish production in inundated paddy fields is at present, mainly a subsistence capture fishery and, generally, no culture measures are taken. However, paddy-cum-fish culture is now considered an ideal method of land-use. Fish culture in paddy fields has enormous potential in Bangladesh and the present low-yield could be increased to 250 kg/hectare/crop by adopting scientific management practices.

Riverine and Estuaries: All the major rivers meet the Bay of Bengal in the south of the country. Near the confluence of the sea and the rivers, freshwater is replaced by a mix of saltwater and freshwater producing brackish water, and forming a distinct estuarine zone. A wide range of salinity gradients is encountered in the rivers up to a considerable distance upstream from the shoreline of the Bay of Bengal. In the Southwestern region, the principal ecological feature is the presence of the largest mangrove forest in the world, known as the Sundarban. It is criss-crossed by an intricate network of large and small rivers, canals and creeks. The total water area is estimated to be 175,600 hectare (Ali, 1991). Many marine species of fish such as hilsa *(Hilsa ilisha)* use the Sundarban estuaries to migrate upstream into the freshwater portions for spawning. Conversely, many freshwater species such as giant freshwater prawn *(Macrobrachium rosenbergify* migrate from freshwater to the estuaries for breeding. Many marine species of fish utilize the Sundarban estuaries as nursery and grazing grounds for their larvae, fry and juveniles or/and as spawning ground. The Sundarban estuaries also provide good commercial fisheries for ribbonfish, clupeids, polynemids, anchovies, pomfrets, chirocentrids and similar other salt water fishes. In addition, shrimps including tiger shrimps, giant freshwater prawn and brown shrimps are also harvested.

Hilsa is the largest single species fishery in Bangladesh, contributing nearly 25% of the total fish production. There is also thriving fishery for the young Hilsa, generally known as *Jatka.* It has been estimated that some 4,000 tons of *Jatka* are annually caught from a section of the river Meghna. Some estimates suggest that a 10%-20% conservation of *Jatka* would be equivalent to an additional 40,000-100,000 tons of Hilsa (BOBP, 1997).

2.1.2. Marine fishery:

There are two types of marine fishery in Bangladesh. One is artisanal fishery and the other one is industrial fishery. The artisanal fisher folk operate in inshore (coastal and estuaries) area and the industrial fisher folk operate in offshore (deep sea) area. Both types of fisher folk use fishing gears (different types of nets) and crafts (boats, trawlers etc.). Most of the fishermen in Bangladesh are, however, small-scale fishermen, who use both motorized and non-motorized boats. Some commercial firms use trawlers for catching fish in the deep sea. The artisanal fisheries sector operated mainly with five types of gill nets (drift gill net, fixed gill net, large gill net, bottom-set gill net and mullet gill net), two types of set bag nets (estuarine set bag net and marine set bag net), trammel nets, bottom long lines, beach seines, fine mesh push nets, fixed bag nets and drag nets in harvesting the major catch by applying the primitive^ethods and techniques (Table 2.3).

Table 2.3.

The Area/Depth of Fishing Gears and Crafts Engaged in Different Fisheries

Type of fishing	Major shrimp exploited.	Annual shrimp prod, (ton)	Area/Depth (meter) of Production.
Industrial Trawl Fishing:			
Shrimp Trawler	Adults	4,641	40-100
Fish Trawler	Adults'	232	40-100
Artisanal:			
Gill net:			
Drift			Up to 30
Fixed			8-10
Large mesh drift			30
Bottom			South Patches
Mullet			5-10
Set bag net:			
ESBN	Juveniles	72,786	5-20
MSBN	Adults and Pre-adults	26,111	10-30
Large mesh net		-	10-20
Trammel net		1,753	8-20
Bottom long line		2,853 -	10-13
Beach seine	Small	8,090	8-10
Ghar Pata Jal		-	Up to 10
Cast net		-	Up to 10
Push net	Larvae,	1,294 million	Up to 10
Fixed bag net	Larvae.	741 million	Up to 5
Dragnet	Larvae.	14 million	Up to 2

Source: Khan, M. G. (1994).

A frame survey of traditional and mechanized boats was carried out in 1984-85 and according to the survey a total of 17,331 boats were in operation in the marine artisanal fishery of which 3317 were mechanized boats. According to another estimates the totai number of traditional and mechanized boats in the estuaries and coastal waters of Bangladesh is 20,000 and 12,700 respectively. Recently, coastal and marine fisheries strengthening project of DOF has reported a total number of artisanal boats as 50,530, of which 28,700 are non-mechanized and 21,830 are mechanized including 3317 registered mechanized boats. Mechanized boats, with minimum 6 to maximum 10 crewmembers, are operated with engines of horsepower as low as 9 to the highest 33. The gross capacity of these boats is 7-8 tons. But per trip of 4-6 days of these boats produces average catch 2-3 tons normally.

The number of motorized boats increased from 276 in 1974 to 1,000 in 1975, growing more than three times in a year. The number of motorized boats increased from 1,300 to 2,000 between 1979-80 and 1980-81 and from 2,100 to 3,347 between 1982-83 and 1983-84. After some fluctuations, it finally settled at the current number of 3,317 (Table 2.4).

Table 2.4

Numbers of Fishing Crafts and Gears During 1972-1973 to 1996-1997.

Years	Trawlers number	Mechanized Boats	Non-mechanized Boats	Gill nets	Set bag ' nets	Long lines	Trammel nets	Other nets	Total fishing gears
72-73	10	200	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
73-74	21	276	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
74-75	21	1,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
75-76	26	1,000	n.a.	n.a.	•n.a.	n.a.	n.a.	n.a.	n.a.
76-77	26	1,050	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a,
77-78	26	1,100	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a,
78-79	26	1,200	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
79-80	26	1,300	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
80-81	24	2,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
81-82	35	2,050	n.a.	n.a.	n.a.	n.a,	n.a.	n.a.	n.a.
82-83	53	2,100	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a,
83-84	73	3,347	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
84-85	67	3,300	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
85-86	45	3,137	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
86-87	49	3,317	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
87-88	52	3,317	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
88-89	52	3,317	n.a.	n.a.	'n.a.	n.a.	n.a.	n.a.	n.a.
89-90	53	3,317	14,014	6,389	12,615	2,084	500	2,222	23,810
90-91	53	3,317	14,014	6,389	12,615	2,084	500	2,222	23,810
91-92	53	3,317	14,014	6,389	12,615	2,084	500	2,222	23,810
92-93	53	3,317	14,014	6,389	12,615	2,084	500	2,222	23,810
93-94	53	3,317	14,014	6,389	12,615	2,084	500	2,222	23,810
94-95	53	3,317	14,014	6,389	. 12,615	2,084	500	2,222	23,810
95-96	53	3,317	14,014	6,389	12,615	2,084	500	2,222	23,810
96-97	54	3,317	14,014	6,389	12,615	2,084	500	2,222	23,810

Source: Statistical Year Book of Bangladesh, 1998 (Note: n.a, stands for not available).

There are two categories of exploitable fishes in marine- Pelagic and Demersal. Estimation of stock of two categories marine fishes- Pelagic and Demersal - are not made continuously in Bangladesh through survey and thus annual time series data of stock level are not available. However, some occasional surveys on marine resources were made and those survey data are available.

Pelagic Fishes: Detail surveys for pelagic fishery resources have not yet been carried out in Bangladesh marine water. Saetre (1981) estimated standing stock of pelagic fish at 60,000- 120,000 metric tons through an acoustic study. Both Dr. Fridjof Nansen (1979-1980) and Thai-Bangladesh joint survey (1979) reported a good abundance of large pelagic i.e. tuna and tuna-like fishes and sharks in Bangladesh marine waters. These surveys were also aimed at demersal studies and some extra efforts were made for pelagic studies with offshore drift gillnet. In the course of these studies, 10 types of tuna and tuna-like fish; 4 types of mackerels; 4 types of sardines; 13 types of sharks and rays; 13 types of carangids and clupeids (mainly *Hilsa ilisha* i.e. shad) were identified.

Demersal fishes: Several surveys have been conducted in Bangladesh marine waters to assess particularly the demersal fish resources since 1968. Results of these surveys exhibit different estimates of demersal fish stock ranging from 55,000 -3,73,000 metric tons. Significant works were carried out by West (1973), Saetre (1981), Penn (1983), Khan et al. (1983) and Lamboeuf (1987). Amongst them, Lamboeuf (1987), on the basis of 17 cruises covering 581 stations estimated standing stock of demersal fish as 157,000 metric tons in 10-100 meter depth and as 1,88,000 metric tons in 10-200 meter depth. On the average, the figure stands at 157,000 metric tons. Two other estimations, Saetre (1981) and Khan et al, (1983) although do not cover huge number of cruises as like as Lamboeuf, do not greatly vary from the estimation made by Lamboeuf. Saetre (1981) reported standing stock of demersal fish as 1,60,000 metric tons and Khan et al. (1983) reported as 152,000 metric tons. The MSY was estimated at 40,000-50,000 metric tons within 10-100 meter depth and 47,000-88,500 metric tons within 10-200 meter depth zone (Lamboeuf, 1987). The finfish species those presently exploited are mainly demersal fishes, shallow water estuarine species, some mid-water species arid a few pelagic species. Most of them are common to both artisanal and industrial fisheries.

2.2. Shrimp Fishery in Bangladesh':

There are two types of shrimp fishery in Bangladesh, one coastal aquaculture shrimp fishery and the other one is capture shrimp fishery i. e. marine shrimp fishery.

2. 2.1. Coastal Aquaculture:

Brackish water aquaculture, also known as coastal aquaculture, is rapidly expanding farming activity and plays an important role in the overall fisheries development effort in Bangladesh. Brackish water aquaculture has been a definite economic activity since the early 70s when Bangladesh started exporting shrimp. Amongst the coastal districts, brackish water aquaculture activities are most visible in Satkhira, Khulna, Bagerhat, Cox's Bazar and Chittagong. Extensive areas in the coastal belt are, however, under brackish water aquaculture, which is entirely shrimp-based. The total area currently under aquaculture is 2,92,378 hectare of which 48% is under brackish water aquaculture. Brackish water aquaculture products are largely export-oriented and account for 52% by volume and 64% by value of the total fisheries export. Again, brackish water products contributed 86% by volume and 84% by value, of total exported aquaculture products. Well over 200,000 people are directly employed in brackish water aqua farming which has also led to the establishment of various rural based cottage industries i.e. making of bamboo screens, cages, traps, baskets, mats, nets, wooden sluices, rickshaw vans, boats etc. Brackish water aquaculture, particularly of shrimp, is fast expanding in Bangladesh due to the high demand for its products in the world market. The most commercially important brackish water shrimp are Bagda *(Penaeus Monodon)* and the white shrimp *(Penaeus Indicus).*

Shrimp culture area has expanded from 20,000 hectare in 1980 to over 140,000 hectare in 1994 and production has increased from 2,220 tons in 1982-1983 to 57,000 ton in 1994-1995. While gross production has increased, production per unit area, however, is very low. It is 100-160 kg/hectare in traditional extensive systems and about 250-350'kg/hectare in improved extensive systems. Semi-intensive culture, through higher stocking, supplementary feeding, aeration and water exchange has indicated productions of 2,50 kg/hectare {BOBP, 1997).

Tiger shrimp larvae is of high demand for aquaculture and the process of collection of tiger shrimp larvae is destroying million of other fish and shrimp larvae. Fine-mesh push nets, fixed bag nets and drag nets are used throughout the coastline for harvesting of post laivae of tiger shrimp. It is estimated by the DOF/BOBP survey (Paul *et* a/.1993, BOBP, 1993) that 2,92,397 persons including women and children are involved in the collection of shrimp seed and 2,28,658 gears of different types are engaged in this fishery.

More than 2,035 million tiger shrimp post larvae are collected annually (Paul, af *al,* 1993) which is only over 1% of the total catch of the push net fishery. The rest of the catch is thrown *on* the sand to die, which is equivalent to about 200 bilJion of the larvae of other shrimp and fishes. Presumably the amount is increased by at least two times in number at present. This is considered as a serious growth overfishing. Seed is the main input for any aquaculture operation. At present, a major portion of the seed of Bagda shrimp is collected from natural resources. But the availability of seed from nature is erratic, unreliable and is on the decline due to various reasons. Mortality of seed collected from nature is high, due to the crude methods used in collection and transportation. It is estimated that over 50% of the seed collected dies before reaching the shrimp farms. Jt has been estimated that over 3 billion *Penaeus Monodon* seed are annually collected from natural sources. Along with the desired *Penaeus Monodon* post-larvae, fry of a number of other finfish and shellfish are caught, but are destroyed as they are discarded on the shore. Studies undertaken by the FRI indicate that for every single *Penaeus Monodon* post-larvae collected, 40 other shrimp and 10 finfish seed are destroyed (Majid, 1994).

With the expansion of shrimp culture area and also intensification, the demand for shrimp seed has increased, but the collection from nature is not able to meet the demand. Only in recent years have a few hatcheries been established in Bangladesh, but their production capacity is very insignificant. These hatcheries are also facing several problems. As a result, as such adverse conditions in meeting the demand, seed are being imported from neighbouring countries.

As an ancillary to shrimp fishing, freezing plants and frozen storage (shore based) facilities have developed as industry in Bangladesh in a very big way. There were 115 processing plants by 1993-1994, having a total daily capacity of 800 metric tons of shrimp or fish (approximately annual capacity of 180,000 metric tons on the basis of 220 days of operation in a year). As against this installed capacity, shrimps for export amount to only around 40,000 metric tons live weight or about 25,000 metric tons headless weight. Capacity utilization for shrimp freezing was only 19% in 1992-1993. As a result, most shrimp processing plants are either lying idle or have diversified into finfish processing and freezing. Of the 115 plants only 4 are in the public sector (BFDC) and have a daily freezing capacity of 51 metric tons. The private sector exporters mainly use BFDC plants as service facilities. (BOBP, 1997).

The major export markets during 1992-1993 for frozen shrimp and prawn from Bangladesh were the USA (40.22%), EEC (33.50%), Japan (12.64%) and Germany (10.41%). Regional countries in the South East Asia are buying only 2.88% of this commodity. Market share of frozen shrimp and prawn are shown in Table 2.5.

Table 2.5

Major Export Markets of Bangladesh Frozen Shrimp (million US $)

Year	Market Share	USA	EU	Japan	South-East Asia	Total
1991-1992	uses) %	45.88 38.33	56.43 47.15	11.83 9.88	4.93 4.12	119.71 100%
1992-1993	US($) %	62.50 40.20	*68.27* 43.91	19.65 12.64	4.48 2.88	155.48 100%

Source: BOBP (1997)

2.2.2. Trawl Shrimp Fishing:

Marine Environment: Bangladesh has a land area of 1,47,570 sq. km. and is bounded by India on the west, north and northeast, by Myanmar (Burma) on the east and southwest, and by the Bay of Bengal on the south. Bangladesh declared an Exclusive Economic Zone (EEZ) of 200 nautical miles in her seawater in1974. Bangladesh EEZ lies from the base line to 200 nautical miles seaward. 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 (Table 2.6). The shelf area covers roughly 66,440 sq. km. and

Table 2.6

Total Marine Water Area of Bangladesh

Description	Area (Sq. Km.)
Coast line	710
Internal water up to 10 fathom (base line) from the coast line •	25,140
Territorial water up to 12 n.nx from the base line	9,060
EEZ (200 am. from the base line) territorial water	1,40,860
Total Marine Water (EEZ + Internal Water)	1,66,000

Source: Fisheries Information Bulletin, GOB, 1986.

the coastal waters are very shallow; with depths less than 10 meter covering 24,000 sq. km (Table 2.7). The shelf area down to about 150 m appears to be very smooth with very few obstacles to bottom trawling. The continental edge occurs at depths between 160 m and 180 m. In the case of Bangladesh trawl shrimp fishery, Penn (1983) estimated 5,180 square kilometer as the effective shrimp fishing area. The actual shrimp-fishing zone is shown in the Figure-2.1.

Diagram shows that there are four major fishing grounds in the Bay of Bengal of Bangladesh. There are South Patches (3662 sq. km.), South of South Patches (2583 sq. km.), Middle Ground (4600 sq. km.), and Swatch of No Ground (3800 sq. km.) (Khan, 2000).

Biological Description of Marine Shrimp Catch: There are altogether ten different types of shrimp of Penaeus (or Meta-Penaeus) family available in the zone of marine trawl fishing in Bay of Bengal of Bangladesh. Biological names along with common

Table 2.7
Area of Shelf of Bangladesh

Depth Zone (Meter)	Area (Sq. Km.)
Up to 10	24,000
10-24	8,400
25-49	4,800
50-74	5,580
75-99	13,410
100 -199	10,250
Total	66,440

Source: Saertre, 1981.

names are listed below. Pictorial presentation of each of the types mentioned here is also provided. Though majority of the shrimp types listed here are common to both artisanal and industrial fisheries, there are differences in nature of catch. While the industrial fishery harvests mostly the adult, the artisanal fishery harvests the pre-adults, post-juveniles, and juveniles because shrimps usually reside in the brackish water estuaries during the early phases of their life.

i) *Penaeus monodon* Giant tiger shrimp
ii) *Penaeus semisulcatus* Tiger shrimp
iii) *Penaeus iaoonicus* Tiger shrimp
iv) *Penaeus indicus* White shrimp
v) *Penaeus merguiensis* Banana shrimp
vi) *Metapenaeus monoceros* Brown shrimp
vii) *Metapenaeus brevicornis* Brown shrimp
viii) *Metapenaeus affinis* Brown shrimp
ix) *Parapenaeopsis sculptilis* Pink shrimp
x) *Parapenaeopsis stvlifera* Pink shrimp

Among all these varieties, *Penaeus Monodon* (giant tiger shrimp) is the most valuable and targeted species and fetches a very good price both in local and international markets but the highest contribution in the total production (63%) is made by *Metapenaeus Monoceros* (brown shrimp),

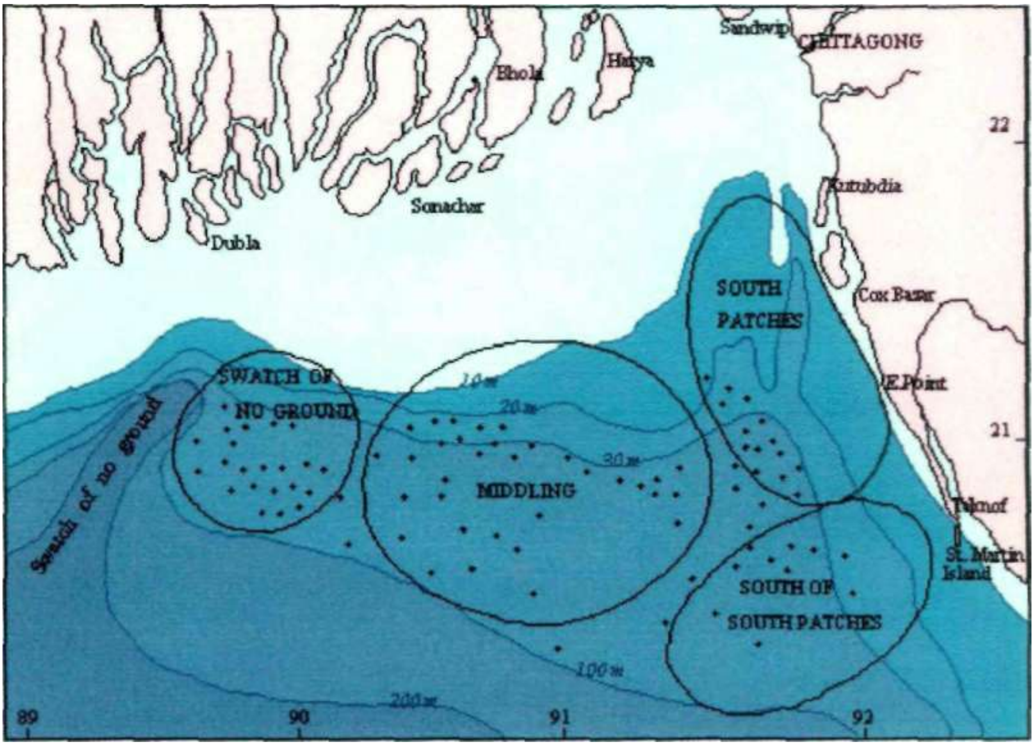
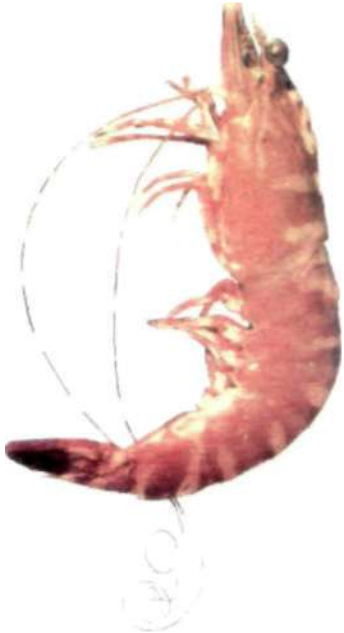


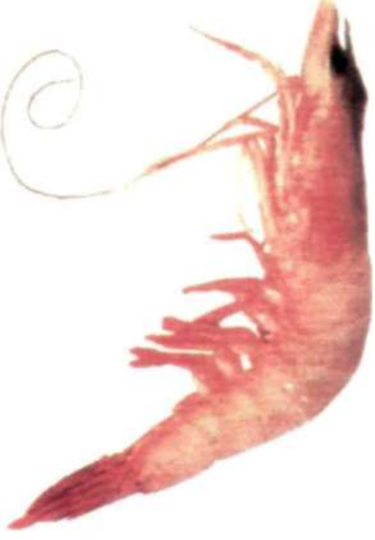
Figure 2.1. Geographical Location of Trawl Fisheries in the Bay of Bengal of Bangladesh

(a) ***Penaeus monodon***



(b) ***Penaeus semisulcatus***

(c) ***Metapenaeus brebicornls***



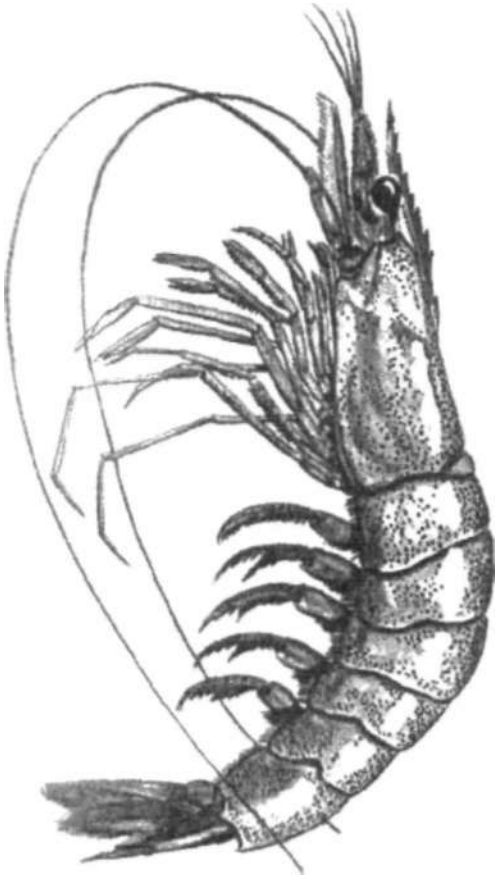
(d) ***Penaeus indicus***

(e) *Metapenaeus monoceros*

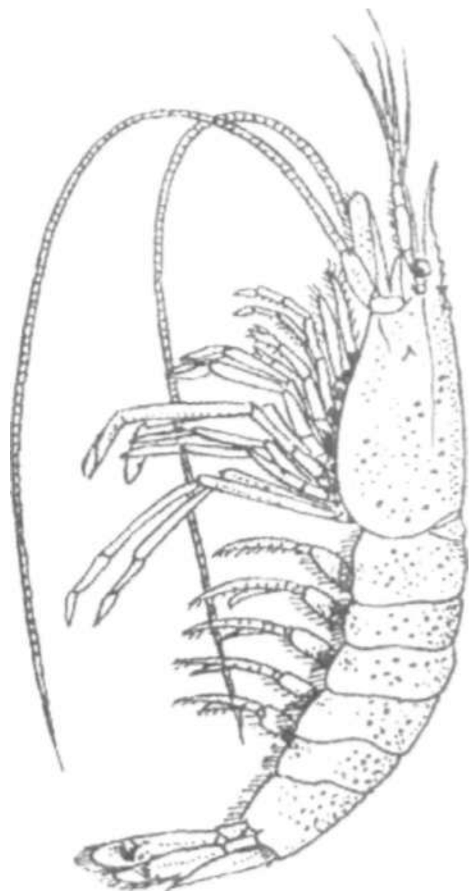
(f) *Penaeus japonic us*

(g) *Parapenaeopsis sculptilLs*

(h) *Penaeus merguiensis*



(i) *Metapenaeus affinis*



(j) *Parapenaeopsis styltfera*

The surveys and researches so far carried out in the Bay of Bengal give a fair idea of distribution of shrimp in different depth strata. The distribution of shrimp by depth strata is 45.2% in 10-20 meter, 31.2% in 20-50 meter, 12.7% in 50-80 meter, and 10.9% in 80-100 meter {Hye, 1994).

Several studies indicate that shrimp migrate to deeper waters as they grow older and larger (Blomo et al, 1982). The literature provides a range of shrimp sizes by depth zone but not migration rates or numbers. During the shrimp life cycle, which is about 1-2 year, the shrimp stock is subject to natural and fishing mortality. Moreover, juvenile shrimp, which grow in marshes (brackish/inshore waters), move to deep waters as they grow. Thus, a trade-off occurs in calching shrimp in various seasons and locations. Small shrimp caught in the inshore are less valuable than larger shrimp caught in the offshore, but catches by the inshore fishermen reduce the stocks available to offshore fishermen. The open access, common property nature of the fishery in the inshore motivates fishermen to harvest as much and as fast they can. This phenomenon may lead to uneconomic use of the resource and a major concern of the policy maker.

Life cyck Patterns of Penaeid Shrimp: Penaeid shrimp live and spawn in offshore waters beyond the 40-meter depth zone. The larvae enter the estuarine habitat with the tidal currents. There they find an environment suitable for feeding and living at that age. As they grow bigger, their physical and biological demands change gradually and so they move back towards the sea. When they reach the parent stock they have grown to adulthood and have matured to participate in the spawning process, During the different phases of their life cycle. the penaeid shrimp population encounter a variety of fishing gear in different areas and depths of the sea (Figure 2.2) starting with shrimp fry collecting gear at the post-larvae stage, followed by the ESBN and beach seine in the open brackish waters and estuaries, when they are at the juvenile stage. The survivors are then captured by the MSBN at post-juvenile and pre-adult stages, by the trammel nets at adult size and finally, the residual population is caught by the shrimp trawlers in the marine environment. Thus, members of a single *stock* are exposed to a multi-gear fisheries exploitation system.

Fleet of Trawlers: 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 number of trawlers changed abruptly in the early eighties and reached a maximum of 73 in 1984. The numbers then fall gradually and stabilized 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 (Table 2.4).

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 one and a half decade have been rotated around 5,000 -6,000 standard fishing days to produce 3,500-6,000 mt 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 mt and the optimum effort for producing the said amount is 7.000-

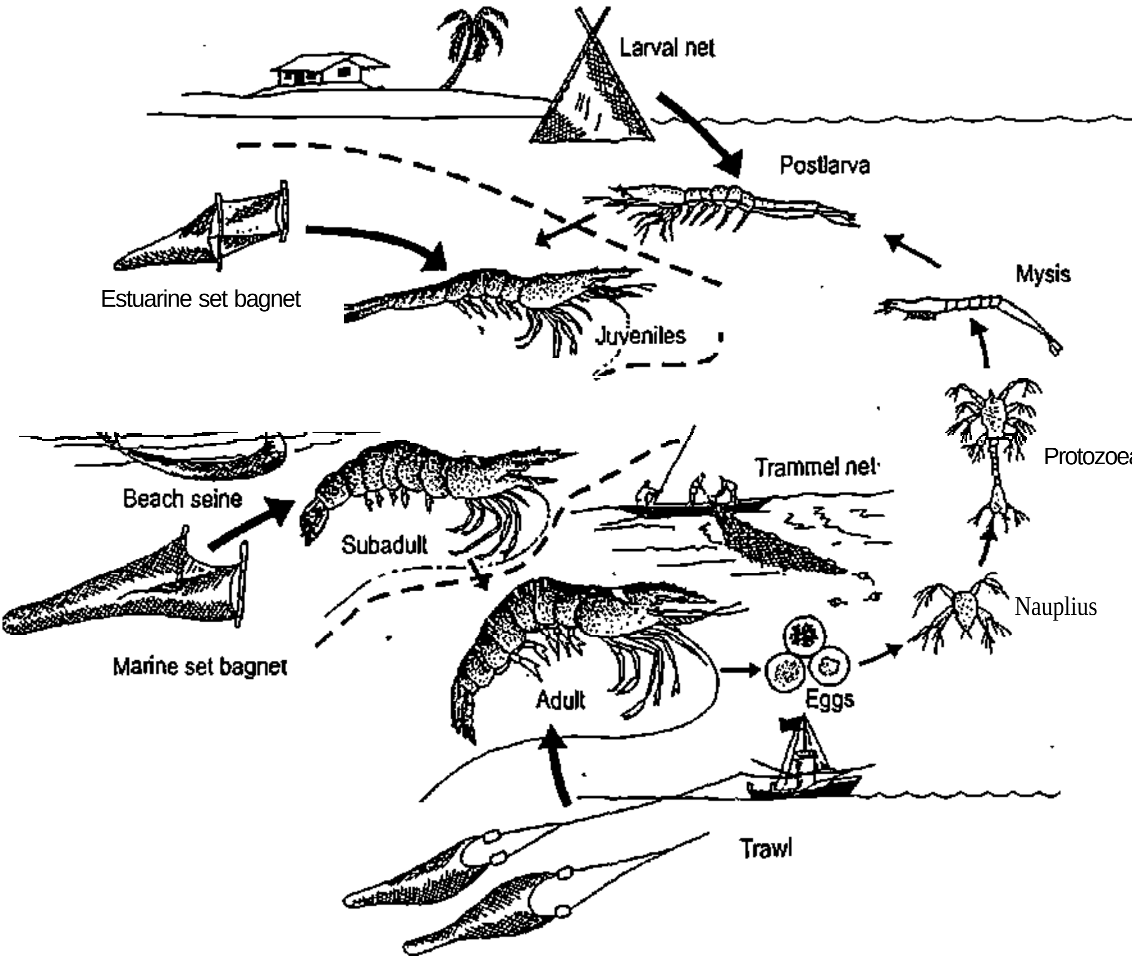


Figure 2.2: Graphical Presentation of Penaeid Shrimp Life Cycle and Harvesting by Different Types of Nets at Various Stages in Bangladesh (Source: Khan and Latif, 1997)

8,000 standard days (BOBP, 1997). The estimated value of MSY of penaeid shrimp is shown as 4145 mt (using Schaefer model) and 4329 mt (using Fox model) in another occasion.

Stock of Marine Shrimp: 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 ton to 11,400 metric tons. Estimation, considered important by different researcher, of West (1973), Saetre (1981), Penn (1983), Rashid (1983), Khan et. al. (1983), White and Khan (1985), VanZalinge (1986), and Lamboeuf (1987) etc.

2.3. Institutions of Fishery Management and Policies:

At present, marine fishery of Bangladesh is supervised and managed by the ordinance called Marine Fishery Ordinance (MFO) that was enacted in 1983. This ordinance was passed for management, development, and conservation of marine fisheries in Bangladesh Fishing Water (BFW). 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. The Marine Fisheries Ordinance (MFO) 1983 provides "Area for fishing with trawiers are earmarked for operation beyond 40 meters of marine waters at its highest tide". The area up to 40-meter depth was kept reserved under the preview of the ordinance for the benefit of small-scale fisheries. Most of the fishermen in Bangladesh are, however, small-scale fishermen, who use both motorized and non-motorized boats. Some commercial firms use trawlers for catching fish in the deep sea. Specific provisions have been made in MFO, 1983 regarding area and gear restrictions. Beyond 40-meters of marine waters at its highest tide is earmarked as area for the fishing with trawlers.

All licensed shrimp trawl use net (boom) with low opening, the minimum mesh size 45 millimeter at the cod end, where as for fish trawl net, mesh size at the cod end is 60 millimeter. Every frozen fishing vessel engaged in trawl fishing may be allowed sailing permission for a period not exceeding 30 days and every non-frozen fishing vessel engaged in trawl fishing may be allowed sailing permission for a period not exceeding 15 days at a time.

2.4 Concluding Remarks:

Bangladesh is a small country with limited natural resources. The long run development and prosperity of the country is, therefore, largely depend on sustainable use of natural resources, particularly replenishable natural resources. The concept of replenishable use of renewable resources gives birth the notion of sustainability. The objective is to take off advantages of the benefit provided by resources up to the point where the rate of extraction from the nature equals the rate of renewal by the nature. So, in agriculture, forestry, livestock and fisheries - marine and inland etc exploitation/utilization must be equal to the extent of capacity of regeneration or refurbishment. Does the scientific management of such resources enhance or keep steady inherent rates[1] of renewability without jeopardizing the implicit basic principles of sustainability i.e. Knowability, Homoeostasis, Bioethics- both internal and external? (Turner, 1992).

Similar to the theme introduced by Kerry Turner (1992) between 'sustainable growth' and 'sustainable development' many draw upon a distinction between 'sustainable utilization' and 'sustainability'. Sustainability has been considered as a much broader phenomenon embracing ethical norms pertaining to the survival of living matters and the rights of the future generations. Thus institutions responsible for ensuring that such rights are fully taken into account in policies and actions are under the preview of the concept. While the first two of the above mentioned premises of sustainability, those pertaining to Knowability and homoeostasis, apply to the concept of sustainable utilization, others which embrace a more bioethical perspective with implications for a great variety of rights and obligations, impinge more directly on the notion of sustainability. Sustainable utilization is a prior condition for sustainability, but not a sufficient one. But, at the same time, the objectives of sustainable utilization cannot be met without incorporating the principles of sustainability.

In this context, the management of one of the major marine resource exploitation in Bangladesh deserves to be studied critically. The present management system of marine fisheries is a complex one. The marine wing has practically no control over the fishermen and fishing along the coast. The size of the fisher folk and their socioeconomic condition makes it hard to implement any management and conservation measures. In addition, there is a scarcity of manpower in the marine sector. The Marine fisheries Ordinance has been identified by experts as the most relevant and dominates of all legislation in managing fishing. It defines territorial seas and economic zones and other marine waters over which it claims to have jurisdiction. However, management through MFO, 1983 does not ensure the optimum utilization of this resource and its sustainability. In the following chapters, we will study the optimum dynamic behaviour of trawl shrimp fishery only.

Chapter 3

Estimation of Bioeconomic Parameters of Trawl Shrimp Fishery in Bangladesh

A part of this work has been published in *Indian Journal of Fisheries* (Vol. 50, No. 2, 2003, pp.251-257) under the title "Estimating Some Parameters of Shrimp Fishery in Bangladesh".

3.1. Introduction:

The optimal allocation of renewable resources like fishery over time can be formulated as a non-linear dynamic optimization problem. In such problems, the common objective is to maximize some measures of net economic value, subject to dynamics of the harvested resource and any other relevant constraints, The solution to the dynamic optimization of a resource would be to evolve a schedule or .time-path indicating the optimal amount to be harvested in each period. The whole system depends upon a few specific bioeconomic parameter values. Economists are often faced with the problem of determining parameters associated with such resource stock dynamics. These parameters are biological and economical. The biological • parameters are, namely, biomass level (x), intrinsic growth rate (r) and carrying capacity (K). The economic parameters are, namely, demand parameters, cost parameters (i.e. slope and intercept of respective functions) and catchability co-efficient (q).

In case of trawl shrimp fishing in Bangladesh, resource stock dynamic models had not been applied so far for the lack of estimation of such values. Instead of time series data of biomass levels, we have occasional estimations of stock at different point of time by different researchers like West (1973), Rashid (1983), Penn (1983), White and Khan (1985) and VanZalinge (1986). Estimated values are not only discontinuous in time but differ significantly with each other (Table 3.2). Because of this lack of time series data on shrimp biomass level, the important parameter *'intrinsic growth rate (r)'* has also not been estimated. However, two sets of data related to trawl shrimp fishing of Bangladesh i. e. standardized fishing effort and total harvest are available for the period 1981-1982 to 1997-1998, though the said operation had been commenced from 1972-1973.

In this chapter, we have attempted to estimate the annual expected shrimp stock level of Bangladesh by applying the method of estimation of the biomass of demersal stock in tropical zone on the basis of marine data. We, on the other hand, estimate the catchability co-efficient from the available data series of effort and harvest. This calculated value of catchability co-efficient then used to obtain predicted harvest level on the basis of biomass levels of shrimp estimated by us. Then a comparison would be made between the actual annual harvest levels (h) and the predicted harvest levels (h'). The close proximity of predicted values with that of actual values can, therefore, be an indirect verification of the accuracy of estimated biomass levels. Once we have a reliable stock level, the estimation of intrinsic growth rate (r) is also possible and seems to be dependable. We will estimate the demand parameters for three different types of demand functions and try to comprehend one that is the most compatible for the market for Bangladesh trawl shrimp. Using the cost data for Bangladesh trawl catch, parameters of cost function are ascertained. Values of all these parameters will make the formulation and application of non-linear dynamic optimization model for Bangladesh trawl shrimp fishery feasible. The solution of this non-linear dynamic system can determine steady state that indicates the condition of maximum benefit, ensures the long run sustainability of the resource and excludes the possibility of depletion due to overexploitation.

Sources of data: We have used published data of (i) BOBP (1993; 1997) and (ii) Department of Fisheries (DOF, 2000), Bangladesh, for the time series data of harvest and effort for the period 1981-1982 to 1997-1998. Due to the unavailability of time series data on dock-price of commercially exploited trawl shrimp, we have used the published data of EPBB (Export Promotion Bureau of Bangladesh) for time series data of exported shrimp price. The data from the sample survey made by Khan and Hoque (2000) are used for the estimation of cost parameters. FAO (1984) is also used for other necessary data.

3.2. Estimation of Biological Parameters:

Unlike non-renewable resource, any renewable resource is regenerative in nature. In case of fishery, it is the biological property of the resource, which gives this special character to the resource. It is, therefore, obvious that any optimization model should incorporate this biological regenerative property in its formulation. Moreover, because of its time dependent nature, this property makes the formulation dynamic. Though the resource's biological properties depend on many environmental factors and most often these factors are exogenous, some of the biological parameters are incorporated in the optimization formulation with the implicit assumption that those exogenous factors, at least on the average, will remain stable. The following are the parameters normally included in the formulation and biological in character subject to certain environmental conditions:

(a) Level of biomass stock (b) Environmental carrying capacity or saturation level

(c) The intrinsic growth rate.

3.2.1. Biomass Level of Shrimp:

Method: We attempt to estimate annual expected shrimp stock of Bangladesh by applying the method suggested by Pauly for demersal stock in tropical zone subject to specific characters of marine area and trawler.

Stock assessment in the tropics is generally perceived as more difficult than in temperate waters. Pauly (1984) suggested a model for estimation of the biomass of demersal stocks. The model is applicable where the sea bottom is smooth for trawling. Trawl shrimp fishing zone of Bangladesh appears to be very smooth with very few obstacles to bottom trawling (Mustafa and Khan, 1993; Khan *etal,* 1997), Accordingly, the standing stock size can be obtained from the following relationship as suggested by Pauly:

$$x = \frac{c/f \cdot A}{a.y_x} \tag{3.1}$$

where,

c/f = catch effort ratio during the harvest period,

A = total area under consideration,

a = area "swept" by the net during one unit of effort, and

y = proportion of fish in the path of the gear that are actually retained by the net.

The surface swept by the gear during one unit of effort is computed from the expression

$$a = t.\ v.\ I.\ y_2 \tag{3.2}$$

where,

t = time spent in trawling,

v = velocity of the trawler over ground when trawling,

/ = length of the trawl's head rope, and

y_2= a fraction expressing the width of the area swept by the net divided by the length of the head rope.

From the equations (3.1) and (3.2) we get the following equation:

$$x = \frac{c/f}{t.\ v.\ 1.\ y_1\ y_2} A \quad (3.3)$$

Values of the dependent variables and constants in the equation (3.3): Penn (1983) and West* (1973) estimated 5,180 square kilometer as the effective shrimp fishing area off Bangladesh. Hence we set the value of A at 5,180 square kilometer for our purpose.

In Bangladesh, two shrimp trawlnets of the same size are operated from outriggers on either side of the vessel. Each net has a head rope of 15.2 meter and a ground rope of 18.6 meter. The codend meshes are 45 millimeter. The gear operates at a speed of 3 nautical miles per hour by a 900-horse power trawler of 32.4-meter length (Mustafa and Khan, 1993). in equation (3.3), the time spent on trawling is given by, 't'. This T is the fishing time. Time spent on trawling 't' being standard shrimp day (not normal day) does represent time spent on trawling and when multiplied with v, I and y_2 (as in equation 3.2) gives us the swept area. As the swept area 'a' is defined as 'area swept by the net during one unit of effort,' T is set to be equal to one standard shrimp day. Hence, the unit of v, represents the velocity, converted to km/day for dimensionality. We have, therefore, v = 3 nautical miles/hour = 133.2 km/day, / = 0.0152 km, t = 1 standard shrimp day for the purpose of our estimation.

In South East Asian waters, the value of y = 0.5 is commonly used (Isarankura, 1971; Saeger era/., 1976; SCSP, 1978) and there are some evidences that this value might in fact be very realistic (Pauly, 1979). Hence we assume that y = 0.5.

Again, in South East Asian waters, values of y_a ranging between 0.4 (SCSP, 1978) and 0.66 (Shindo, 1973) have been used. However, 0.5 possibly being considered as the best compromise (Pauly, 1979), we set y at 0.5. Finally, therefore, values of different dependent variable and constants used in the equation (3.3) are as follows:

Parameters	Values
A	5,180 sq. km.
t	1 Standard shrimp day
V	133.2 km/day
1	0.0152 km.
Vi	0.5
V2	0.5

* The exact value 5,180 sq. km. is actually given by Penn. West mentioned the area as around 5,000 sq. km.

Estimated Results: Substituting these values in equation (3.3), we estimate biomass level (x) of shrimp, in the zone exclusively used by the Bangladesh for commercial exploitation. Accordingly, the expected standing stocks of shrimp of Bangladesh from the year 1981-82 to 1997-98 have been estimated and presented in Table 3.1.

Table 3.1

Estimated Stock of Shrimp in Different Years.

Year	Estimated Stock . (in metric tons)
1981-1982	4592.004
1982-1983	4545.818
1983-1984	5784.25
1984-1985	6921.284
1985-1986	6406.522
19864987	6629.594
1987-1988	5476.848
1988-1989	7210.16
1989-1990	5783.105
1990-1991	7802.254
1991-1992	4851.165
1992-1993	6066.475
1993-1994	4967.783
1994-1995	3657.025
1995-1996	4966.094
1996-1997	5091.759
1997-1998	3338.899

Source: Estimated by the author.

3.2.2. Carrying Capacity:

In the literature of fishery most widely applied growth model, known as Verhaulst equation, is a logistic growth function given as follows:

$$\frac{\quad}{dt} = F(x) \quad = r\,x\,(\,l - \frac{-}{K}\,) \qquad (3.4)$$

Where r, assumed to be positive constant, known as intrinsic growth rate. The other positive constant K signifies the saturation level of a particular species in the inhabitant zone and is normally referred to as the environmental carrying capacity.

The solution of the[1] equation (Clark, 1990) indicates that in between two equilibrium solution at x =0 and at x=K, 0 < x < K implies that x > 0 and x > K implies that x< 0. Mathematically, the solution of this logistic differential equation (3.4) is

$$x(t) = \frac{TC}{l + c.e^{"rt}}, \quad \text{where } C = \frac{K - x}{x_o} \text{ and at } t = 0,\ x_0 = x(0)$$

Thus the environmental carrying capacity K is globally asymptotically stable for positive x in the sense that

$$\lim_{t \to \infty} x(t) = K, \qquad \text{provided that } x(0) > 0$$

It actually shows that x(t) converges towards K at an exponential rate as f tends to infinity. Physical interpretation of the solution is that given the reasonable time, biomass stock, either from below the level of K (curve a) or from above (curve b), will approach the saturation level K, as shown in Figure 3.1.

K

• > t

Figure 3.1: Typical solution curve of the equation (3.4)

However, the stable equilibrium level must be reduced than the saturation level, once the harvesting is started. It is well known in the literature that, depending on the effort level, stock may be around semi-stable equilibrium *KJ2* or may be reduced to complete depletion. On the basis of this general • phenomenon of fisheries, we make an assumption of estimation of the carrying capacity or saturation level of shrimp stock in Bay of Bengal marine zone exclusively under trawl harvesting of Bangladesh.

Table 3.2
Different Estimation of Shrimp-Stock Made by Different Researchers.

Year of Estimation	Estimated Standing Stock (in metric tons)	Reference
1973	11;400	West, 1973
1983	2,000-4,000	Rashid, 1983
1983	4,000 -6,000	Penn, 1983
1985	3,000 -3,600	White and Khan, 1985
1986	1,550	VanZalinge, 1986

In order to estimate the biomass level of shrimp, regular annual survey had not been done in this area, but occasionally survey method were employed by national and international agencies (like BOBP or FAO, UN). Such occasional estimations made by different researchers at different point of time are shown in Table 3.2.

West (1973) estimated 11,400 metric tons of the standing stock of shrimp on the basis of survey data collected during 1968-1971. The trawl shrimp fishing of Bangladesh commenced from 1972-1973. After the commencement of trawl fishing, Penn (1983), Rashid

(1983), White and Khan (1985), and Van Zalinge (1986) estimated the shrimp stocks. Table 3.2 shows that estimated stock differs significantly from each other. Estimation gives as low as 1550 metric tons to maximum 11,400 metric tons. However, all estimations are much less than the estimation made by West. One of the important and plausible factors of the lower estimation may be the time of survey. While all estimations were made after the year 1973, West completed his survey a few years before 1973. Report, however, was published in December, 1973 by the FAO, UN. Commercial exploitation of trawl shrimp fishery having begun in 1973, the estimations made by others should reasonably be less than that of one made by West. As there was no harvesting before 1973, it could be assumed that the biomass level of shrimp fish was allowed to grow towards saturation level (carrying capacity) in the fishing zone of Bangladesh before 1973. Since the period of survey being (data were collected by West during 1968-71, as we have already mentioned) much earlier than the year in which harvesting was started, West's estimation may be assumed to be an estimation of saturation level of the said fishing zone. As we do not have any other estimation of biomass level prior to the commencement of trawl shrimp fishing, we are assuming the estimation of biomass level of West as carrying capacity. This particular zone of fishing being within the jurisdiction of Bangladesh fishing exclusively, we hope our assumption is not much unreliable barring the limitation of usual survey method. Thus the value of K is set at 11,400 metric tons.

3.2.3. The Intrinsic Growth Rate:

One important parameter in the growth function given in equation (3.4) is V i.e. intrinsic growth rate. This implies net growth of biomass and is obtained by subtracting overall mortality rate from biological population growth rate. Overall mortality rate is sum total of three mortality rates - natural mortality, predator mortality and fishing mortality. We know that the biological population growth rate of a species depends on temperature, salinity and other environmental factors. This value of biological population growth rate, therefore, can be obtained through biological research. Thus intrinsic growth rate can be obtained in two ways. First, by obtaining the biological population growth rate, natural mortality rate, fishing mortality rate and predator mortality rate of penaeid shrimp in this specific zone of Bay of Bengal, we can obtain 'r' by subtracting overall mortality rate from the first factor. Second method could be a Statistical estimation. If we have time series data of biomass level over a period of time and the value of positive constant K, then we can obtain the intrinsic growth rate (r) by estimating the equation (3.4). The test of significance of 'r' can also be done for statistical inference. Problem of applying the first method is that the biological population growth rate of commercially exploited shrimp fish in Bangladesh is not available. Three most important agencies relevant for this specific information - namely, DOF, BOBP and FAO (UN) confirmed us that the estimation has not yet been done in the specific climatic condition of Bangladesh trawl shrimp fishing zone. Thus given the constant carrying capacity K as shown in Section 3.2.2 and biomass level [x (t)] for the time period 1981-82 to 1997-98 as in Table 3.1, we then estimate the intrinsic growth rate (r) by applying OLS method.

Table 3.3

Estimated Value of the Parameter: **Intrinsic Growth Rate (r)**

Parameter	Estimated value	Standard Error	df	t-statistic	Function
r	1.330818	0.136198	16	9.771237	Logistic growth function

Source: Estimated by the author.

The estimated value of Y and other estimated statistics are given in Table 3.3. The value of t-statistic implies that the value of 'r' is statistically significant at 1% level of significance. Thus the value of intrinsic growth rate (r) of Bangladesh trawl shrimp may approximately be considered as equal to 1.330818.

Having the estimated values of the saturation level or carrying capacity (K) in 3.2.2, the intrinsic growth rate (r) in 3.2.3 and biomass stock (x_t) in 3.2.1, we now plot the growth function shown by the equation (3.4), This growth curve is shown by Figure 3.2.

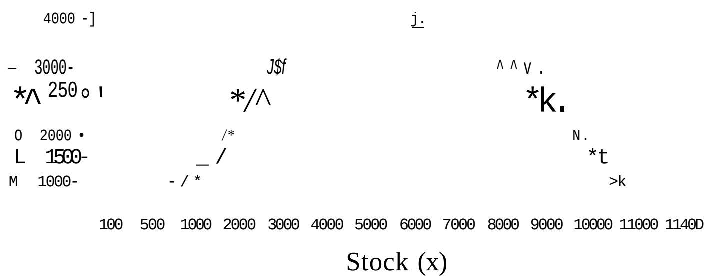


Figure 3.2: Growth Curve for Bangladesh Trawl Shrimp Fishery

3.3. Estimation of Economic Parameters:

As the fishery is considered as an economic resource, therefore, it is assumed that the fishery should be managed to maximize the discounted net revenue overtime. Following this existing practice in fishery, we also assume that Bangladesh trawl shrimp should be managed *in order to achieve the same objective of* optimizing present value of net benefit in terms of revenue. Net revenue is calculated as total revenue less total operating costs. Total revenue is given by the product of harvest and price of fish. The price of the fish is determined by the demand fluctuations expressed by market demand functions. A part of operational cost, on the other hand, depends on the level of effort. But, level of effort to be required in harvesting an unit of catch depends on the biomass stock. The harvest-effort ratio per trawler days is known as catchability co-efficient. For a constant level of effort, this co-efficient will be greater if biomass stock is high and wilt be tow if biomass stock is less. Therefore, the following economic factors are involved with the activities of fishery and are generally incorporated in an optimizing model: (a) parameters of demand function (b) parameters of cost function (c) discount factor (d) catchability co-efficient.

Among these components, first three are economic and the rest, being dependent both on biological factor (biomass level) and economic factor (cost), is considered as bioeconomic.

3.3,1. Demand Parameters:

Three types of demand function have been used in the literatures of fisheries models for different species of fishes by various researchers. Kolberg (1992,1993) and Rowse (1995) used a downward sloping demand function for Northern Anchovy Fishery of California, Grafton *et al.* (2000) used a non-linear demand function for Canada's Northern Cod Fishery. Sandal and Steinshamn (2001) used a non-linear exponential demand function for North-East Atlantic Cod Fishery. As demand function for the market of Bangladesh trawl shrimp fishery has not been estimated by any researcher so far, we have to estimate demand function on the basis of the price and harvest data available for the period 1981-82 to 1997-98. We would try to estimate.all three above mentioned demand functions in order to identify one that gives statistically relatively significant result. Shrimp prices during this period are shown in Table 3.4 and harvests are shown in Table 3.8.

Table 3.4
Shrimp Price in Different Years

Year	Price (per ton iri$)
1981-1982 •	,6531.22
1982-1983	6839.99
1983-1984	7185.98
1984-1985	6083.98
1985-1986	6656.81
1986-1987	6909.8
1987-1988	7772.82
1988-1989	7828.16
1989-1990	7246.84
1990-1991	7115.37
1991-1992 .	,7155.35
1992-1993	8087.7
1993-1994	8963.14
1994-1995	9921.3
1995-1996	10723.92
1996-1997	10846.75
1997-1998	13977.94

Source: Export Promotion Bureau, 2000

(A) Linear Demand Function:

We assume that Bangladesh trawl shrimp fishery follows the linear demand function. Thus the function could be of the following type:

$$p\ (h) = d_{,} + d_2 .\ h \qquad ' \qquad (3.5)$$

where di (the demand intercept) and da (the slope of the function) are the parameters to be estimated here.

We estimate the demand function by using price and harvest data through ordinary least square (OLS) method and get estimated d_1 =10, 759.389 and d_2 = rO.69602. The OLS results are shown in Table 3.5. The fitted demand curve is shown in Figure 3,2 and observed as well as predicted prices over the period of our study are shown in Figure 3.3.

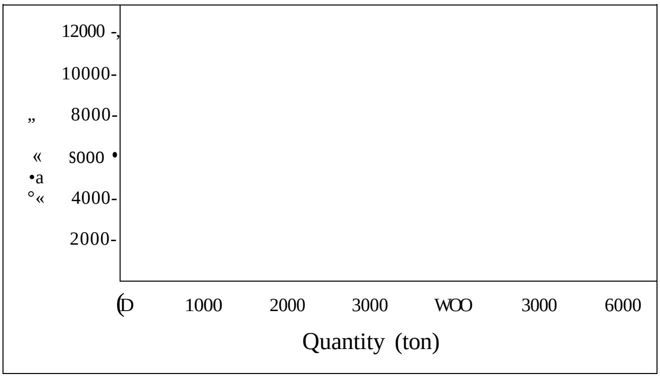


Figure 3.2: Fitted Linear Demand Curve

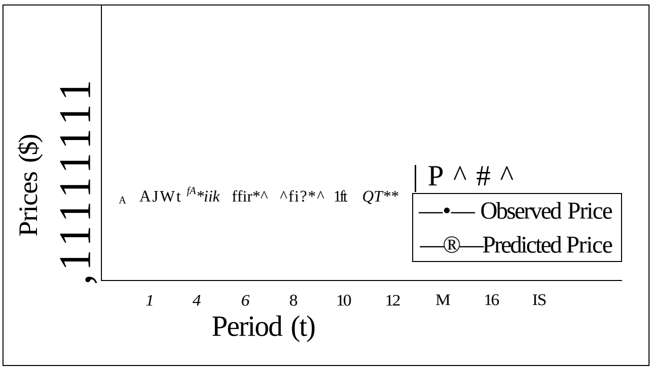


Figure 3.3: Observed and Predicted Prices: Linear Demand Function

(B) Non-linear Inverse Demand Function:

We assume that Bangladesh trawl shrimp fishery follows the-non-linear inverse demand function. Thus the function could be of the following type:

$$p(h) = \frac{p_1 a + p_2 h}{a + h} \tag{3-6}$$

where p_1 is the specified minimum price, p_2 is the specified maximum price and 'a' is a parameter to be estimated. As observed during the period 1981-82 to 1997-98 the minimum price and the maximum price are set at $ 6,083.97729 and $13,977.93881 per ton respectively. Using the time series data on price and minimum and maximum prices, the parameter 'a' has been estimated using the non-linear regression programme. The simple programme is written in C-language, following the algorithm of true non-linear regression technique that minimizes squared residuals for the specified non-linear function. The estimated value of the parameter 'a' is 850.261.

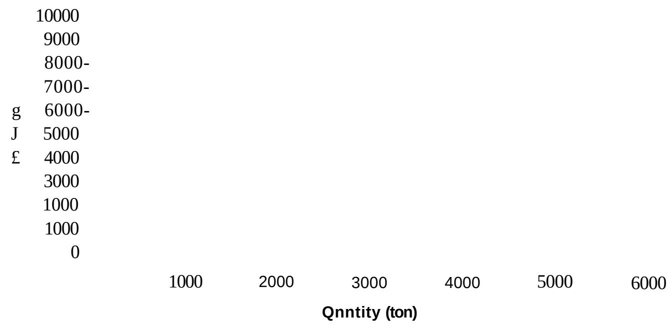


Figure 3.4: Fitted Non-linear Inverse Demand Curve

Other necessary statistical information for inference is given in Table 3.5. The fitted demand curve is shown in Figure 3.4 and observed as well as predicted prices over the period of our study are shown in Figure 3.5.

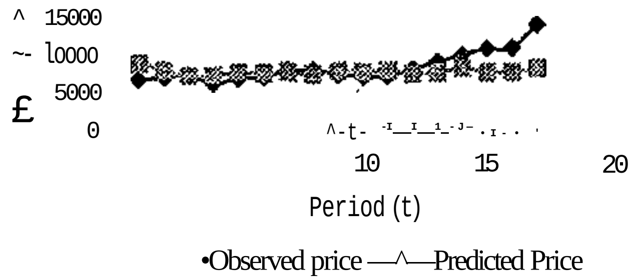


Figure 3.5: Observed and Predicted Prices: Inverse Demand Function

(C) Non-linear Exponential Demand Function:

If we assume that Bangladesh trawl shrimp fishery follows the non-linear exponential demand function, then the function coufd be of the following type:

$$p(h) = p_1 + (p_2 - p_1).e^{-bh} \qquad (3.7)$$

The parameters p_1 and p_2 in the demand function represent minimum price and maximum price respectively, as we have already specified in case of inverse demand function. Using the time series on price data and minimum and maximum prices, the parameter 'b' has been estimated using the same non-linear regression programme with a change in place of specified function. The estimated value of the parameter is 0. 0004682. Other necessary statistical information for inference is shown in Table-3.5. The fitted demand curve is shown in Figure 3.6 and observed as well as predicted prices over the period of our study are shown in Figure 3.7.

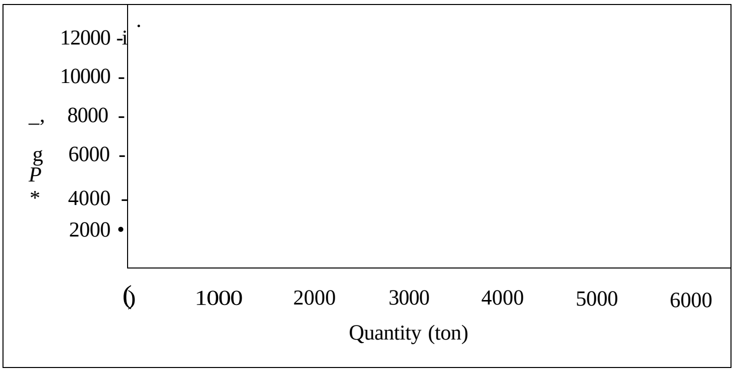


Figure 3.6: Fitted Nonlinear Exponential Demand Curve

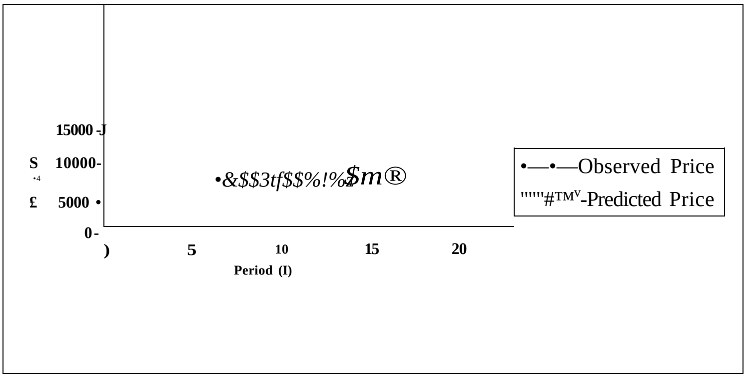


Figure 3.7: Observed and Predicted Prices: Exponential Demand Function

Statistical Comparison Of Demand Functions:

Estimated values of demand parameters of three different types of demand function of Bangladesh trawl shrimp fishery are given in the following table-3.5.

Table 3.5
Estimated Values of Demand Parameters of Three Different Types of Demand Function of Bangladesh Trawl Shrimp.

Function	Parameter	Estimated Value	. » *	Standard Error	df	t-statistic
Linear	di d*	10759.389 -0.69602	0.1242	0.90477 0.477	15	11891.90755 1.45859
Inverse	a	850.261	0.1342	506.33619	16	1.67924
Exponential	b	0.0004682	0.2293	1.003	16	0.00046685

Results indicate that the exponential demand function is relatively 'good fit' for Bangladesh marine shrimp (R^2 = 0,2293) in comparison with other two. in different international recent publications of similar work on fishery management, most often reported values of R^2 are around 0.20. One such example is estimation of demand function made by Grafton *et at* (2000). They used the inverse demand function for Canada's Northern Cod Fishery. The value of R^a of the estimated demand function has been reported as 0.198. One of the possible explanations of the low value of R^2 may be that the price of the shrimp is exogenousiy determined. Marine shrimp production of Bangladesh being insignificant with respect to global as well as national production, the fluctuation in marine shrimp catch in Bangladesh possibly has little impact on price.

However, t-statistic and S. E. of the demand parameters of each of the three functions, except di in linear function, do not appear significant. Since di appears significant but not d_2, it indicates actually that price remains fixed. Another important point is that the difference between values of R^2 of linear and inverse demand function is only 0.01 and between inverse and exponential is only 0.09. It is indicative that three different types of demand function statistically do not differ with each other and the use of any one of three demand functions likely to produce identical results.

However, we obtain the following statistical test of significance*. Denoting the square root of 'co-efficient of determination' for i=1,2,3 for linear, inverse and exponential demand function respectively, we have null hypothesis H_0: P i= Pj, i £ j, which is to be tested against alternative hypothesis Hi: P # P|. Transforming Z i = $^1/_2$In[(1+ri)/(1- nj] for i=1,2,3 an approximate pair wise test for Ho is provided by the statistic

Z.-Z.

yn.-3 + n.-3

which is approximately a normal deviate under.H_0. Computed values are given below:

T-values

	n	r_2	r_3
h	~		
r_2	-0.04	--	
r_3	-0.4056	-0.3633	—

Since, neither of the values exceeds Tooos = 2.576 or T0025 = ,1.960, the null hypothesis is accepted for all pairs of test. It implies that statistically neither of the functions differs significantly with each other.

For this reason, we will use only one demand function for optimal control problem and we prefer exponential demand function which is relatively 'good fit' as well as consistent with demand theory.

3.3.2. Cost Function:

In all the fisheries models, fishing costs have been assumed to be directly related to fishing effort. Fixed costs are assumed to be consisting of (i) registration cost (ii) Ifcense cost

* Rao, C.R.(1974). Linear Statistical Inference and' Its Application (2nd Edn), Wiley Eastern Pvt. Ltd., New Delhi, pp. 432-434

and (iii) cost due to interest and depreciation on invested capital. Those items of costs that are directly proportional to fishing effort constitute the variable cost. The variable cost, therefore, consists of fuel cost, food cost, labour cost (salary of crews), vessel's maintenance cost etc. Costs per unit effort are normally independent of the harvest rate but dependent on the stock level. We assume this very common phenomenon to be true for Bangladesh trawl shrimp fishery. This assumption reflects both long-run factor adjustment opportunities and stock effects on cost along an optimal time path toward a steady state.

A cost function satisfying this set of assumptions, stated above can be derived directly from a production function model of harvest. The well-known Schaefer model assumes that harvest is proportional to fishing effort. Fishing effort is a standard day of fishing for a representative sized vessel in the fleet. Some authors have argued that there could be diminishing returns to fishing time as the gear would become saturated and difficult to work and searchable areas might become larger requiring more search time. The relation proposed by Gulland (1977) and applied by Reed ,(1979) was

$$h = q.\ E.\ x^{u}, \quad \text{with} U = 1 + y$$

$$\text{or, } E .= h / qx^{u} \qquad (3.8)$$

where rf= harvest level, x = biomass level,

q = catchability co-efficient, E = effort level

In the Schaefer model, as y is set equals to zero, the value of U becomes one. In the case of Bangladesh Trawl Shrimp Fishery, Penn (1982/1983) estimated 5,180 square kilometer as the effective shrimp fishing area. The shrimp fishing area is not too large in comparison with the total capacity of the fleet of trawlers generally operate in Bangladesh. This area is easily searchable and may be covered by the existing fleet of trawlers. We thus set U = 1".

$$\text{Therefore, effort is, } E = h / qx \qquad (3.9)$$

The aggregate cost function for fishingeffort is assumed linear; reflecting long-run constant minimum average cost per unit effort allocated and takes the form:

$$C(E) = 02.\ E \qquad (3.10)$$

wh ere c_2 is th e constant proport ion.

From (3.9) and (3.10), we finally get the cost function as,

$$C(h,x) = c_2.\ h/qx \qquad (3.11)$$

where c_2 may be regarded as the slope of the cost function.

The cost function represents an average cost per unit of effort weighted by the ratio of the exploited biomass in the respective year to the current level of biomass. We represent the relevant data for the estimation of cost function from the sample survey in Table 3.6. Using the aggregate survey data for that year an average operating cost per unit of effort was determined. Average annual effort of a shrimp trawler in Bangladesh has been estimated as 200 fishing days (Khan and Hoque, 2000). Total variable cost is thus divided by

* Author acknowledges Professor William C. Kolberg for his suggestion to use U = 1 in reply to our query regarding some problems related to trawl shrimp fishery modelling in Bangladesh.

Table 3.6
Cost Structure

Item	Taka
Fuel Cost	50,61,600
Food Cost	5,43,470
Labour Cost/ Salary of crews	15,38,200
Maintenance Cost	9,42,010
Other Variable Cost	30,19,600
Total Variable Cost	1,11,04,880
Depreciation Cost	14,11,400
Interest Payments	31,46,200
Registration and License Cost	98,770
Total Fixed Cost	46,56,370
Total Cost	1,57,61,250

Source: Khan and Hoque (2000), Sample survey 1998.

the annual effort to obtain cost co-efficient (c_2). For standardizing this value we converted it to dollar value by using the exchange rate prevalent at the time of survey (1 US $ = 48 Taka). Thus, the minimum average cost of effort with representative shrimp trawler was estimated as $1156.76 per effort. This implies that $c_2 = 1156.76$.

3.3.3. Estimation of the Catchability Co-effident:

Catchability co-efficient (q), by definition, is measured by catch per vessel per unit of fishing days. From the time series data of annual average harvest and effort, the catchability co-efficient can be calculated. In Bangladesh, two types of trawlers are employed for shrimp fishing - one is shrimp trawler and the other one is fish trawler. Shrimp trawlers are exclusively engaged in shrimp harvesting. But, the fish trawlers are used for harvesting marine fishes and thus they trawl not only in the shrimp zone but also beyond that. It necessitates adjusting the total effort of shrimp fishing. It is reported that one-third effort of a fish trawler is normally accounted for shrimp trawling (Khan and Hoque, 2000a). We adjust the number of trawlers accordingly. Required number of trawlers is the sum of the number of shrimp trawlers and one-third of fish trawlers (Because of this calculated number of shrimp trawlers may not be integer). However, the adjustment in efforts by the shrimp trawlers and fish trawlers has been made by and provided separately in Khan and Latif (1995). These adjusted values of efforts and number of both types of trawlers are given in Table 3.7.

Unfortunately, separate data of both types of operational trawlers are only available for the period 1981-82 to 1990-91. For this reason, we use the data for the period 1981-82 to 1997-98 in all cases of parameter estimations but catchability co-efficient when we consider the period from 1981-82 to 1990-91. Dividing the catch-effort ratio by adjusted number of trawlers and number of fishing days per trawler in each year, we obtain the catchability co-efficient per vessel for each year of the period. The average of these values gives us the catchability co-efficient (q) for Bangladesh trawl shrimp fishing. The computation of this value is shown in Table 3.7.

Table 3.7
Estimation of Catchabiiity Co-efficient (q)

Year	Total Harvest	Total Effort	Catch/Effort	Total Trawler	No. Of fishing Days	Catchabiiity Co-efficient
1981-1982	1697	3782	0.44870	16.46	200	0.0001363015
1982-1983	3120	7024	0.44419	28.03	200	0.0000792350
1983-1984	5461	9662	0.56520	30.16	200	0.0000937009
1984-1985	5518	8159	0.67631	37.76	200	0.0000895535
1985-1986	4034	6444	0.62601	33.62	200	0.0000931006
1986-1987	4488	6928	0.64781	33.30	200	0.0000972682
1987-1988	3523	6583	0.53517	34.82	200	0.0000768475
1988-1989	4893	6945	0.70454	36.75	200	0,0000958552
1989-1990	3134	5546	0.56509	36.57	200	0,0000772617
1990-1991	3430	4499	0.76239	36.50	200	0,0001044372
Computed Value of **Catchabiiity Co-efficient (q)**						0.0000943561

Source: Calculated by the author on the basis of DOF and BOBP data.

Computing the predicted values of harvest:

We can thus obtain predicted levels of harvest (h') for different years on the basis of calculated value of catchabiiity co-efficient (q) (Section 3.3.3), estimated stock (x) (Section 3.2.1) and standardized effort (E) from Schaefer's equation (3.9). Actual (h) and predicted values of harvest levels (h.) are presented in Table 3.8.

Table 3.8
Actual And Predicted Harvest Level

Year	Total Effort	Stock (Estimated)	Harvest (Predicted)	Harvest (Actual)
1981-1982	3782	4592	1681.14	1697
1982-1983	7024	4545	3090.29	3120
1983-1984	9662	5784	5409.73	5461
1984-1985	8159	6921	5466.21	5518
1985-1986	6444	6406	3995.97	4034
1986-1987	6928	6629	4445.66	4488
1987-1988	6583	5476	3489.54	3523
1988-1989	6945	7210	4847.17	4893
1989-1990	5546	5783	3104.66	3134
1990-1991	4499	7802	3397.83	3430
1991-1992	6122	4851	2874.78	2902
1992-1993	7065	*6066*	4148.54	4188
1993-1994	7169	4967	3446.93	3480
1994-1995	6761	3657	2393.40	2416
1995-1996	7394	4966	3554.40	3588
1996-1997	7107	5091	3502.43	3536
1997-1998	7491	3338	2420.51	2444

Source: Calculated by the author on the basis of DOF and BOBP data.

Table 3.8 shows that the predicted harvest levels (h) by using the estimated value of q are very close to the actual harvest levels (h). This seems to imply that our estimated stock levels of biomass (x) may reasonably be presumed to be dependable for further use in studying the optimizing aspects of this resource under commercial exploitation.

However, a frequency distribution of the difference between h and h may be obtained by simulating the values of q in equation (3.9) if the values of effort (E) and biomass (x) are assumed to be given and remained constant. We can thus obtain the refined value of q for which this difference is minimum. We find that this value of q = 0.0000977332. We will use this value of q in our subsequent work.

3.4 Concluding Remarks:

The assessment of standing stock of any commercially exploited renewable resource like shrimp is of great importance for the effective control of exploitation. Earlier stock estimates are so widely varied that it is not possible to reach any conclusion. Moreover, estimations at different point of time do not give the time series data of biomass level. But the present day management decision making process for optimal control on resource's utilization and exploitation, demands time series data. We have generated time series data of shrimp stock of Bangladesh by Pauly's model using trawler and swept area specific values. Interestingly, most of the values are lying between the lower and upper limit of the estimation made by Penn (1983). Moreover, considering the present level of harvest in each year and the MSY calculated by the earlier workers, these values seem to be good fits. The estimations made by White & Khan (1985), Van Zalinge (1986) and Rashid (1983) appear to be conservative, because if their estimates are valid, the present levels of harvest could not be sustained at the current rate of intrinsic growth (r).

Apart from the estimation of biomass stock of shrimp in Bay of Bengal of Bangladesh, we have estimated some biological and economic parameters in this chapter. These are (a) carrying capacity (b) intrinsic growth rate (c) demand parameters and (d) cost parameters.
Demand parameters show statistically insignificant results. Estimation of demand, however, seems to indicate that there is no significant difference between linear, inverse and exponential demand function. Moreover, low value of R^2 possibly suggests that the price is exogenously determined. However, we prefer to consider exponential function in order to formulate non-linear dynamic models in next chapters as it relatively 'good fit' and consistent with demand theory.

Values of the parameters estimated in this chapter are to be used in discrete and continuous time non-linear dynamic optimization models for the Bangladesh trawl shrimp in the subsequent chapters of this thesis.

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

$$\mathbf{pvNB}=\overset{T}{\underset{t=0}{\mathbf{£}}}\mathbf{/r\text{-}n(x_t,h_t)} \qquad 1$$

Subject to ,

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

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

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

$$\text{and } x_t,\ h, > 0$$

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, -

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

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

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

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):

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

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

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

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) (4.12)

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

And $V = (1 + 8) [p - c_2/qx^*]$ (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

$$PVNB = £/?' .n\ (x_t, h_t) + /rn(x_{t+1}, f(x_{t+1}))$$

Subject to (4.15)

$$x_{,+}i - x_t = f(x_t) - h_t$$

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

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,

$$jjfbA_{t=0} \; +(p_2 - p_1)e^{bh'}.h_t \; '' \wedge_{<l^x t}) + \%^{\circ} \; rx_t(1-\wedge-_{k-}) +$$

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

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.

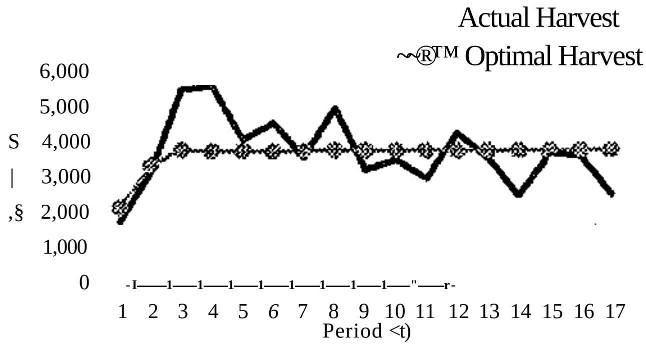


Figure 4.1: Harvest Approach Path Comparison

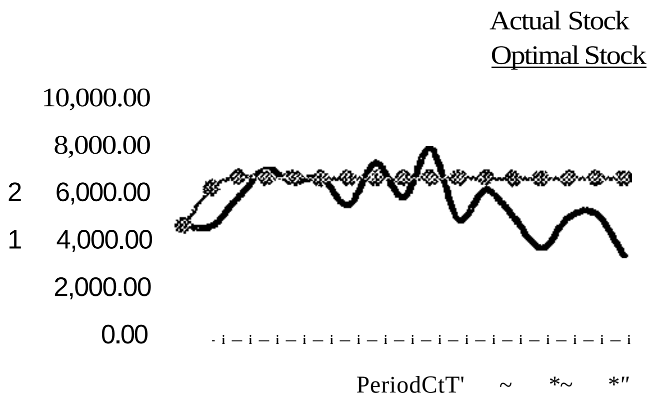


Figure 4.2: Stock Approach Path Comparison

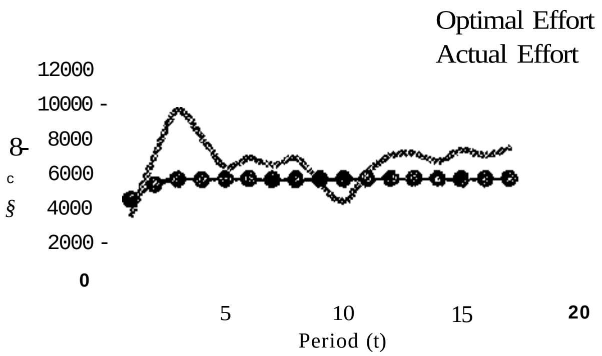


Figure 4.3: Effort Approach Path Comparison

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.

Chapter 5

Optimal Control and Feedback Rule:

Non-Linear Dynamic Optimization Model in Bangladesh Trawl Shrimp Fishery

-Continuous Time Analysis

5.1. Introduction:

In management of renewable resources, the sole target that has been tried to achieve is the control of the level of exploitation subject to attainment of maximum economic benefit. In our last chapter we tried to analyze Bangladesh trawl shrimp fishery both under static and dynamic situation. Using the bioeconomic parameters estimated in Chapter-3, we also tried to compute optimal values of the decision and control variables when the system is at steady state. But all these are done when the time is supposed to be discretized at yearly interval. Considering the present practice and policy of Bangladesh trawl shrimp fishery, this assumption grossly *underm'mes* the basic objective of optimal management of this renewable resource. In Bangladesh, trawlers are given annual license to operate in the zone and thus, there is no effective controlling and monitoring system on the extent of effort level being operationalised and the amount of fish actually harvested. If we sincerely desire to manage the resource optimally and to achieve the objective of operating at steady state when both the level of biomass stock and level of harvest are maximum, then continuous monitoring is required. It requires two essential managerial conditionalities to be satisfied. Firstly, there should be a mechanism to provide managers with an adaptive method of regulating resource use to achieve this defined target. Secondly, the mechanism simultaneously should be able to evaluate alternative harvesting strategies.

One of the mechanisms that has been suggested in recent literatures to fulfill these two conditionalities. simultaneously improving the management of renewable resources is to develop optimal feedback rules. This short of adaptive management policy which requires adequate and appropriate feedback rules as essential, necessitates to assume the time variable (t) as continuous. Clark and Munro (1975), Conard and Clark (1987) attempted to provide such feedback rules. Recommendations made by them, however, have not been proved feasible to be operationalised. Grafton et al. (2000) put forward a model to show how to operationalise a feedback rule which is generalization of one suggested by Sandal and Steinshamn (1997a) and tested for the data of Canada's Northern Cod Fishery. This chapter is an attempt to study the applicability of such feedback rules for management of renewable resources like trawl shrimp in Bangladesh.

The other important point *to* be noted here is that, in recent times, the resources in economics is, viewed from capita! theoretic approach. From this point of view, we can assume that shrimp fishery desires to maintain its total net revenue over some period of time. Depending on past, history of exploitation of resource, the fishery will have initiated a certain stock of capital at any time(t). With this stock of capital, x(t) in our case, at that particular time(t), the fishery is in a position to take'decisions. This decision at time(t) is h(t) in our case. Inherited stock of capital (biomass level) together with the specified current decision (harvest policy), fishery derives a net benefit per unit of time. This can be denoted by ri(x(t),h(t),t) when appropriately discounted. This function Tl(.), therefore, specifies the rate at which net benefits are being earned at timeft) over a stock x(t) and as a result of the decision h(t).

Now, for any terminal time T, starting with initial stock x_0 at time t=0, the total net discounted benefit will be given by a function, say dp(Xo, h), which is integral of n(.), discounted and added up for all instants over the time period (0,T). This implies that if fishery starts out with an initial amount of capital (biomass level x_0) and then follows the decision policy h, will obtain a sum total of net benefit, *<p,* which is the integral of the benefits obtained and discounted at every instant. These results, however, in turn are depending upon (i) the pertinent instant, i.e. time (ii) the capital stock at that time and (iii) the decision applicable to that moment. Thus h does represent the entire time path of the decision variable h from the initial time t=0 to t=T. The fishery managers are at liberty to choose the time path of h but cannot select independently the amount of capital at different instant, which is actually a consequence of x_0, the stock of capital at the initial time, and the time path chosen for decision variable. This phenomenon acts as a constraint upon the objective function. This constraint thus represents the rate of change of capital stock at any instant as a function of its present level, the time and the decision taken. This explicitly indicates that the decisions taken at any time have two consequences: (i) they vary the rate at which net benefits are realized at that time and (ii) they moderate the rate at which the biomass stock is changing and thereby the actual stock of biomass that will be available at subsequent times.

Representing the task of resource optimization under the above mentioned setting shows that the essence of the problem is of making decisions in a dynamic context, Moreover, it reveals that the problem is to select the time path, h, so as to make the total net benefit, dp, as high as possible taking into account the effect of the choice variable h on both the instantaneous rate of net benefit and the biomass level of shrimp to be carried into the future. The solution of this problem is not to assign the best possible variable (s) to a single variable or multiple variables but to identify an entire time path which is the best. It is, therefore, imperative that the time must be continuous. The advance mathematics which is applicable for the solution, is the maximum principle of Optimal Control Theory.

For the reason that the present day technique in managing resources from the capital theoretic approach gives the best understanding, which, in turn, demands application of the maximum principle of Optimal Control Theory, we take resort to continuous analysis. Moreover, the effective feedback rules for adaptive policy of resources management also implies time to be continuous. Hence, in this Chapter, we undertake to apply Optimal Control Theory which actually will provide us the feedback rules for Bangladesh trawl shrimp fishery. In the literature, a feedback rule means that the optimal control is a function of state variable.

In this Chapter we also try to provide a schema which can be best suited for the specific situation which differs significantly from developed country both in nature and complexity, of how an optimal feedback rule may be applied in exploiting and managing this particular resource in Bangladesh.

5.2. The General Model:

On the basis of the discussion in Section 5.1, our integral function, $ (x, h, t) (eliminating the argument t in x(t) and h(t) for convenience), is the objective function constrained by the growth function of the resource, depending upon biomass stock, x and harvest policy h. The resource utilization will be at optimum when it reaches at steady state given enough time {t tends to infinity). '

The problem of Bangladesh trawl shrimp fishery can thus be formulated as a general dynamic optimization problem as follows:

Maximize

O (x, h, t) = j e " 5 *l* **n** (x, h>dt

Subject to (5.1)

$$\frac{dx}{dt} = f\ (x,\ h)\ ,\quad \lim_{t \to \infty} x\ (t) = x^*$$

where f (x, h) = f (x) - h ;

and f (x) = r x (l —)
Js.

n (.) is the net revenue function of state variable x and control variable h. Here, x, the state variable, denotes the size of the resources; h, the control variable, denotes the exploitation of the resource; x* denotes state variable at steady state; **t** denotes time; 8 is a constant discount rate; r denotes the intrinsic growth rate and K denotes the saturation level or carrying capacity. Since, we integrate our objective function over the time interval (0,°°). It is necessary that the functions fulfill the Mangasarian sufficiency theorem for infinite horizon.

5.2.1. Sandal-Stienshamn Solution Procedure of the Model:

Solution of the model may appear, at the first sight, to be very common in optimal control theory if maximum principle is applied on the Hamiltonian function (H) after introducing the fourth variable (m), known as co-state variable, along with already existing time(t), state(x) and control(h) variables in the function. Maximum principle provides three equations through (i) equation of motion for the state variable (x), (ii) equation of motion for the co-state variable (m) and (iii) transversality condition. Usually first order condition for the maximization of the Hamiltonian with respect to the control variable is also set equal to zero. These four relations are sufficient to solve the system of the differential equations sequentially to get the optimal trajectory or the decision path. But it is the transversality condition which is unknown both in terms of finite time or in terms of the value of the state variable at terminal point, makes the solution of the model difficult. Transversality condition m(T) is such a condition which only gives what should happen at the terminal time T, when T tends to infinity in our case. The finite time horizon does not facilititate the solution either. Moreover, for any renewable resource management it is always emphasized and discussed that the solution must be of infinite time horizon. Because, the complete finite time problem should imply to cut the time at a point beyond which the resource exploitation is undesirable, whatever may be the reasons. Moreover, the finite time does not help to get rid of the difficulties of the solution procedure, unless either the terminal time{T) or the terminal value of the state variable(x) is exogenously determined.

Conventional 'brute force' numerical methods, as suggested by Conard and Clark (1987), may be applied in some cases. Sandal and Steinshamn (1997a) is another general model to search the optimal stock for quadratic objective function. This is, however, not applicable in our case. We follow Sandal and Steinshamn (2001) to find the solution of the non-linear dynamic problem of the marine shrimp fisheries of the problem of Bangladesh formulated as above.

Sandal and Steinshamn (2001) provides a procedure by which co-state variable(m) can be expressed as a function of other two variables - state and control. Then the argument co-state variable in the Hamiltonian will be replaced by this function in order to make Hamiltonian as a function of two variables only. Combining this with the first order conditions of maximization of the Hamiltonian function, we get, in general, a highly non-linear ordinary differential equation (ODE). We get an exact solution of the ODE in the limiting case when there is no discounting. It thus facilititates to find very good approximative solutions using perturbation theory. Thus the procedure suggests solution sequentially in the following order:

(i) to find the exact solution when the discount factor 6=0. Under this situation the value of the Hamiltonian function becomes constant:

(ii) to find an approximate solution by the perturbation method when the discounting factor 5> 0. It has been shown that the approximation is a good one and relatively easy to obtain.

Common practice of the perturbation method is to formulate a general problem, find a particular solution and, using this solution as a starting point, find an approximate solution. Present procedure differs from the common perturbation method in a way that it uses solution with zero discounting as a starting point. Sandal and Steinshamn (2001) shows that the solution at zero discounting contains most of the complexities and non-linearities in the model and is such a nontrivial in character that the perturbation method does not require many correction terms.

The same approach will be adopted to solve our formulated problem here except the perturbation method which has been used in case of the situation 'with discounting'. In fact, there are two basic ways to continue with the non-zero discount cases: (a) Numerical method (b) Perturbational approximation. Numerical method again can follow any one of the two numerical ways. Sandal and Steinshamn follow the perturbation approximation. But we shall adopt one of the two numerical methods. All these three approaches will be discussed in 5.2.1 (b), where we will deal with the solution of non-zero discount case.

Mathematics of Solution Procedure: The current value Hamiltonian of the problem (5.1) is given by,

$H(x,h,m) - II(x,h) + mf\ (x,h)$ (5.2)

where m is the co-state variable.

Thus, the first order conditions for the maximization problem are

$H_h = 0$,

$m = 8\ m - H_x$

and $x = f\ (x,\ h)$

From time derivative of the current value Hamiltonian function together with these equations we get

$H = 8\ m\ x$, since $H\ h = 0$,

.". $IIh + m.\ f\ h = 0$

$^n\ h$

(5.3)

Now it shows that co-state variable is a function of state and control variable. Hence we can write

$$m = M(x,\ h) = \frac{n}{f\sim h} \qquad (5\text{-}4)$$

Thus, if we substitute this M(x,h) in place of m in the current value Hamiltonian function H(x, h, m), then we get a new function which is always equal to the Hamiltonian in value along an optimal trajectory. Let the new function be denoted as P (x, h) = H (x, h, M (x, h)) (5.5)

Thus,

$$P = \frac{dp}{dx}$$

$$\frac{dp}{dx} \quad \frac{dp}{dh} \quad \frac{dh}{dx}$$

Since P = H (by construction) and $H = 8\ m\ x$, We have

$$\wedge = 5m = 5M(x,h) \qquad (5.6)$$
dx

For convenience, we like to write the equation in the following forms:

$$\left(\frac{dp}{0x} + \frac{dp}{dh} \cdot \frac{dh}{dx}\right) = 5\ M(x,\ h) \qquad (5.6a)$$

$$P_x + p_h . h' = 5M(x, \quad h) \qquad (5.6b)$$

where partial derivatives with respect to a variable are denoted by respective subscripts, like

$$\frac{3p}{dx} = P_{x'}, \quad \frac{d^2v}{3_x 9h} = P_{xh}$$

This (5.6) is a basic equation that will be utilized to find the optimal value of the control variable expressed as a function of state variable.

The solution may be sought from relation (5.6) for two different situations, with 5 = 0 and 5

(a) When 5 = 0 (without discounting): When 5 is set equal to zero, it implies that the discounting is not being done, i.e. a situation'without discounting. Thus, if 5 = 0 then from (5.6) we get dp/dx = 0. It implies that the value of the Hamiltonian P is constant. Let it be denoted by P_0. From the Hamiltonian function (5.2) and expression of the co-state variable given in (5.4) we get,

$$n(x, h) - T \frac{{}^n h}{n} . f(x, h) = P_0 \qquad (5.7)$$

In order to find out the value of this constant Po, the infinite time horizon limiting condition may be imposed on (5.7). With the objective of exploitation of surplus production, the resource would reach at the steady state when f (x, h) = 0. Under this situation, equation (5.7) gives that

$$Po = n\ (x, h) \qquad (5.8)$$

Since, (5.8) indicates net revenue, it must be maximized and therefore, it represents maximum sustainable economic rent. As harvest level (h) will reach at the maximum and will remain constant, therefore this sustainable economic rent will be a function of x alone. We denote this function as S (x) as follows,

$$S(x) = n(x,h)|_{f()(,h)=0} \qquad (5.9)$$

The terminal time T can be calculated to know the time horizon. Let the initial given level of biomass is x_0 and the steady state biomass level is x\ The time to be taken to reach the biomass stock from Xo to x* is given by the integral value of the rate at which the growth function grows when harvest itself is determined by the level of biomass stock maintained with zero discounting. The growth function is

$$f(x_; h) = f(x_J h(x; Po))$$

and the time T is

$$T = \int_{x_0}^{x^*} \frac{r}{f(x, h(x; p_0))} \qquad (5\text{-}10)$$

where, $h(x;P_0)$ is actually the solution of the equation (5.7).

Since S (x) = 0 is a necessary condition for an interior solution with respect to optimal steady state, the optimal steady state is given by x* = arg.[max S (x)] and the corresponding exploitation level can be found by solving f(x*,h)=0 with respect to h. Thus, both x* and h* can be obtained. Knowing the values of x* and h*, optimal effort (E*) and optimal shadow price (A*) can be obtained from the equation (4.13) and (4.14) when price (p) is supplied by the demand function.

(b) When 8 s* 0. (with discounting): Let us first describe the existing methods of solution of non-zero discounting cases. ,

(1) Numerical Procedure:

(i) Let us take the first order ODE in h(x) given by the equation (5.6b). Differentiating (5.6b) further with respect to x and inserting the equilibrium point x = x* and h = h*, we get a second order differential equation as P_h = 0 at (x*, h*). It then, gives us the slope of the feedback solution at the equilibrium point. Moving a little away from the equilibrium point along the tangent we get another starting point (with non-zero velocity). AH initial value solvers or straight forward discretizing will give the exact numerical solution. The equilibrium point of this kind models are saddle points. The correct slope through the saddle point is the one with positive slope. This is a standard numerical way to get the separatrices through the equilibrium points. .

(ii) For the second numerical procedure, integrating on both sides of equation (5.6b), we get,

$$P (x, h) = P (x^*, h^*) + 5.\ JM (x, h (x))dx$$

$$= R (x, h)$$

For each chosen x-value, we iterate on h in the following way:

$$R (k) = R (x, h [k]), \text{ and}$$

$$P(x,h[k+1]) = P(k+1),$$

then we solve for h[k+1]. We can get a sequence of functions (or numerical values) h(1), h(2), ...for each value of x. This iteration is extremely efficient (strong contraction) if one starts with h(1)=f (x) (the growth function).

(2) Perturbational approximation method suitable for such cases in discussed in details in Sandal and Steinshamn (2001).

We, however, follow the first numerical procedure. When 5 is not set equal to zero, the optimal steady state would change and can be obtained by solving the following equations with respect to x : ,

$$S'(x) = -6, \quad {}^{f}h \quad f(x.\ h) = 0 \qquad (5.11)$$

$$S/(x) = 8.M(x, h) \quad I(X,h)=0 \qquad (5.11a)$$

Now, an initial point in (x,h) plane is needed. The steady state point without discounting may be used as a starting point. But it may not appear to be very good starting point. For this, we can try to manipulate the equation (5.6b) further to have the slope of the control path and thus get the initial point in (x, h) plane.

Differentiating (5.6b) with respect to x, we get

$$P_{xx} + 2P_{xh}h' + P_{hh}h'^2 = 5(M_x + M_h h') \qquad (5.12)$$

Arranging the equation as a quadratic function of h', we find

$$P_{hh}h'^2 + (2P_{xh} - 5M_h)h' + (P_{xx} - 5M_x) = 0 \qquad (5.13)$$

The solution of this quadratic function gives the slope of the control path as,

$$\frac{dh}{dx} = \frac{(5M_h - 2P_{xh}) \pm [(2P_{xh} - 5M_h)^2 - 4P_{hh}(P_{xx} - 5M_x)]^{1/2}}{2P_{hh}}$$

This h' is the general expression of the slope of the feedback solution at equilibrium point and would be applied in section 5.4 for each of the three different demand situations of Bangladesh trawl shrimp fishery for optimal control path.

5.2.2 Algorithms of the Solution:

Algorithms of the solution procedure that we have followed for both the situations of with and without discounting are given below:

Algorithms are written in an informal notation called pidgin algol[1].

(i) Without Discounting:

```
Procedure Solution without:
begin
     K = 11400:1=1
        begin
              Find x such Uiat S'(x) = 0
              X*: = x
              Find the value of S(x) at x = x* to get Max S(X)
              Constant Po: = S(x*) = Max S(x)
              Find the value of h setting Po = P( x*, h)
              h*:=h
              (x*, h*) gives steady state
        end
        begin
              Take any value xfi]
              if xp] < K then find h for Po = P( x[i], h)
              if h< >0 then
              begin
                       h[i]:=h
                          i: = i+1
              end
        end
end.
```

[1] "The teem pidgin algol appears to have been introduced in A. V. Aho, J. E. Hopcroft and J. A. Ullman, The Design and Analysis of Computer Algorithms (Reading, Mass. : Addison-Weseley Publishing Co., Inc., 1974" - *Papadimitrioa & Steiglitz, Combinatorial Optimization: Algorithm &Complexity,* Prentice-Hall, India, 1997

(ii) With Discounting:

```
Procedure Solution with:
begin
    Limit = an assigned value : i=1
    [Comment: depending on the required precision the assigned value
    is a very small number representing zero]
    Find x setting S'(x) - 5 m = 0
    x*[i] := x
    begin
            Find h = f(x*[i])
            h*[i]:*h
          . Findh'at(xmh*[i])

            If —7 > limit then
               h
            begin
                    x*[i+1] :=x*p]+Ax
                    h*[i+1]:=h'[i]+Ax.  h'

            end
    end
end.
```

Algorithm of without discounting will provide steady state (x*, h*) at the beginning and then for different values of biomass levels, higher and lower than x*, would give corresponding values of harvest levels. This series of biomass levels and corresponding levels of harvest will give the complete trajectory of the control path when there is no discounting. Levels of harvest (h) corresponding to any given value of biomass levels (x) physically signify the optimal level of harvest at that level of biomass.

5.3 Optima] Control Path of Bangladesh Trawl Shrimp Fishery without Discounting:

Using the net profit function given in 4.2 and the values of other parameters i.e. c_2, q, u, r and K, the numerical solution of the non-linear dynamic system that we have formulated, now can be obtained.

With the willing to pay (WTP) function of harvest h described in section 3.3.1, the exact net benefit function of our model becomes,

$$n(h,x) = [(p_1 + (p_2 - p_i).e^{'bh}].h - \frac{\wedge}{qx} \qquad \{5.15)$$

given that, pi = 6083.97729, pa= 13,977.93881 and b = 0.0004682.

Sustainable economic rent, therefore,

S(x) = n (x, h)|

$$= [(P_i+(P_2-p_1).e^{bh}].h - \frac{c_2 h}{qx}$$

Since, at the steady state harvest equals to growth, we find

$$S(x)=[(p_1 + (p_2.p_1).e^{-brx(1-\frac{x}{K})}].[rx(1-\frac{x}{K})]-\frac{c_2.rx(1-\frac{x}{K})}{qx}$$

and differentiating with respect to x, we have

$$S'(x) = p_1 r \frac{}{K} \wedge - + \frac{\wedge}{Kq} - + (p_2 - p_1).$$

$$[(rx-\frac{rx^2}{K}).(-\frac{2brx}{K}-br).e^{-brx(1-\frac{x}{K})}+(r-\frac{2rx}{K}).e^{-brx(1-\frac{x}{K})}] \qquad (5.16)$$

$$\text{and } m = \wedge = p_1+(p_2-p_1).(1-bh).e^{-bh}-\wedge \qquad (5.17)$$

The Hamiltonian equation of our model, given by (5.5), becomes

$$P_0=[\{p_1+(p_2-p_1).e^{bh}\}.h-\frac{\wedge}{qx}] +$$

$$[fe+fe \bullet!>!).(1-bh)e^{bh}\}-\wedge-].[fC»)-h)] \qquad (5.18)$$

The Hamiltonian equation 5.18 defines the optimal harvest as a feedback control rule for non-linear exponential demand situation. Setting S'(x) = 0, we calculate x which implies optimal biomass x*. Again putting the value of x = x* in S (x), we get S (x*) = P_0 =Max S (x). Po remaining constant, each of the different values of x* when substituted in the Hamiltonian equation 5.18 gives corresponding different values of h*., These computed values, presented in Table 5.1, are optimal values of biomass stock and optimal harvest of marine shrimp of Bangladesh along the optima! control path. The optimal control path which implies optimal values of state variable (x*) a function of optimal control variable (h*) is shown graphically in Figure 5.1. This optimal control path shows the steady state situation.

5.4. Optimal Control Path of Bangladesh Trawl Shrimp Fishery With Discounting:

Steady state solution with discount of the marine shrimp of Bangladesh are computed in this section. We have already discussed the complexities involved in such type of solution in section 5.2. The steady state solution has been provided here in accordance with the assumed exponential demand function. Net revenue, function and the values of the parameters are same as in the case of without discounting.

The Hamiltonian equation will be same as 5.18 but it would not be equal to a constant Po. The Hamiltonian would be,

$$P=[\{p_1+(p\wedge-p_1).e^hM.h-\frac{\wedge}{qx}]+[\{p_1+(p_2-p_1).(1-bh).e^{bh}\}-\frac{\wedge}{qx}].Crx-\frac{\wedge}{K}-h) \qquad (5.19)$$

where P is not given as constant. Partial differentiation of (5.19) with respect to x and h gives,

$$P_{x}^{A} := P_1 r - - \wedge^{+} \wedge^{+r} - (P2 - Pi) - (l - bh) d - - \wedge) . e'^{bh} \quad \text{K} \quad \text{Kq} \quad \text{K} \tag{5.20}$$

$$P_h = b.(p_2 - p_l).(bh.-2).(rx \frac{rx^2}{iv} - h).e''^{bh} \tag{5.21}$$

Differentiating partially (5.20) further with respect to x and h, we get 5.22 and 5.23 respectively as follows:

$$P_{xx} = \frac{-2p_l r}{} \sim \frac{2r(p_2 - p_l)(l - bh).e^{-bh}}{K} \tag{5.22}$$

$$P_{xh} = br(p_2 - p_l).(bh-2).(l - \wedge).e^{-bh} \tag{5.23}$$

Similarly, differentiating partially 5.21 further with respect to h we get 5.24 as follows:

$$P_{hh} = b(p_2 - Pi) - e^{h(l} t''^{b} \; hrx + \frac{b^2hrx^2}{} + b \; h + 3brx \frac{Sbrx^2}{} 4bh + 2] ; \tag{5.24}$$

The co-state variable 'm' is given by the equation 5.17 as before. Partial differentiation of 5.17 with respect to x and h gives the relations 5.25 and 5.26 respectively.

$$m = \frac{}{T} \tag{5.25}$$

$$m_h = b(p_2 - p_l).(bh-2).e^{-bh} \tag{5.26}$$

Following the algorithm that we have discussed in Section 5.2.2, we calculated the value of x* when S'(x) - 8 m = 0. This value of x* gives the corresponding value of harvest h* from the growth function and thus provide a point (x*, h*) in (x, h) plane. Equations 5.20 to 5.26 provide all the values of the arguments of equation 5.14, and thus, the slope or the tangent of the trajectory dh/dx, is calculated. Moving a little away from the equilibrium point along this tangent we get another starting point. With this as an initial point, we get a new equilibrium (x*, h*). Repetitive process gives us the separatrices of the optimal control path. Computed values of optimal biomass (x*) and optimal harvest (h*) are presented in Table 5.1 for discount rate 5 = 0.05 and 5 = 0.10. Graphical representation of the control paths for two different discount rates are shown in Figure 5.1. The graph shows the steady state where control path intersects with growth function and the minimum viable biomass level when control path intersects with horizontal axis.

Table 5.1
Optimal Harvest Levels of Bangladesh Trawl Shrimp at Different Discount Rates

Stock (tons)	Optimal Harvest (tons) (0% Discount Rate)	Optimal Harvest (tons) *(5%* Discount Rate)	Optimal Harvest (tons) (10% Discount Rate)
2000	-187.36	-108.34	-42.29
2500	167.12	295.96	363.76
3000	• 501.46	668.74	738.47
3500	823.09	1017.49	1089.82
4000	1139.28	1350.23	1426.35
4500	1457.84	1676.90	1757.71
5000	1788.34	2005.40	2096.01
5500	2144.53	2354.27	2459.43
6000	2550.48	2750.73	2883.95
6500	3063.12	3274.55	3500.13
7000	4468.40	—	~

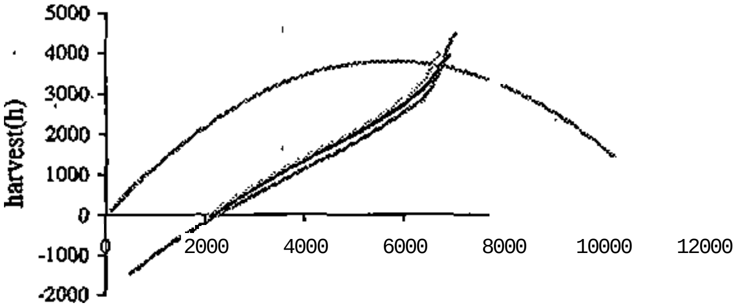


Figure 5.1: Optimal control paths (non-linear exponential demand function) with discount (5% &10%) and without discount (0%).

5.5. Results and Discussion:

Steady state solution of Bangladesh trawl shrimp fishery have been derived under 'with' or 'without' discounting condition. At different level of stock, optimal harvest levels are shown in Tables 5.1. Since, harvest represents control variable and stock represents state variable, these values when plotted along with growth function give us the optimal control path or optimal harvest path as shown in Figure 5.1. The point at which this control path intersects with growth function implies the steady state optimal situation, thus, we get optimal biomass stock (x*) and corresponding optimal harvest levels (h*). Table 5.2 is provided with such steady state optimal stock (x*) and optimal harvest (h*) under 'without' discounting and 'with' discounting condition.

Two different discount rates, 5 percent and 10 percent, are considered. Results presented in Table 5.2 reveal that optimal stocks or biomass levels are relatively lower for higher discount rate. Similarly, the optimal harvest levels appear relatively higher for the higher discount rate than the system under without discount. Both the results substantiate the expected notion regarding the direction of change. It is known that the biomass stock would

Table 5.2

Optimal Stocks and Optimal Harvests under Exponential Demand Situations for Different Discount Rates

	Optimal Stock (x*)			Optimal Harvest (h*)		
Demand function	8 = 0	6 = 0.05	5 = 0.10	5 = 0	5 = 0.05	5 = 0.10
Non-linear exponential	6866.35 (-)	6728.13 (-2.01)	6592.81 (-3.98)	3634.02 C-)	3669.43 (0.97)	3699.78 (1.81)

Note: Figures in the parenthesis indicate percentage change with the increase in discount rate.

be lesser with the increase in discount rate as the harvest level would be higher for higher discount rate. But the extent of variation due to discounting, shown by the percentage changes over the values of the parameters at the steady state (without discount) given in the parenthesis in Table 5.2, is very small and insignificant. Optimal control path along with growth function shown by the Figure 5.1 also indicates this insignificant variations due to discount factor. However, when we tried for the non-linear inverse demand function we observe that it shows relatively greater variation due to increase in discounting factor than the non-linear exponential demand function (Results of inverse demand function is not shown here).

These optimal control paths (or optimal harvest paths) along with growth function also provide minimum viable stock point. The point at which the optimal harvest path intersects with x-axis is called limit reference point. The physical significance of this point is that the exploitable biomass is at minimum viable stock Xmin. It implies that the exploitable biomass is at such a level that a harvesting moratorium is bioeconomically optimal at that point of stock. These values of Bangladesh marine shrimp and at different discount rates are given in the Table 5.3.

Table 5.3

Minimum Viable Levels (X^n)
for Different Discount Rates

X min			
Demand function	Discount Rate		
	5 = 0	8 = 0.05	5 = 0.10
Non-linear exponential	2260.05 (-)	2129.52 (-5.78)	2050.08 (-9.29)

Note: Figures in the parenthesis indicate percentage change with the increase in discount rate.

Results shown in the Table exhibit that $x_m$in values are 2260.05, 2129.52 and 2050.08 at zero, 5 and 10 percent discount rates. It shows that 5% and 10% increase in discount rate leads to 5.78% and 9.29% decrease in limit reference point respectively. It implies that the increase of discount rate upto 10%, decreases the limit reference point by 9.29 percent and, in absolute terms, it lies between twenty two hundred to twenty hundred metric tonns.

If optimal stocks (x*) and optimal harvests (h*) are known, then optimal values of other parameters can be obtained. By using relations 4.13 and 4.14 we calculated optimal effort levels (E*) and shadow prices (A*). These calculated optimal values are shown in Table 5.4.

Table 5.4

Optimal Efforts and Shadow Prices at Different Discount Rates

	Optimal Effort (E*)			Optimal Shadow Price (X*)		
Demand function	Discount Rate			discount Rate		
	5 = 0	5 = 0.05	5 = 0.10	5 - 0	5 = 0.05	5 = 0.10
Non-linear exponential	5415.27 (-)	5580.37 (3.05)	5742.01 (6.03)	5800.23 (-)	6028.20 (3.93)	6254.12 (7,83)

Note: Figures in the parenthesis indicate percentage change with the increase in discount rate.

Results show that higher the discount rate, higher is the optimal level for both effort and incremental cost or shadow price. Results clearly establish that the present level of actual effort is much higher than the optimal level of effort. As we find in the'last chapter, when the system was studied under discrete-time, that higher level of effort is employed at present to harvest lesser amount of catch - exactly identical situation is revealed by this continuous time analysis. It, therefore, causes loss due to the same reason that we have explain in the previous chapter {section 4.3). Following the same procedure, we calculated the notional losses for three different discount rates on the basis of optimal harvest and stock on 1997-98. As optimal harvest (x*) and optimal effort (E*) are different for different discount rates, the estimated losses would also be different. These estimated losses are given in Table 5.5, However, it is to be mentioned that causes of limitations in the estimation, explained earlier in Section 4.3, equally applicable here. Results presented in Table 5.5 show that the annual estimated loss is nearly $32 million. The result is almost identical to the losses under static and dynamic discrete analysis for the year 1997-98, As the cumulative loss of the nation over the whole period of our study starting from 1981-82 to 1997-98 compounded with appropriate rate upto present year would be same as before, we prefer to avoid repetition, and therefore, did not mention separately in a table here in this chapter again.

Table 5.5

Annual Losses Calculated at Different Discount Rates
(for the year 1997-98)

Demand function	5 = 0	5 = 0.05	8 = 0.10
Non-linear exponential	31814841.33	31832201.53	31767154.09

5.5.1. An Optimal Feedback Rule for the Bangladesh Trawl Shrimp fishery:

Many fisheries operate under some type of suitable feedback rule. Bangladesh marine shrimp fishery operates under an ad hoc policy at present. Different parameters, such as biomass stock, effort level etc., subject to constant change, are seldom taken into account as feedback to decide on the catch- quota at present. Naturally, the present practice of allotting trawling permission to different trawlers is not aimed at to optimize the resource utilization keeping the long-run sustainability in mind. Moreover, policy makers have to consider various type of socio-economic factors while allotting quota, such as, employment of people, investment made in advance of catching season by owners of a trawler, political

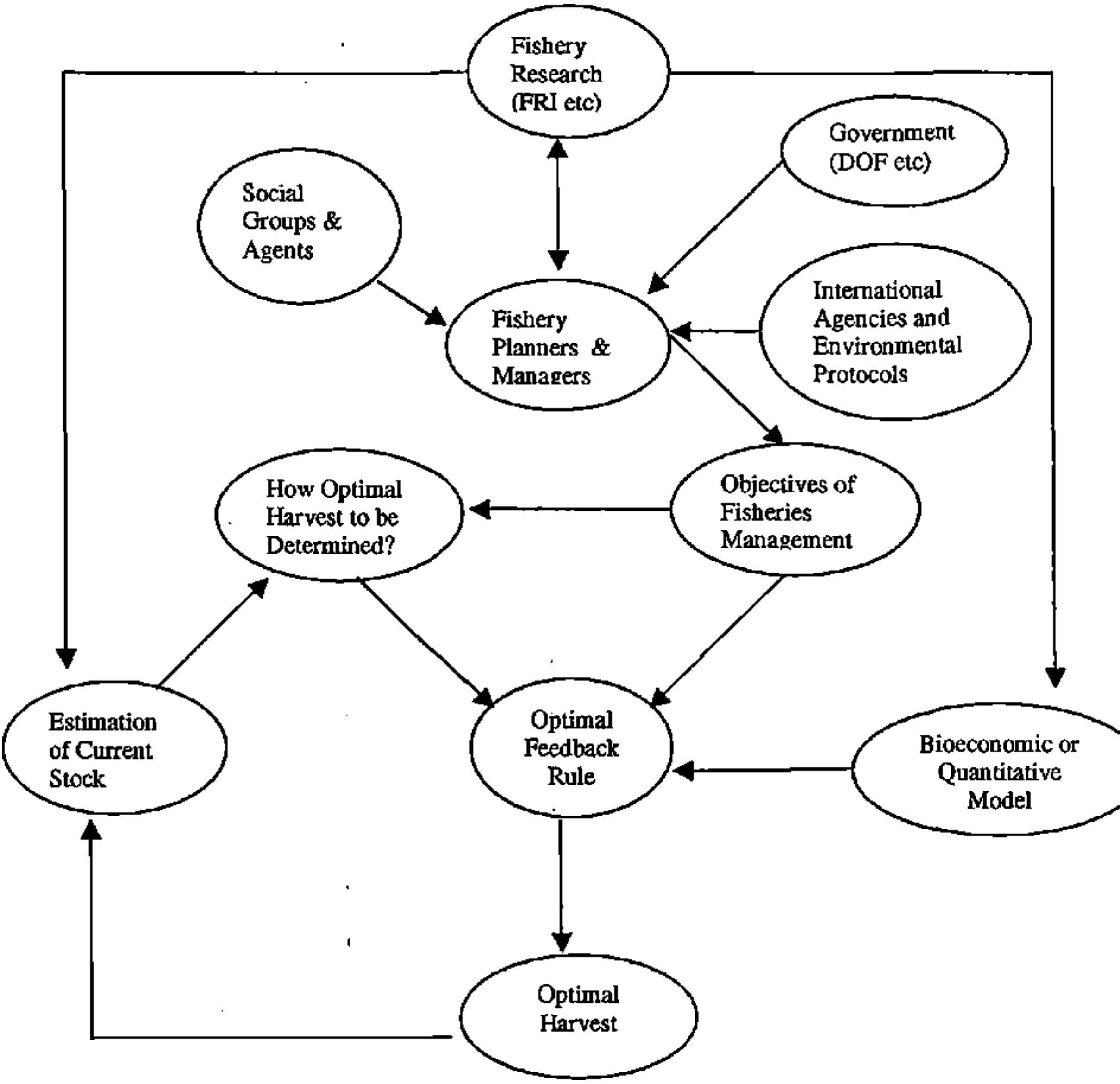


Figure 5.2: A Schema of Implementation of the Feedback Rule for Optimal Management of Trawl Shrimp Fishery in Bangladesh.

compulsion of avoiding social unrest among the people involved in the industry etc. All these factors combined together along with the lack of optimization model, gives birth an ad hoc management system which is in any sense be termed as optimal feedback rule.Our study perhaps be able to provide an optimization model which can be implemented as an optimal feedback rule for Bangladesh trawl shrimp fishery if proper system can be developed. A feedback rule means that the optimal control is a function of the state variable. This feedback rule may be used in a sense of passively adaptive policies (PAP) (Walters, 1986). It is adaptive for the reason that the control variable (harvest) changes immediately when new knowledge about the state variable (stock) is available. This feedback rule is PAP as sporadic shocks and disturbances can be handled within certain limits not beyond catastrophic discontinuities. Moreover, the adaptive management can be able to make the system gradually perfect as the data series grow. Results of our study already expressed how an optimal control path can be obtained.

This optimization model can determine the optimal harvest if the existing stock can be estimated. A simple method of stock assessment has been provided in Chapter-3. Given the values of other parameters - either determined by the appropriate govt, or non-govt agencies, the present model can be suitably used in ease. Following Grafton et. al, we provide here a simple schema in order to give an idea that how different factors can be considered simultaneously and,, at the same time, resource can be managed optimally as practical as possible. A set of objectives of trawl shrimp management would be laid down in consultation with several agencies by the fishery planners and managers. This set of objectives actually provide the specific values of different parameters of the model. For an example to illustrate, the policy decision by the planners that how the resource revenue would be discounted, would give us the value of the factor 5. Estimation of current stock, relevant data from the set of objectives and new information provided by the bioeconomic or quantitative research etc. would be used as an input of optimal feedback rule. For example, if a new study shows change in cost parameter or demand'curve, then those changes would be appropriately incorporated in the specific function of the model. Optimal harvest thus can be determined continuously and trawlers movements, trawling time, net size, gear size etc. can be monitored accordingly at any point of time of season. There is no need in fixing the quota prior to the season started and issuing license to the trawlers in an ad hoc basis.

However, we do not claim that this optimal feedback rule is able to capture all the complexities of the ecological and fish population dynamics, which is perhaps simply not possible, but it certainly provide a useful and easy-to-handle tool in determining optimal harvests and thereby to optimize the resource utilization with a long-run sustainability objective.

5.6. Concluding Remarks:

Results of this study presented in this chapter have the following findings and possible conclusions.

(a) We have found the optimal control path of Bangladesh marine shrimp fishery which is observed to be not managed and utilized optimally in this present study of non-linear dynamic (continuous) analysis in conformity with the findings obtained in previous chapter of discontinuous situation. We also obtained optimal steady state solution of the system. Thus it follows that following the optimal control path the present sub-optimal level of operation, level of exploitation of resource can be attained. This will also ensure to restore the optimal stock of resource froni the present sub-optimal level which appears to pose a genuine threat of depletion.

(b) The study also reveals that the optimal control path varies insignificantly with the social discount rate and thereby substantiate the theoretical findings of Farzin (1984), Hannesson (1983/1987) and Sandal and Steinshamn (1997).

(c) The study has been able to find out the minimum viable level of Bangladesh shrimp. The result, however, appears to be consistent with the expected theoretical value. However, the present practice of harvesting, the calculated minimum viable level and present estimated biomass stock together appears to be indicative that there is a possible threat of extinction if the present practice of harvesting continues.

(d) The study also show that due to non-optimal management system, the nation suffers loss both in terms of revenue and conservation of resource. Unlike cumulative revenue loss over the years calculated in the previous chapter, the loss in a particular year has been shown and the amount appears to be of serious proportion.

(e) The study has been able to formulate a feedback rule which gives control variable as a function of state variable. The study, therefore, suggest a scheme, through which the feedback rule can be implemented for effective management of the resource.

(f) The study is implicitly indicative in the sense that it seems to assert that a serious and in-depth study is required to understand the real dynamics of equilibrium situation under chaos. Dynamics of the system arising out of fluctuation in price and biomass population may help to formulate appropriate policy of the management of this resource.

Chapter 6

A Study of
Chaotic Dynamics and Catastrophic Discontinuities
in
Bangladesh Trawl Shrimp Fishery

A part of this work has been published in the proceedings of the UGC sponsored national seminar in the Department of Geography & Applied Geography, University of North Bengal, Darjeeling, India on *Resource Utilization and Environmental Management of Eastern States of India* titled "Chaotic Dynamics and Catastrophic Discontinuities of Trawl Shrimp Fishery in Bay of Bengal (Bangladesh)".

6.1. Introduction:

Studies on the application of theory of chaos in the management of fishery prove that chaotic dynamics are more likely to happen when there is either, (i) the system is under open access, (ii) the high discount rate prevails or (iii) the demand curve is relatively inelastic. Actually, all these three factors ultimately lead to possible 'overexploitation' of the resource i.e. 'overfishing'/ 'overharvesting' of fishery. Clark (1973) thus said that "population can be driven to extinction by commercial hunting hardly needs to be emphasized".

Gordon's (1954) theory of common property fishery' and Hardin's (1968) tragedy of commons', both of which have since become classic, explained the logic behind the tragic consequence of exploitable natural resources under 'open-access' system. Marine fishing zone of Bangladesh in Bay of Bengal is not an "open access' in true sense. In fact, a very few resource stocks anywhere in the world at present satisfy the definition of open-access in true sense in general and fishery in particular. But, many theoretical studies of recent times and empirical verification on past data of either extinct or depleted fish stocks amply prove that the chances of this tragic consequence still persist. It may be for the reason of biological overfishing in spite of the fact that the system is not purely 'open access'.

So far the social discount rate is concerned, the marine resources of the area under study being exploited by the common fisher folk of a less developed country, the rate may expectedly be very high. Besides, we have found that the shrimp fish price is sticky, though the demand curve is not perfectly elastic (Figure 3.2, 3.4 and 3.6). Analysis of the results of our study in the last two chapters amply prove that, though the system officially is not under 'open access', overfishing is causing reduction in both the biomass stock and harvest with increasing effort level over the last few years.

In this context, it may be recalled that Lisbon Principles (Portugal, 1997) were laid down to address five major problems in the oceans. These are overfishing, ocean disposals and spills, the destruction of coastal eco-systems, land-based contamination and climate change. Of 200 major fish stocks accounting for 77% of world marine landings, 35% are currently classified as overfished (Costanza *et al,* 1998). Overfishing is, therefore, identified as the most serious problem of these five as the complex dynamics arising from non-linearities in fishery can show chaotic and catastrophic dynamic patterns (Rosser, 2001). Though overfishing has multiple causes and varies fishery to fishery, study of non-linear complex dynamics of a species which is targeted for large scale commercial exploitation has invited a lot of attention from researchers who have been trying to understand 'chaos' in fishery.

6.1.1. Chaos and Catastrophe:

The term 'chaos' often appears to be misleading and confusing. It is precisely defined as *'effectively unpredictable long-time behaviour arising in* a *deterministic dynamical system because of sensitivity to initial conditions'.* Thus, given the perfect knowledge of the initial conditions, a deterministic system is perfectly predictable and, in practice, is always predictable within short time span. However, any observed time series from chaotic systems may appear irregular and disorderly as a consequence of long-term unpredictability. It implies that chaos is definitely not to be confused with complete disorder. It is in-fact a disorder but in such a dynamical system which is deterministic and always predictable in short run. Thus chaos theory as a scientific theory about situations that obey particular laws but appear to have little or no order, identifies that i) any complex system has an underlying order and ii) any apparently simple system can produce complex behaviour.

On the other hand, catastrophe connotes such a sudden event that causes destruction or unfavourable/undesireable eventuality what may usually be termed as a calamity. Complex dynamics arising from non-linearities can show chaotic and catastrophic dynamic patterns (Rosser, 2001). While chaotic systems tend to remain bounded and thus may represent sustainable solutions despite associated apparently erratic nature of the dynamics, catastrophic discontinuities demands special investigation to determine the critical boundaries within which the system must be kept in order to maintain sustainability.

Experts are unanimous that management of fisheries operates in a highly uncertain environment. Harvest levels of most of the fisheries worldwide in recent years record large fluctuations. This is also reported in estimated stock levels. Since fish stocks cannot be observed directly, estimates of present and past stock levels are themselves subject to considerable error. Conard, Lopez and Bjorndal (1998) show that observational errors can combine with biological stochastic to generate a non-linear increase in risk. Zimmer (1999) shows that environmental noise can interact with endogenous chaotic population dynamics to generate fluctuations of greater variance. It must be recognized that on top of the noise from environment there is the problem of noise induced by the poor information available to fishery managers and policy makers regarding the actual state of *any* fish population.(Rosser, 2001).

The chaotic behaviour in fisheries is required to be studied from the angle of population dynamics of the fish as well as the economic characteristics of the harvesting process. Instability' in simple bioeconomic model due *to* harvest activity has already been reported (Hilborn and Walters,1992; Opsomer and Conard, 1994). On the other hand, relatively low cost of harvesting with respect to price may cause backward bending supply *curve.* This is an economic phenomenon which creates the condition of multiple equilibria some of which may be 'bad' and unstable. Moreover, fishery dynamics subject to stochastic constraints of ecologic and economic are in most cases nonlinear. So multi-disciplinary modeling of fishery dynamics should be such that must be nonlinear and complex but be able to capture its irregular or chaotic behaviour. It should be such that the economic agents would be able to successfully follow an underlying truly chaotic dynamics, even through a self-fulfilling chaotic mistake, (discussed in 6.3) so that system does not lead to the collapse of that fishery. In this chapter, we have attempted to study the possibility of existence of backward bending supply curve as well as consequential chaotic dynamics and catastrophic discontinuities in large scale commercially exploited trawl shrimp fishery in Bay of Bengal (Bangladesh). Our objectives of study in this chapter are to find the following:

(i) whether the supply *curve* of marine shrimp fishing of Bangladesh shows any sign of backward bending at any level of discount rate.

(ii) Whether any tangent bifurcation of such bending supply curve with the demand curve exists and at what rate of discount.

(iii) Whether catastrophic discontinuities exist as a possibility or the system is deterministically chaotic.

6.2. A Brief Discussion on Chaos and Catastrophe in Fishery Management:

May (1974) first introduced the term 'chaos' into the study of dynamical systems in ecological populations. He focused deterministic chaos in biological growth processes on the growth sector of bioeconomic models. Hassell et al. (1976), however, found that the intrinsic growth 'energy' required for a chaotic stock growth process is significantly greater than the actual intrinsic growth of fish stocks world-wide. Thus, it appears that fish stock growth relations themselves cannot generate deterministic chaotic fluctuations. Hence, the ecological deterministic chaos will not be an endogenous component of a bioeconomic fisheries model unless the model is extended to include a more comprehensive 'chunk', of the ecological system to be studied. Although, Zimmer's (1999) study of chaotic dynamic systems in natural populations does not corroborate this fully. However, similar controversy exists in economics with some arguing that *certain* markets, especially in agriculture, exhibit chaotic *dynamics* (Chavas & Holt, 1991,1993 ; Finkenstadt and Kuhbier, 1992), whereas others question such findings and argue that true chaotic dynamics have not been definitively established for any economic time series (Jaditz and Sayers, 1993 ; LeBaron, 1994). Chen (1997) argues that the combined interaction of the global climate and economic systems may be a chaotically dynamic system.

Similarly, the chaotic behavior in fisheries are not likely to originate simply from the population dynamics of the fish stock but also from the economic characteristics of the harvesting process. It is also to be noted that harvest activity can produce instability in simple discrete-time bioeconomic models (Hilborn and Walters, 1992; Opsomer and Conard, 1994). In these models, harvest adjustments depend on previous profit with exogenously determined multiplicative adjustment of sensitivity parameters. Actual stability depends on the interplay of population dynamics and market conditions. Harvests can have an unassuming destabilizing effect under certain growth and market conditions. Market oriented harvest may also have a stabilizing influence, even when applied to stocks having extreme intrinsic growth rate. Conklin and Kolberg (1994) address the question of whether market-driven harvest activity has a stabilizing or destabilizing influence on stock fluctuations. They observed that 'chaos may be lurking in unexpected place in renewable resource models when harvest is market-driven'. They verify their predictions in the context of the Pacific Halibut fishery. Their model has beenfound to be capable of exhibiting chaotic behavior under a range of plausible market conditions. However, they had to make the note that Pacific Halibut Fishery was not necessarily on the verge of behaving chaotically even though their model exhibited many of the features of chaos.

Harvest activity can influence the dynamic model by two ways - one through the 'growth factor' and other through the 'market response effect'. The growth factor has a systematic influence on stability of the bioeconomic equilibrium point along a given open-access supply iocus. The 'market response effect' involves variation in harvest in response to the stock level changes. Conklin and Kolberg (1994) found that changing slope of the demand curve could thrust the model into instability, chaos and extinction without changing.the bioeconomic equilibrium point. They also showed that the increased market demand without changing the slope of the demand curve i.e. enhanced market response due to expansion of the market, could push the model into instability, chaos and even extinction.

While it is relatively simple to understand mathematically that deterministic chaos is potentially important in fisheries, it has yet to be established how far the fluctuations in real-world system outputs {biomass stock, harvest, etc.) are due to chaos rather than to stochastic influences. The assertion by Wilson *et ai.* (1994) that the fisheries may be 'chaotic' has been challenged by Fogarty (1995) on the ground that very few available proper documentation of chaos in ecological systems may hardly be considered sufficient to conclude affirmatively.

However, for analysis and management of chaotic fishery dynamics, the long-term forecasting of system outputs have generally been regarded as doubtful due to critical dependence on initial conditions. The accuracy of short-term forecasting, on the other hand, depend on the type of forecasting model used. McGlade (1994) points out that the predictive power of short-term forecasting will be poor when chaotic time series are modeled using a linear stochastic process. However, while the long-term unpredictability *of* chaotic fisheries systems may certainly complicate the task of resource managers, it does not negate the management function completely. Fogarty (1995) argues that the issues of predictability and control are different. Grafton and Silva-Echenique (1997) show that the uncertainty caused by chaos does not necessarily imply a 'precautionary' approach to the fisheries management but rather a 'mixed strategy' approach. This approach provides managers more options for controlling fisheries even when the dynamics of the system are not known. Now, apart from this theory of chaos', other theories that have been developed in the field of studying dynamic behaviour, particularly in the field of dynamic discontinuities, is the catastrophe theory. The catastrophe theory developed by Thorn (1975) and Zeeman (1977) may be regarded as the best expressed mathematical approach to modelling dynamic discontinuities. The collapse of the blue whale population (Jone and Walters, 1976) was studied by the application of catastrophe theory.

6.2.1. Fishery Dynamics and Economics:

The explanation of collapse or sudden biomass shift of fishery was initiated from the economic point of view by the revelation of the possible existence of backward bending supply curve - under certain conditions.

Copes (1970) first described the backward-bending open-access supply curve in fisheries subject to the condition that average revenue equals average cost of effort. He contrasts this case to the optimal supply curve (for 8=0) in which marginal revenue equals marginal cost of effort. He identified the open-access that had long been understood as a prime source of aggravating the overharvesting problem in many fisheries (Gordon, 1954; Hardin, 1968). However, Clark (1990) shows that such a backward-bending outcome even can occur in an optimally managed fishery without open access, as long as there is sufficiently high discount rate. In such cases we already know that chaotic dynamics can arise in fairly simple models with discrete dynamics. Conklin and Kolberg (1994) have provided a specific model of chaotic dynamics for the Pacific Halibut fishery with'such a backward-bending supply curve. In economics of fishery, such backward-bending supply curve is assumed to be derived from such optimally managed fish resources by a sole-owner whose objective is to maximize discounted revenues.

As the objective is assumed to be maximization of discounted revenues, then two aspects become very important: First one is the price of the resource as revenue directly depends on price. It has also been known (Clark, 1973) that extinction is always feasible if extinction cost is less than the price. It is important to note that as the owner maximizes discounted future revenues, the price actually implies future price. Second important aspect, therefore, is the expectation regarding the future price as the owner decides his harvesting policy prior to realization of actual price in the market. The expectation of realizable price is every time formed out of the realized price at present. Because of the fluctuations in observed prices, formation of expectation is an adaptive learning process. Hommes and Rosser (2001) studied the price fluctuations under adaptive learning in renewable resource markets such as fisheries.

Most of the economic models thus involve a description of human behaviour with a basic postulation that economic agent behaves rationally. This postulation of 'rational behaviour' has two different aspects. One of the aspects is that economic agents always behave optimally in any given situation. Thus economic agent is always either a utility/profit maximizer (or cost minimizer). The second aspect of rationality is that 'agents form expectation about the future in a way that is not systematically wrong'. There is no disagreement among the economists regarding the way optimization behaviour of the first aspect be formulated. But there are various options on how one should, model the second aspect of rationality. Because of this possible difference in the second aspect, the conditions under the adaptive learning process vary. Economic agents form an expectation regarding price in future which decides upon certain decisions like harvesting at present and again, the actual realization of price at present decides upon his expectation formation of the future price. The difference between the expected price and actual realization of price is mistake which the *economic* agents want to minimize systematically. *Economic* agents thus want to be within the predicted limit of mistake. If the actual realization of price appears outside the calculated limit frequency, then the economic agent is said to be irrational due to his systematically wrong expectation formation. A dynamic economic model, for this reason, is considered always an expectation feedback system - expectation affect actual dynamics and actual dynamics feedback into the expectation scheme. This is what we called Rational

Expectation Hypothesis (REH) - the most predominant paradigm in expectation formation in economics, which was first introduced by Muth (1961) and was first applied to macroeconomics by Lucas (1971). The REH describes an equilibrium point which is a fixed point of this expectations feedback system and is known a rational expectation equilibrium (REE). Though REE is very much appealing as a normative model of expectation formation, it requires that the information set on market forces is completely known to the economic agent in such a way so that agent can compute the equilibrium point instantaneously and takes his decision accordingly. This is an extreme task, if not impossible task, imposed on economic agent. Under non-linear market equilibrium condition, even if all the market equilibrium conditions are known to the economic agent at every point and in every time, in most of the cases it would be impossible to find the equilibrium point analytically and would require the computing power like super computer to find the equilibrium point numerically. Because of this practical impossibility, several alternatives have been proposed by many economists, like Bray (1982), Bray and Savin (1986), Marcet and Sargent (1989), Woodford (1990), Bullard (1994), Evans and Honkapohja (1995). Fundamental difference of expectation formation hypothesis of all these works with that of REH is that the economic agent does not require to have a complete information set on market forces but beliefs only on actual time series. Under this assumption, REE is not an obvious outcome of adaptive learning process within the expectations feedback system even asymptotically.

Hommes and Sorger (1998) introduced the notion of **consistent expectation equilibrium** (GEE) in non-linear dynamic economic models. The key feature of CEE is that "agents expectations of a certain variable are consistent with the realizations of that variable in the sense that their sample average and their sample autocorrelations are the same". For example, suppose that the agents believe that prices follow a stochastic low-order AR(k) process and thus predict that tomorrow's price will be some linear combination of past prices. Given this belief, a certain time path of actual prices will be realized through market clearing. In literature, this time path of equilibrium prices is called a CEE if its sample average and its sample autocorrelation function equal the average and the autocorrelation function, of the AR(k) belief process respectively. Stated differently, a CEE is a fixed point of the expectations feedback system in terms of the observable sample average and sample autocorrelations. CEE is thus "an equilibrium concept for which beliefs are self-fulfilling in a linear statistical sense" (Hommes and Sorger, 1998: 288). This approach is described as bounded rationality hypothesis in 'expectation formation and learning' where the agents base their expectations upon time-series observations and adopt their beliefs accordingly. This concept of consistent expectations equilibrium is crystallized as a more general framework by combining the notion of a **self-fulfilling mistake** (Grandmont, 1998) with constructions of Sorger (1998) and Hommes (1998). The concept of quasi-rational expectations introduced by Nerlove ef *al* (1979) may be compared with this approach. According to this approach, expectations about variable(s) are given by those predictor(s) that minimize the mean squared prediction errors in an ARIMA model. List of recent related works on bounded rationality and expectation formation includes the rational belief equilibria of Kurz (1994), the pseudo rational learning of Marcet and Nicolini (1995), the expectational- stability and adaptive learning rules of Evans and Honkapohja (1994, 1995), the perfect predictors of Bohm and Wenzelburger (1996), and the adaptive rational equilibrium dynamics of Brock and Hommes (1997; 1997a). Stability and instability of adaptive learning processes have been investigated by Grandmont and Laroque (1991), Bullard (1994), Grandmont (1998), Chatterji and Chattopadhyay (1996), and Schonhofer(1996).

6.3. Chaotic Dynamics and Catastrophic Discontinuities in Bangladesh Trawl Shrimp Fishery:

We use an optimal control theoretic version of the Clark-Gordon-Schaefer fishery model as proposed by Hommes and Rosser (2001). According to this proposition, the presentation of the optimal equilibrium supply and demand is in terms of a continuous model, whereas the price fluctuations in the corresponding speculative Cobweb dynamics are in discrete time. Characteristics of population or stock of shrimp, harvest h and growth function are identical to the description we have already made in earlier chapters. The intrinsic growth rate of the shrimp population (r), the ecological carrying capacity for the shrimp fishery (K) follow the same definition as in chapter-3 and assume the respected values estimated there. Catchability co-efficient (q) follows Gordon (1954) and reflects the level of technology used, labour employed and amount of capital invested. We accept the capital stock behaviour of Clark's (1990) dynamic models *m* which capital stock has inertia. Thus, the optimum levels of effort, stock and harvests at the infinite discount rate are identical to usual open-access equilibrium or bionomic equilibrium. The cost function is assumed as given in section 3.3.2. The carrying capacity K, the catchability co-efficient q, the marginal cost of effort c_2 and the intrinsic growth rate r being given, the optimal stock expressed explicitly by the equation 4.11 becomes a function of discount rate (6) and price (p). The equation 4.11 then can be written as,

4 pqK r pqK r pqKr

The optimal solution x^*_s is usually referred to as the bioeconomic equilibrium.

At this optimal population level, the corresponding optimal sustained yield is

$$S_6(p) = h = f[x;(p)] \qquad (6.2)$$

where, S_5 (p) is denoted as the discounted equilibrium supply curve.

As the discount rate 5 tends to infinity, then this discounted supply curve reduces to Gordon's (1954) open-access supply curve as shown below:

$$S_8(p) = \frac{\wedge}{pq}\left(l - \frac{\wedge}{pqK}\right) \qquad (6.3)$$

The equation (6.3) shows that for the price $p > \frac{c_2}{qK}$, the discounted supply $S_B(p) > 0$. Thus, the price $p = \frac{c_2}{qK}$ is the minimum below which we assume that the equilibrium supply equals zero.

In Bangladesh trawl shrimp fishery, the values of the parameters are given as (chapter-3), K = 11,400, q = 0.0000977332, r = 1.330818 and c_2 = 1156.76. Substituting these Values in 6.1, we find the discounted equilibrium supply curve at different discount rate δ. These discounted equilibrium supply curves are presented in figure 6.1. It is revealed that, at discount rate $\delta=0$, that is, when far-distant future is considered as equally valuable to to-day, the supply curve of Bangladesh trawl shrimp fishery is upward sloping and approaches the maximum sustainable yield (MSY). But for $\delta > 0$, the supply curve (6.2) appears as backward bending. We observe that the bionomic equilibrium $x^*(p)$ is a decreasing function of the fish price p and the population growth map is non-monotonic. Figure 6.1 shows that, as the discount rate δ increases, the supply curve becomes more backward bending. Thus, the most backwardly bent supply curve must corresponds to the discount rate $\delta = \infty$, which usually means the myopic case. This is what corresponds to the open-access bionomic equilibrium case studied by Gordon (1954) and this is associated with overfishing situation. It is to be noted that the supply curve bends backward at such small values of the discount rate that makes sense with respect to economic explanation, in contrast to the rates that are necessary to generate chaotic dynamics in golden rule neoclassical growth models (Muntrocehio and Sorger (1996), Nishimura and Yano (1996), Mitra (1998).

As we know the fact that a backward-bending supply curve together with a sufficiently inelastic demand curve may lead to multiple steady state equilibria even for a static case, we like to investigate the parameters of the demand curve for which this phenomena is possible in Bangladesh trawl shrimp fishery. For this, we choose a simple demand function in linear form as

$$D(p) = A - B\,p \qquad (6.4)$$

The marginal demand B has been chosen intentionally so small to make multiple equilibria possible. Thus the value of marginal demand B = 0.00053. The constant A has been chosen such that at the minimum price, consumer demand would be exactly equal to the MSY. Hence, the value of A is given by,

$$A = \frac{Kr}{4} + \frac{Bc_2}{qK} \qquad (6.5)$$

and we obtain the numerical value of A=3793.35

This way of parameterizing the demand curve is adopted by researchers for convenience (Hommes and Rosser, 2001: 287). This is convenient to define well the price dynamics under adaptive learning and to remain bounded for all time. Linear demand curve with the given value of the parameters A and B thus plotted in figure 6.1 to investigate the existence of multiple equilibria. There are two extreme cases, when 5 = 0 and when 8 = ». Figure 6.1 shows that, at 5 = 0, there is a unique steady state equilibrium point. This point is (20,000, 3782.78). But at other extreme case at S = », because of backward bending, there would be three different steady state equilibrium points. In between these two extreme cases, naturally there would be a situation where a tangent bifurcation would create two equilibrium steady state points. We find that this 'two-steady-states' situation is created through a tangent bifurcation at 8=8*=0.12. In Bangladesh trawl shrimp fishery, therefore, at discount rate 8 greater than 0.12, there are three different equilibrium points. For example, in Figure 6.1, we indicate such three equilibrium points by mi, m_2 and m_3 for the discount rate 8=0.15>5*.

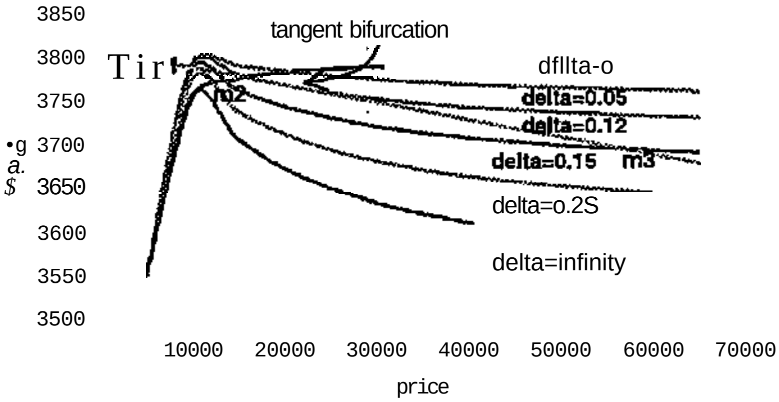


Figure 6.1: Demand and Discounted Equilibrium Supply Curves Ss in 6.2 under naive expectations for Different Discount Rates.

This finding verifies the original argument of Copes (1970) that in the case of strongly backward-bending supply curve, multiple equilibria are possible. But under this condition, increasing demand could lead to a collapse of a fishery and a jump in the equilibrium. This is what is called catastrophic discontinuities. The collapse of the Antarctic fin whales was tried to explain by the application of such catastrophe theory. The possibility of existing such a situation in Bangladesh trawl shrimp fishery exists provided discount factor 8>0.12 and the slope of the demand curve B = 0.00053. In the next section, we would try to investigate price dynamics under adaptive learning.

6.3.1. Price Dynamics of Bangladesh Trawl Shrimp under Adaptive Learning:

In the previous section, we have shown the equilibrium supply of Bangladesh marine shrimp when it is managed optimally. We can now consider price fluctuations under adaptive learning process. It has been shown theoretically by Hommes and Rosser (2001) that, in some fisheries, the naive forecasts can be improved in a linear, statistical sense, even when price fluctuations are chaotic.

Our objective is to investigate whether, under naive expectations, price fluctuations can be described by Cobweb type price dynamics and naive forecasts can be improved in the same way in case of Bangladesh trawl shrimp fishery. Following this, we will try to investigate CEE, as introduced by Hommes and Sorger (1998), in our proposed optimal control marine shrimp fishery model'of Bangladesh.

Cobweb Dynamics under Naive Expectations in Trawl Shrimp of Bangladesh: *in* order to study the price fluctuations in this marine shrimp fishery, we assume the following:

(i)Decision regarding investment for fishing equipment has been made by. the producers some fixed time period ahead of harvesting.

(ii)The optimal production decision is derived from the discounted equilibrium supply curve (6.2) when producers' price expectation is given.

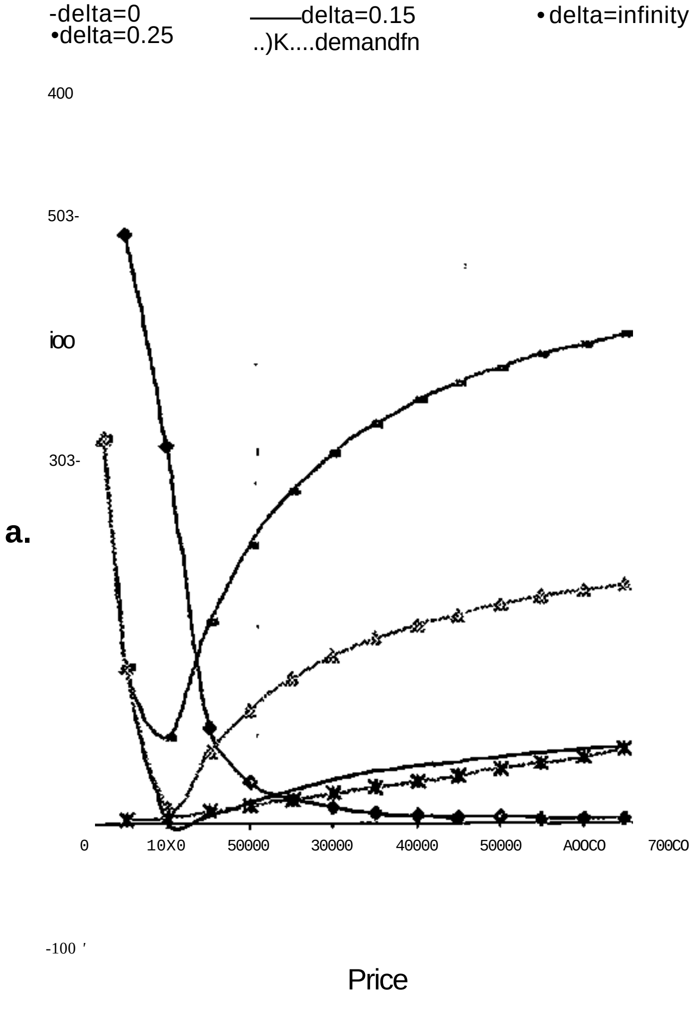


Figure 6.2: Implied Law of Motion under Naive Expectation Gs in 6.6 under naive expectations for Different Discount Rates.

(iii)Investment lag is one fixed time period, ahead of which price expectations are formed.

(iv)Adjustment period of fish stocks is one year (production lag).

Given the consumer demand function (6.4) and the discounted supply curve (6.2), the market equilibrium price at time 't' is determined by demand and supply. Thus we get,

$$D(p,) = S_s(P,^{e})$$

Under naive expectations hypothesis, producers believe that expected current price will be last year's price and thus $P_t^e = P_{t-1}$.

Hence, the implied actual law of motion becomes,

$$P, = G_8\ (p_{..,}) = D^{''J}\ S_s\ (p_{..,}) = \frac{A \sim S \wedge (p' - i)}{B} \qquad (6.6)$$

Graphs of the implied actual law of motion G_5 under naive price expectation, for different values of the discount rate, are shown in Figure 6.2.

It is to be noted that we observe a critical parameter value S*=0.12 for Bangladesh trawl shrimp fishery. This is the critical value of the discount rate 8 for which tangent bifurcation occurs. At this point, number of steady states changes from one to two steady states. Thus for 8 < 0.12, there is only one steady state and for 8 >0.12, there are three steady states. But at bifurcation value, there are two steady states. Hence, for discount rate 0< 8< 8*, the unique steady state $p_t = p^*$, for all 't', is the only rational expectation equilibrium (REE). But for discount rates 8 > 8*. as three steady states co-exist, there are multiple stationary REE.

To know whether economic agents, who are boundedly rational and do not have exact knowledge about underlying market equilibrium equations, would be able to discover regularities in their forecasting errors under naive expectations and change expectations accordingly, we find chaotic price series under naive expectations and corresponding chaotic forecasting errors for different values of discount rates (8 = 0.02, 8 = 0.10, 8 = 0.15), and are shown in Figure 6.3 to 6.8. Sample autocorrelations and partial autocorrelations of forecasting errors under naive expectations are presented in Table 6.1 to 6.3 for three different discount rates, two of which are less than 8* and other one is greater than 8*. Tables show that, for each of the discount rate, the chaotic forecasting errors have a strongly significant first-order autocorrelation co-efficient p > 0.4. Thus, it can be said that any boundedly rational agent would be able to conclude by using standard linear statistical tools that naive expectations are 'systematically wrong', even when prices fluctuate chaotically. It is, therefore, expected that economic agent in Bangladesh trawl shrimp fishery may try to improve effectively his/her forecasting accuracy and thereby, try to optimize the forecasting parameters by adaptive learning as additional observations become available.

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Figure 6.3: Chaotic Prices Under Naive Expectations for 5=0.02

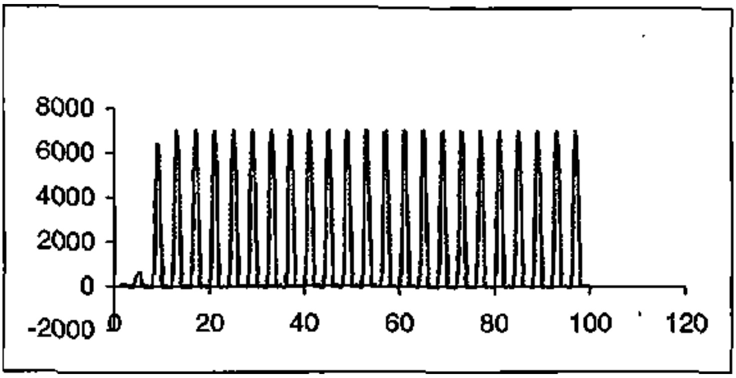

Figure 6.4: Chaotic Prices Under Naive Expectations for 5=0.10

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* - c o i n c \ i a > (D » o | v . ^ j - , - c o i r > (N C »

Figure 6.5: Chaotic Prices Under Naive Expectations for 5=0.15

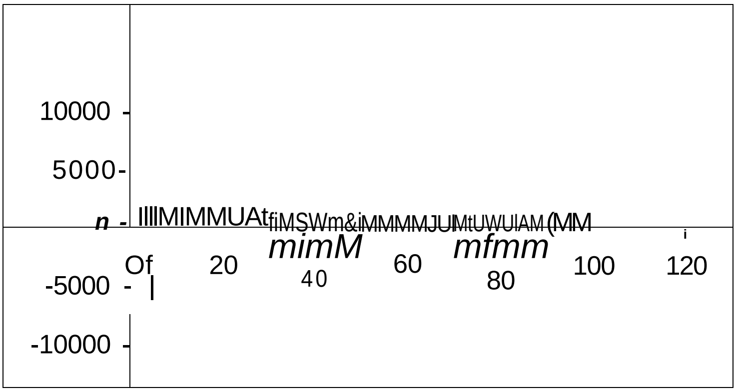

Figure 6.6: Chaotic Forecasting Errors Corresponding to Figure-6.3 Under Naive Expectations for 5=0.02

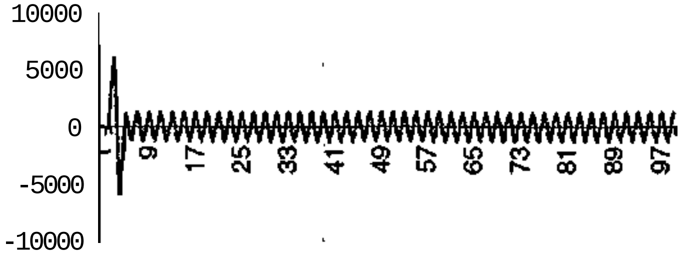

Figure 6.7: Chaotic Forecasting Errors Corresponding to Figure-6.4 Under Naive Expectations for 5=0.10

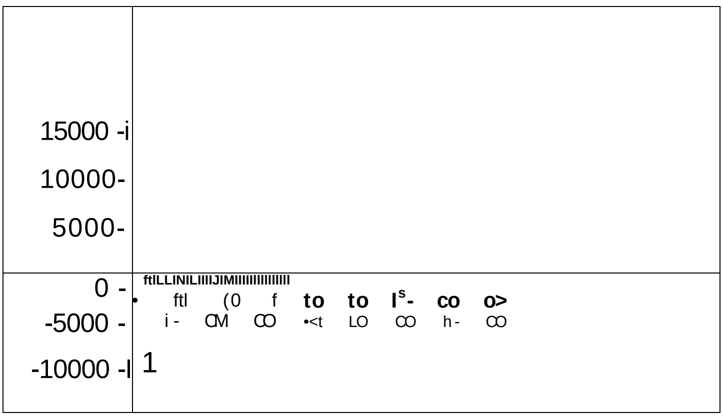

Figure 6.8: Chaotic Forecasting Errors Corresponding to Figure-6.5 Under Naive Expectations for 6=0.15

Table 6.1
Autocorrelations, Partial Autocorrelations and Box-Lung-statistics of Forecasting Error under Naive Expectations for 5=0.02

Lag .	AC	PC	Box-Lunge-Stat.	Prob.
1	-0.861	-0.861	75.761	0.000
2	0.722	-0.076	129.415	0.000
3	-0.717	-0.441	182.941	0.000
4	0.712	-0.028	236.353	0.000
5	-0.705	-0.267	289.176	0.000
6	0.697	-0.014	341.406	0.000
7	-0.690	-0.178	393.151	0.000
8	0.683	-0.009	444.409	• 0.000
9	-0.676	-0.122	495.170	0.000
10	0.669	-0.007	'545.429	0.000

Table 6. 2
Autocorrelations, Partial Autocorrelations and Box-Lung-statistics of Forecasting Error under Naive Expectations at for 6=0.10

Lag'	AC	PC	Box-Lunge-Stat.	Prob.
1	-0.499	-0.449	25.433	0.000
2	-0.001	-0.334	25.433	0.000
3	-0.481	-0.972	•49.491	*0.000*
4	0.963	-0.001	147.050	0.000
5	-0.481	-0.003	171.636	. 0.000
6	-0.001	-0.004	171.637	0.000
7	-0.459	0.100	194.510	*0.000*
8	0.919	-0.007	•287.352	0.000
9 .	-0.459	-0.006	310.765	0.000
10	-0.001	-0.004	310.766	0.000

Table 6.3
Autocorrelations, Partial Autocorrelations and Box-Lung-statistics of Forecasting Error under Naive Expectations for 8=0.15

Lag	AC	PC	Box,-Lunge-Stat.	Prob.
1	-0.493	-0.493	24.597	*0.000*
2	0.000	-0.322	, 24.597	0.000
3	-0.004	-0.241	24.599	0.000
4	-0.001	-0.192	24.599	0.000
5	0.000	-0.159	24.599	*0.000*
6	0.000	-0.136	24.599	0.000
7	0.000	-0.118	, 24.599	0.001
8	0.000	-0.104	24.599	0.002
9	0.000	-0.092	24.599	0.003
10	0.000	-0.083	24.599	• 0.006

6.3.2. Consistent Expectation Equilibrium :

Hommes and Sorger (1998) defines CEE as under:

A triple {(p_t)^1_0; a, B), where (pj^o *^s a sequence of prices and a and B are real numbers, pe [-1,1], is called a consistent expectations equilibrium if

- (i) the sequence $(p_t)^{\infty}_0$ satisfies the implied actual law of motion (6.10);
- (ii) the sample average price p exists and is equal to a; and
- (iii) the sample autocorrelation co-efficients pj, J21, exists and the following is true:
  - (a) if $(P_t)^{\infty}_0$ is a convergent sequence, then sgn (pj) = sgn (B^1), j >: 1;
  - (b) if $(p_t)^{\infty}_0$ is not convergent, then pj = p', j > 1.

A CEE is a price sequence together with an AR(1) belief process such that the expectations are self-fulfilling in terms of the observable sample average and sample autocorrelations. Along a CEE, expectations are thus correct in a linear statistical sense and, using time-series observations only agents would have no reason to deviate from their belief.

Given an AR(1) belief, there are at least three possible types of CEE: (i) a steady state CEE in which the price sequence $(p_t)^{\infty}_0$ converges to a steady state price p*; (ii) a two-cycle CEE in which the price sequence $(p_t)^{\infty}_0$ converges to a period two cycle {p^Pj} with p* ^Pj; and (iii) a chaotic CEE in which the price sequence $(p_t)^{\infty}_{=0}$ is chaotic.

If the economic agent is not naive and has a definite AR(1) belief process described by the parameters, say, a and p, then those parameters may be obtained as under:

Agents are normally supposed to stick to their belief over the entire time horizon. Moreover, it is necessary that the entire price sequence is to be known in order to verify the consistency of the implied actual dynamics. However, if we consider the adaptive learning situation as a slightly flexible one and assume, that agents change their forecasting function over time within the class of AR(1) beliefs and update their belief parameters α_t and p_{ti} as additional observations become available, then a natural learning scheme that fits the framework of CEE is based upon sample average and sample autocorrelation.

Let us assume that economic agents do not know market equilibrium equations and form expectations based on time series data. Agents know all past prices {p_0, pt, ..., pt) and use these prices in their forecasting (P_t^e). They assume that prices are generated by a stochastic AR (1) process and follow a simple linear stochastic process. Let us assume thai expectations are homogeneous. Thus the expected price is given by

$$(P^c_{t+1}) = a_t + p_l(p_t - o_t) \qquad (6.7)$$

where, at is the unconditional mean of the AR (1) process and p_t is the first order autocorrelation co-efficient.

For any finite set of observations {p_0, pi,..., pt) the sample average is given by

t + l i = n

and the 1st order sample autocorrelation co-efficient is given by

i-\

$$0,=\wedge—,\text{————}\bullet\text{——————}t>1. \qquad (6.9)$$

(=0

Thus p_t is a real number and B, E [-1,1].

When in each period the belief parameters are updated according to their sample average and their 1st order sample autocorrelation, the law of motion becomes,

$$Pi_{+}i = G_{Ui|li}(pJ = G(ii_t + p_1(p_t - a_t)), \qquad t > 0 \qquad (6.10)'$$

This dynamical system (6.8) to (6.10) is known as the *actual dynamics with sample auto-correlation learning* (SAC learning). The initial state for the system can be any triple (p_{0l} cio, Po) with poe [-1,1].

Theoretically, three typical observed outcomes are expected by Hommes and Sorger (1998) in simulations of the adaptive SAC-learning process:

(i) Convergence to the 'good' steady state equilibrium

(ii) Convergence to the 'bad' steady state equilibrium

(hi) Convergence to the chaotic CEE.

Chaotic CEE occurs when parameters a_t and P_t converge to a constants a* and p* while prices never converge to a steady state (or to a cycle), but keep fluctuating chaotically. This phenomenon is referred to as learning to believe in chaos. Learning to believe in chaos means that the SAC learning dynamics converges to a chaotic system, when a, and p, have converged to constants a* and p*, while prices keep fluctuating chaotically. For Bangladesh trawl shrimp fishery, we simulate the dynamic system (6.8) to (6.10) as adaptive SAC-learning process. We obtain a and p from (6.8) and (6.10) for the given trawl shrimp price of 17 years. Setting the average price as p_0 and values of a and p obtained above as a„, p_0 respectively, we find the initial triple (p_0, a_0, Po) for simulation. Simulated values of a,, and p, are shown in Figures 6.9 and 6.10. Fluctuations in prices are shown in Figure 6.11. It is observed that price initially, upto approximately 25th time period, fluctuates chaotically and then settles down to a stable steady state. The stable steady state price p*D9017.24 is at 63rd period. Figure 6.9 and 6.10 shows the parameters (a_t, p,) converging to (a*, p*) = (9017.24, 0.856638). It depicts permanent chaotic price fluctuations with, sample average a* and strongly positive first order autocorrelation co-efficient p*.

Table 6.4 shows the first 10 lags of the sample autocorrelation and partial autocorrelation of 100 observations of the chaotic price series under SAC learning. The first order partial autocorrelation co-efficient is strongly positive. Table 6.5 contains the estimation results of AR (1) model to the chaotic price series of 100 observations implying estimated belief parameters p, =0.856638 and a, = C/(1- p_t) = 9192.415. The forecasting errors are shown in Figure 6.12. •

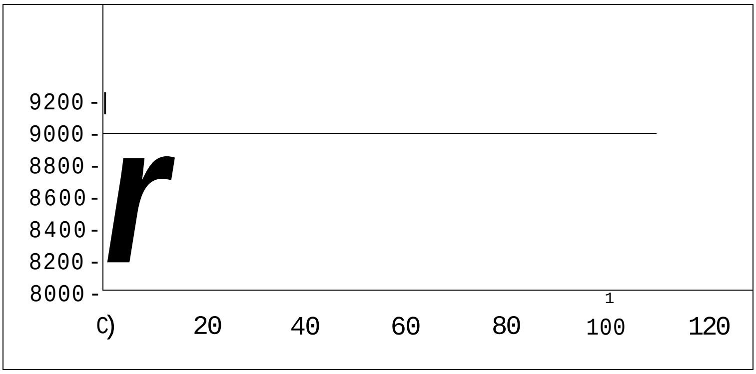

Figure 6.9: Belief Parameters a in SAC learning process converges to constant a*=9017.24

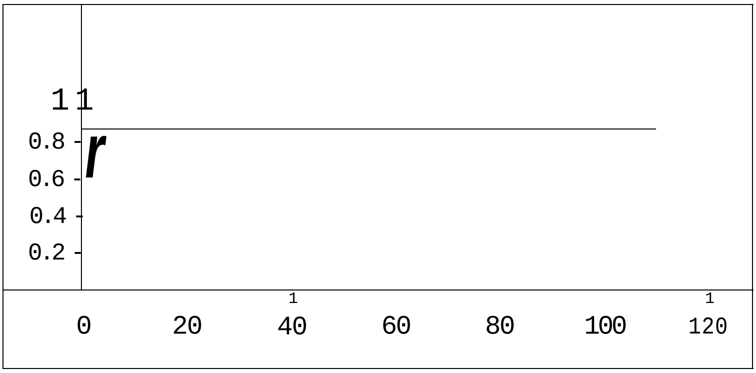

Figure 6.10: Belief Parameters p in SAC learning process converges to constant p''=0.856638

Table 6.4

Autocorrelations, Partial Autocorrelations and Box-Ljung-statistics of Prices of CEE under SAC Learning

Lag	AC	PC	Box-Ljung-Stat.	Prob.
1	0.857	0.857	74.873	0.000
2	0.742	0.032	131.669	0.000
3	0.610	-0.122	170.468	0.000
4	0.449	-0.206	191.673	0.000
5	0.308	-0.050	201.793	. 0.000
6	0.166	-0.091 .	204.748	0.000
7	0.074	0.088	205.340	0.000
8	-0.008	-0.026	205.347	0.000
9	-0.081	-0.066	206.077	0.000
10	-0.167	-0.192	209.213	0.000

Table 6.6 contains the first 10 lags of the sample autocorrelation, together with their Box-Ljung-statistics of the residuals of the fitted AR(1) model. The autocorrelation co-efficients of the residuals *of* the fitted AR (1) model are *not* statistically significant and the Box-Lunge-statistics indicate that the null hypothesis that prices follow a stochastic AR (1) process can not be rejected.

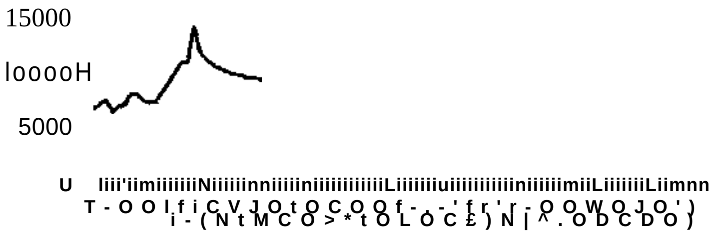

Figure 6.11: Chaotic Prices in SAC Learning Process Shows Gradual Movement Towards Stability

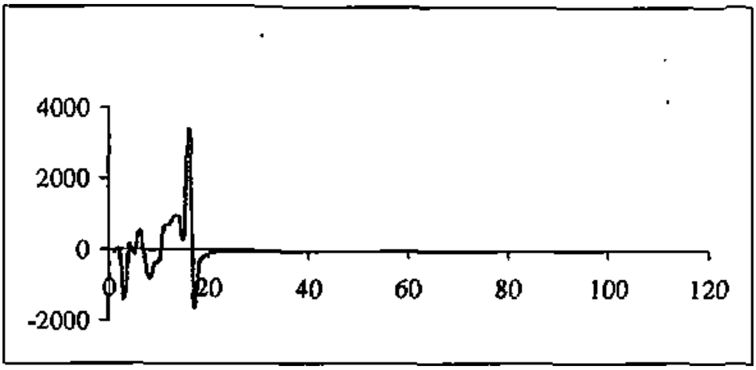

Figure 6.12:Forecasting Errors in SAC Learning Process Shows Chaotic Behaviour at Initial Phase

Table 6.5

Estimation Results for AR (1) Model on Chaotic CEE

Model $p_t = C + P\, p_{t-1}$. (C = a (1- p))			
Variable	Co-efficient	Std. Error	t'Statistic
C	1317.843	414.1436	3.182092
p	0.856638	0.045652	18.76441
R -squared	0.784014		
Adjusted R squared	0.781787		
S.E of regression	450.8387		
Durbin-Watson stat	2.08987		

Table 6.6

Autocorrelations, Partial Autocorrelations and Box-Ljung-statistics of Residuals of Fitted AR (1) Model on CEE under SAC Learning

Lag	AC	PC	Box-Ljung-stat.	Prob.
1	-0.045	-0.045	0.207	0.649
2	0.151	0.149	2.559	0.278
3	0.010	0.023	2.570	0.463
4	-0.029	-0.052	2.660	0.616
5	0.025	0.017	2.727	0.742
6	-0.132	-0.121	4.589	0.598
7	-0.056	-0.074	4.926	0.669
8	-0.138	-0.112	7.009	0.536
9	-0.008	0.005	7.016	0.635
10	0.049	0.084	7.289	0.698

Hence, based on this linear statistical analysis, a careful boundedly rational economic agent would not reject the null hypothesis that prices follow an AR (1) process. Thus the economic agents/planners will be able to successfully follow an underlying dynamics in Bangladesh trawl shrimp fishery. Thus the possibility of jumping to unstable steady state equilibrium and occurrence of catastrophic discontinuities may be ruled out if economic agents involved in Bangladesh trawl shrimp fishery behave rationally and try to understand the true dynamics of shrimp stock.

6.5 Concluding Remarks:

The supply curve of Bangladesh marine shrimp fishery is found backward bending with non-zero discount rate. The extent of bending increases with the increasing value of discount rate. As it is known that backward bending supply curve may cause multiple equilibria and the shifting of demand may result in sudden jump to a new equilibrium position, there exists a possibility of catastrophic discontinuities. Thus, the chaotic dynamics and catastrophic discontinuities of Bangladesh trawl shrimp fishery have been studied under consistent expectations equilibrium (CEE) paradigm. Rational expectations hypothesis (REH) being found extremely stringent for the reason of underlying implicit requirement of perfectly complete information set, the consistent expectations equilibrium (CEE) is considered as more plausible through self-fulfilling mistake under adaptive learning process. The study finds the following:

(i) A linear demand curve being fixed with the intercept where price is minimum and supply equals to MSY, the appropriate slope of the curve, for which the demand curve is a tangent bifurcation of the backward bending supply curve, is determined.

(ii) The study finds that the critical values of the discount rate (5*) is appropriately equals to 12 percent. The dynamic system of Bangladesh marine shrimp fishery has a unique equilibrium point when 5 < 6* and has multiple equilibria when 5 > 6*.

(iii)Dynamics of the system under the process of expectations forming with naive assumption regarding price of economic agents show that the agents be able to learn that their expectations are 'systematically wrong'. Thus adaptive learning process even under naive expectations hypothesis proves that agents can improve their forecasting gradually by incorporating additional observations.

(iv)The mode! of the dynamic system for Bangladesh trawl shrimp fishery shows that the system converges to a ,'good' CEE with all parameters (p, a, p) converging to constant steady state value. Price initially fluctuates chaotically and then settles to a stable state. Thus the fluctuations of the parameters of Bangladesh trawl shrimp fishery, like, stocks, harvests and efforts are deterministically chaotic. If the economic agents follow SAC-[earning process with AR(1) belief described by the parameters a and p, the system converges to 'good' CEE. Values of the belief parameters a and p are found to be steady with highly positive autocorrelation. Autocorrelations of residuals of fitted AR(1) model on CEE under SAC-learning are found insignificant.

Chapter 7

Conclusion

7.1 The absence of optimum decision-making process in natural resource management is a major concern of government, policy makers, non-government agencies of conservationists of nature, managers and economists. The reason behind this great concern is due to the fact that extravagant exploitation of natural resources may prove to be disastrous both for economy and ecology. Bangladesh is not only an underdeveloped country of small in geographical size but also with less natural resources and population burden. Efficiency in management of natural resources imply that the appropriate application of managerial techniques which are dealt with in the subject called''Operations Research' (OR) is an imperative. In this respect, Bangladesh, like any other under-developed country, has become a technological and psychological laggard leading to wasteful utilization of resources. With a view to long-run sustainability, the study of current practices of resource management is needed to find out the problems and scope of improving managerial efficiency in each and every sector of natural resource. It has already been proved by many recent studies that through improved managerial efficiency by applying OR-techniques, the social benefit can be enhanced in short-run and can be optimized for conservation and sustainability in the long-run. The present thesis is a humble attempt to study the existing management practices in commercially exploited marine shrimp fishery of Bangladesh with a view to identifying the scope and problems of applicability of such OR-techniques. The marine fish being a biological species having regeneration capacity involves population dynamics. This dynamics is complex as uncertainties are present in unpredictive character of ecological and economic factors. This thesis, therefore, humbly attempts to provide a suitable dynamic model which could offer a feedback rule for optimal management of this renewable resource.

Chapter 2 provides a brief description of fishery resources in Bangladesh. However, as our objective is to study optimal utilization of marine shrimp, a separate section deals exclusively with different aspects of marine shrimp.' This section contains topological description of harvesting zone, details of trawlers along with the discussion on biological description of shrimp family. The information and data provided in this chapter reveal that Bangladesh is not very rich in natural resources of non-renewable nature but has a great potential in utilizing renewable resources fruitfully and effectively. Movement of number of trawlers over time shows that the industry suffered from a crowding problem a few years after initiation of commercial harvesting of shrimp and possibly reached an open-access equilibrium point. The regulation thereafter has brought back the industry to an economically viable equilibrium point at present.

Formulation of dynamic optimization model of any marine resource requires time series data of effort and harvest level along with a set of bioeconomic parameters, namely, carrying capacity <K), intrinsic growth rate (r), catchability co-efficient (q), parameters of demand and cost function. But the top of the requirement is time series data of estimated biomass stock (x). While the first two time series data are available, the occasional survey estimates of biomass stock are available instead of time series. In chapter 3, we have attempted to estimate said bioeconomic parameters. On the basis of trawlers' specification

and marine characteristics, the estimation of biomass stock of marine shrimp in the exclusive harvesting zone of Bangladesh in Bay of Bengal for the period 1981-82 to 1997-98 has also been made by applying Pauiy's method. On the basis of the annual biomass stock, the expected level of harvest has been predicted for the given actual effort level. The analysis of the result shows that the calculated level of harvest differs insignificantly from the actual level of harvest and thus confirms the validity of the biomass estimation. The result also shows that the estimated biomass stocks predominantly lie within the lower and upper limit given by one of the surveys made by Penn.

In chapter 4, we have formulated a non-linear dynamic model of Bangladesh trawl shrimp fishery for optimal control with discrete-time. The model is such that it maximizes present value of net benefit subject to harvest and growth constraints. The solution of the model provides optimal (steady state) level of biomass stock, harvest level, effort level and shadow price. The comparative study of actual and optimal harvest, stock and effort given by approach paths for non-linear exponential demand condition reveal that marine fishery is not managed and utilized optimally at present in Bangladesh for both under static, and dynamic situations. The country thus bears loss due to non-optimal allocation of marine shrimp resource. The chapter provides annual loss in each year and approximate cumulative loss of the whole period. Both type of losses are appeared to be substantial in amount..However, the analysis shows that the steady state may be attained by the system very quickly. It seems that marine shrimp fishing of Bangladesh would probably take less time and cost to recover if corrective measures are taken. Both the actual level of harvest and biomass stock being much less than the optimal value, the study also indicates that the danger of gradual depletion of the resource leading to extinction cannot be ruled out.

A study on application of non-linear dynamic optimization (continuous-time) has been taken up in chapter-5 for optimal control of the resource and in order to have an optimal feedback rule for management of Bangladesh trawl shrimp fishery. A non-linear dynamic optimization model has been formulated, which integrates the discounted net revenue with infinite time horizon. Stock is assumed to be converging to steady state biomass level as time tends to infinity. The functional is optimized subject to the constraints of harvest, growth and time derivative of biomass. The current value Hamiltonian is obtained and the solution of the optimal control problem provides a highly non-linear ordinary differential equation, which is then solved by applying Sandal and Steinshamn procedure with zero and non-zero discounting factor. Algorithms for both zero and non-zero discount rate have been provided in this chapter. The study gives optimal values of harvest, biomass stock, effort level and shadow price. It is observed that the difference between the optimality under continuous and discontinuous time is insignificant. The study gives the optimal control path which enables to provide minimum viable level of the resource. Analysis of the result shows that the optimal control path does not vary significantly with the social discount rate and thereby substantiates the theoretical findings of Farzin (1984), Hannesson (1983/1987) and Sandal and Steinshamn (1997). The calculated value of minimum viable level for non-linear demand situation appears to be consistent with the expected theoretical value. The value of minimum viable level seems to be a possible danger of extinction if the present practice of harvesting is continued though the estimated biomass level at present may not considered to be indicative of very close to our calculated minimum viable level. Like discontinuous case, the notional loss has been calculated for a particular year. The chapter provides the feedback rule which represents control variable as a function of state variable. A schema under the context of Bangladesh has been provided for implementing such rule.

In the next chapter of the thesis, the chaotic dynamics and catastrophic discontinuities of Bangladesh trawl shrimp fishery have been studied under consistent expectations equilibrium (CEE) paradigm, as we have found that the supply curve is backward bending with non-zero discount rate. As it is known that backward bending supply curve may cause multiple equilibria and the shifting of demand may result in sudden jump to a new equilibrium position, there exists a possibility of catastrophic discontinuities. Rational expectations hypothesis (REH) being found extremely stringent for the reason of underlying implicit requirement of perfectly complete information set, the consistent expectations equilibrium (CEE) is considered as more plausible through self-fulfilling mistake under adaptive learning process. The study shows that Bangladesh trawl shrimp fishery is deterministically chaotic and converges to the 'good' steady state CEE inspite of the fact that at non-zero discount rate demand curve exhibits tangent bifurcation. Simulation of the SAC learning dynamics under AR (1) belief process suggests that convergence to this 'good' equilibrium steady state is the outcome of the SAC learning process. The belief parameters are determined and shown. Simulated results show that all the parameters of the triple {p*,a*,p*) of CEE converge to a stable steady state and a 'good' CEE is deterministically possible subject to rational adaptive learning behaviour of economic agents involved in marine shrimp exploitation in Bangladesh.

7.2 Scope of Further Studies:

In Chapter-2, we discussed the present scenario of shrimp fishery in Bangladesh (section 2.2). Life cycle patterns of Penaeid Shrimp and practice of harvesting by different types of nets at various stages in Bangladesh are also discussed. We observed that a substantial portion of artisanal catch is at juvenile stage (Table-2.3). Moreover, the discussion shows that no records on how much shrimp is harvested at pre-juvenile stage are available. It, therefore, indicates that trawl shrimp fishery is affected by the artisanal fishery. The result could have been much more meaningful and significant had the artisanal fishery been incorporated in our study. Since, no systematic and official records or data on this aspect are available, an extensive survey is required for this purpose. Further studies in this direction could be undertaken.

Our attempt to estimate the actual demand function indicates that price is possibly exogenously determined. A study could be undertaken to study the non-linear dynamics of marine fishery considering price as an exogenously determined factor. A separate study could be undertaken to estimate the loss due to non-optimal harvesting of resources, as we have already mentioned in sections 4.3 and 5.5, incorporating adverse effects on ecology and environment.

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Appendix -A

Table Shows Some Applications of Operations Research and Benefit Derived

Organisation	Nature of Application	Year of Publication	Annual Savings
The Netherlands Rijkswaterstatt	Develop national water management policy, including mix of new facilities, operating procedures, and pricing	1985	$15 million
Monsanto Corp.	Optimise production operations in chemical plants to meet production targets with minimum cost.	1985	$2 million
Weyerhauser Co.	Optimise how trees are cut into wood products to maximise their yield.	1986	$15 million
Eiectrobras / CEPAL, Brazil	Optimally allocate hydro and thermal resources in the national electrical generating system.	1986	$43 million
United Airlines	Schedule shift work at reservation offices and airports to meet customer needs with minimum cost.	1986	$6 million
Citago Petroleum Corp.	Optimise refinery operations and the supply, distribution , and marketing of products.	1987	$70 million
SANTOS, Ltd. Australia.	Optimise capital investments for producing natural gas over a 25-year period.'	1987	$3 million
San Francisco Police Dept.	Optimally schedule and deploy police patrol officers with a computerized system.	1989	$11 million
Electric Power Research Institute.	Manage oil and coal inventories for electric utilities to balance inventory costs and risk of shortages.	1989	$59 million
Texaco,Inc.	Optimally blend available ingredients into gasoline products to meet quality and sales requirements.	1989	$30 million
IBM	Integrate a national network of spare-parts inventories to improve service support.	1990	$20 million +$250 million less inventory
Yellow Freight System, Inc.	Optimise the design of a national trucking network and the routing of shipments.	1992	$17.3 million
U.S. Military Aircraft Command	Quickly coordinate aircraft, crews, cargo, and passengers to run the Operation Desert Storm aircraft.	1992	Victory
Americans Airlines.	Design a system of fare structures, overbooking, and coordinating flights to increase revenues.	1992	$500 million more revenue
New Haven Health Dept.	Design an effective needle exchange program to combat the spread of HIV/AIDS.	1993	33% less HIV/ AIDS.

Source: (Hillier & Lieberman, 1995: 4)