The United Nations University
FISHERIES TRAINING PROGRAMME
P.O. Box 1390, Skulagata 4
120 Reykjavik, Iceland

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THE POTENTIAL OF THE ARTISANAL HILSA FISHERY IN BANGLADESH: AN ECONOMICALLY EFFICIENT FISHERIES POLICY

Masud Ara Mome
Evaluation Officer
Department of Fisheries
Matshya Bhaban, Ramna, Dhaka-1000
Bangladesh
masudara_momi@yahoo.co.uk

Supervisor
Professor Ragnar Arnason
Department of Economics, University of Iceland
ragnara@hi.is

ABSTRACT

The hilsa shad (*Tenualosa ilisha)* fishery is by far the largest single species fishery in Bangladesh. In this paper, a simple bio-economic year-class based model is developed to describe the fishery and examine its properties. With the help of this model, the optimum sustainable yield of the fishery is calculated and compared to the existing situation. In addition, the model is used to locate a socially and economically reasonable dynamic path from the current situation to the optimal one. The results indicate that the fishing effort (measured in standardised boat units) required to make the hilsa fishery attain sustainable maximum economic benefits is about one-third of the current fishing effort. At this sustainable fishing effort level, annual net economic benefits from the fishery would be worth about US $260 million according to my calculations compared to virtually nothing today. The present value of the fishery along a moderate effort adjustment path to this long-term equilibrium position is US $3,650 million at a 6% rate of discount. The dynamic path that maximises the present value of the fishery involves quite dramatic effort reductions for the first two years. Such a path would increase the present value of the fishery by perhaps 10-15%.

LIST OF ABRRIBIATIONS

ARDMCS	:	Aquatic Resources Development, Management and Conservation Studies
BFRI	:	Bangladesh Fisheries Research Institute
BBS	:	Bangladesh Bureau of Statistics
CPUE	:	Catch Per Unit Effort
DoF	:	Department of Fisheries, Bangladesh
EEZ	:	Exclusive Economic Zone
FRSS	:	Fisheries Resources Survey System
FIQC	:	Fish Inspection and Quality Control
FFP	:	Fourth Fisheries Project
GDP	:	Gross Domestic Product
GEF	:	Global Environmental Facility
HP	:	Horse Power
MSY	:	Maximum Sustainable Yield
MT	:	Metric ton
MB	:	Mechanised Boat
NMB	:	Non-Mechanised Boat
NFP	:	National Fisheries Policy
NFS	:	National Fisheries Strategy
OSY	:	Optimum Sustainable Yield
PV		Present Value

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1 INTRODUCTION

Bangladesh has established a credible record of sustained growth within a stable macroeconomic framework. The country has made substantial progress in the fight against poverty, and the devastating impact of frequent cyclones and floods. The huge population of the country is now becoming a strength full resource.

Bangladesh is criss-crossed by hundreds of rivers and blessed by rich marine and fresh water resources. Fisheries play quite an important role in Bangladesh society in terms of protein supply, generation of employment and earning of foreign currency.

The country's most important aquatic resource is the ilish, or the hilsa shad. It is the largest and single most valuable fishery in Bangladesh. In the year 2005-06, about 11% of the country's total fish production came from hilsa. Average hilsa production is about 215 thousand mt which is valued at about US $380 million. Hilsa contributes 1.0% to the GDP (DoF 2006). Until 1972 the hilsa fishery was restricted to the upstream rivers, mainly the rivers Padma, Meghna, Karatoya, Rupsa, Shibsa and Payra. Since 1972, the fishery has severely declined in the upstream areas and is now mainly in downstream rivers, estuaries, coastal areas and the sea. Low water discharge from the river Ganga at the Farraka barrage (which is a dam located 10 km from the Indian side of the border between India and Bangladesh) and associated heavy siltation, indiscriminate exploitation of juveniles (jatka), disruption of their migration routes, loss of spawning, feeding and nursery grounds and increased fishing pressure have all contributed to a decline in the catch per unit effort in both the marine and river hilsa fishery. The radical decrease of catches of both mechanised and non-mechanised boats indicates the excess of fishing effort, which could lead to over-exploitation and vulnerability of the fishery. The declining trend of catch per unit effort of hilsa fishing is threatening the livelihoods of about 464 thousand hilsa fishermen. Fish stocks are renewable and a pragmatic approach is essential to maximise the sustainable benefits they can generate. It must be ensured that the resources are protected from irreversible damage and managed on a sustainable basis. The existing situation of the hilsa fishery suggests that proper assessment is necessary and finding a way to stimulate the recovery the fishery and make it sustainable while maximising economic benefits.

The hilsa fishery of Bangladesh is characterised by the usual common property conditions where the available resources are exploited by a large number of fishermen. As expected the number of fishermen and fishing effort increased so long as the fish catches and market prices were sufficiently high. In certain upstream areas this process has ended and even reversed itself because of lack of fish. The social implications are severe. Hilsa fishing intensity has been increasing in downstream areas and especially the inshore waters where sufficient concentrations of hilsa are now found. Sufficient limitations and controls on fishing vessels and fishing effort have not been put in place to counter this. However, a study in 2004 pointed out that over time high level of fishing effort would seriously reduce the fish stock and consequently the rate of catch per unit of effort in both river and marine hilsa fisheries (Halder 2004b)

In Bangladesh both the marine and river hilsa fisheries are important. Unfortunately, due to the unavailability of reliable data for the river fishery, it was not possible to include both sectors in the study. Therefore, this study is restricted to the marine hilsa fishery in Bangladesh. Presumably, however, because of the upstream spawning migrations of the hilsa, what is good for the marine fishery is also good for the river fishery.

The marine hilsa fishery is an artisanal type of fishery. Socio-economic conditions of the coastal fishermen communities are characterised by lack of alternative sources of subsistence. The sector is further characterised by open access with crowding of effort in the coastal waters. This crowding is often attributed to the absence of technical skills and capital on the fishermen side to go beyond the inshore water to exploit other resources. This is a problem that shows lack of enforcement of existing management measures and lack of appropriate policies against over-fishing. Therefore, it is most timely to examine as far as possible whether the fisheries can be sustained at the current level of exploitation and whether society could gain from a change in current fishing effort.

In spite of the importance of the hilsa fishery, up-to-date studies are not available and there are practically no studies of the economics of the fishery. To maintain and enhance the hilsa stock many biologically based management controls have been implemented. However, as we have seen, these measures have not been entirely successful in preventing decline in the stock. More importantly, these measures are not capable of maintaining or generating the flow of net economic benefits from utilising the stock or even informing the managers of the socially and economically optimal fishing effort levels.

The knowledge which would be obtained through the application of a bio-economic model to the hilsa fishery could be utilised in future projects for conservation and management of the fishery and socio-economic development of hilsa fishers' communities. The model development skill through this project will be used to conduct other fisheries studies in the country.

The aim of this study is to develop a bio-economic model of the hilsa fishery which can be used as a first step towards improved management of this fishery. More precisely, the objectives of the present study are:

- To calculate the optimal sustainable yield for the hilsa fishery in Bangladesh.
- To compare the current situation with the optimal fishery.
- To find an economically and socially reasonable path from the current level of fishing effort to the optimal sustainable yield level.

To attain these objectives a simple bio-economical model has developed. On the basis of this model, the optimal sustainable yield will be calculated and compared to the existing situation. In addition, the model will be used to locate a socially and economically reasonable path from the current situation to the optimal one. Measures of the social gains from doing this will be calculated.

This study will provide baseline information concerning the bio-economics of the hilsa fishery. The results will provide some preliminary answers to questions concerning the utilisation of the hilsa stock. On that basis, recommendations for regulating the fishing effort over time leading to the hilsa recovery process may be derived. On the basis of my findings, policy makers will be able to design management policies based on a sound optimal sustainable yield level for the hilsa fishery, and thus, hopefully, prevent further biological and economic deterioration of the hilsa fishery.

2 BACKGROUND

2.1 Overview of Bangladesh

Bangladesh is situated in the northeast corner of South Asia. It is located between latitude 20°-34' and 26°-39' north and longitude 88°-01' and 92° -41' east. It borders with India in the west, north, and east, with Myanmar in the southeast, and with the Bay of Bengal in the south. The country's area is 144.000 square kilometres (55.598 square miles), and it is divided into six administrative divisions (Dhaka, Chittagong, Khulna, Barisal, Rajshahi and Sylhat).

Figure 1: Geographic location of Bangladesh with major rivers

The population of Bangladesh was estimated at 150 million in July 2007, making Bangladesh the 10^{th} most populous state in the world. Its population has almost doubled since the 1960s (CIA 2007). The Bangladesh population is relatively homogeneous. Religion plays a very important role in this country and the main division is between Islam and Hinduism. There are three main seasons in Bangladesh, winter, summer and monsoon. Winter lasts only for about 2 months in the country. Temperature and rainfall ranges from 7° C to 40°C and 1170 to 3400 mm respectively. The climate and geography of Bangladesh is well suited for fish culture and various kinds of fisheries resources.

Bangladesh is a predominantly agricultural nation. The country's economy is based on agriculture. Within the agricultural sector fisheries is the most important sub sector of the country. Fisheries have made up 5-6% of the country's GDP for the past several years.

2.2 Fisheries sector of Bangladesh

Bangladesh possesses an immense wetland area comprising a multi-species ecosystem. Numerous rivers, streams and tidal creeks intersect the vast alluvial tract, which are largely, formed by the fertile deltaic region of three mighty rivers the Ganges, the Brahmaputra and the Meghna. The large rivers flowing from the Himalayas, the Ganges unites with the Jamuna (main channel of the Brahmaputra) and later joins the Meghna to eventually empty into the Bay of Bangladesh. About 230 rivers and their tributaries with a total length of 24.000 km flow down through the country. There are about 54 rivers shared with India (Bangladesh Bureau of Statistics 1991).

The fisheries sector has played a vital role in the economy of Bangladesh. This sector has high potential from the perspective of economic development of the country. The fisheries sector contributes about 4,9% of the national GDP and 20% to the total agricultural production. Also 5,7% of the country's total export earnings come from this sector. Fish alone contribute about 63% of the animal protein in the daily dietary requirements of Bangladeshi people. Per capita fish consumption is 16 kg/year. The average growth rate of this sector for the last five years was about 5.2%. The sector provides full time employment for about 1.3 million professional fishermen and 12 million part time fisherfolk, which is about 10% of the total population (DoF 2005a). The country's total fish production has nearly doubled since 1996, reaching 2.2 mt in 2007 (Figure 2).

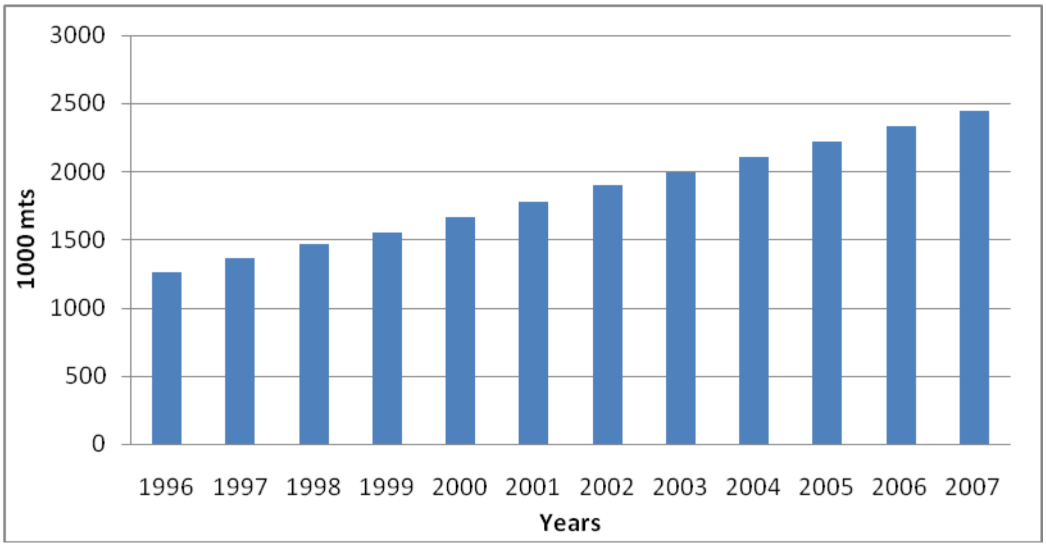

Figure 2: Total fish production in Bangladesh (1996 to 2007)

Fisheries in Bangladesh fall broadly into four categories: (i) inland capture (open water), (ii) inland culture (closed water), (iii) marine industrial or trawl fishing, and (iv) marine artisanal or small-scale fishing. Fishing techniques are mainly categorised as traditional, artisanal and commercial. Traditional and artisanal fisheries in rivers, beels, haor and baor as well as in freshwater is primarily inshore which is done by independent fishermen in small boats usually using simple gear like traps, gillnets, beach seines, purse seines, dip nets, cast nets and small long lines. Most of the catch is consumed locally either processed or fresh. There is no effective central marketing agency in the villages.

There is a wide variety of fish species in Bangladesh which can be grouped into five broad categories: hilsa, carp, catfish, prawn and others. In the inland open water system, there are 260 native species, 13 exotic fish species and 20 species of shrimp (Rahman 1989). Besides this, 31 species of turtles and tortoises are found of which 24 live in fresh water (Sarker and Sarker 1988). In the upper Bay of Bengal, 475 species of finfish are known to occur, of which about 65 species are commercially important. In the upper Bay of Bengal there are 38 species of marine prawn (Ali 1992). Of all fish species, the most important one is hilsa.

<u>Present status of water resources and production fisheries in Bangladesh</u>

There are different types of water bodies in Bangladesh. The soil, water and climate of Bangladesh are very favourable for inland fisheries, both open and closed water. Various kinds of fish culture practices have been done for many years. The following table (Table 1) depicts the picture of total catch and productivity in the fisheries sub-areas of the country.

Table 1: Annual (2005-2006) production and area productivity of fisheries by different resource types. Department of fisheries (DOF) (2005-2006).

Resource type	Water area (ha)	Production (MT)	Production/area (Kg/ha)	% of total production
A. Inland fisheries				
Inland open water fisheries				
River and estuaries	1.031.563	1.378,59	134	
Sundarbans	-	16.423	-	
Beel*	114.161	76.365	669	
Kaptai Lake	68.800	7.548	110	
Flood land & haor**	2.832.792	718.491	254	
Total Inland open water	4.047.316	956.686		41,1
Inland closed fisheries				
Pond and ditch	305.025	759.628	2.490	
Baor***	5.488	449,8	820	
Coastal shrimp farm	217.877	127.923	587	
Total inland closed water	528.390	892.049		38,3
Total inland fishery	4.560.900	1.848.735	-	79,4
B. Marine fisheries				
Industrial fisheries	-	34.084	-	
Artisanal fisheries	-	445.726	-	
Total marine		479.810		20,6
Total fisheries		2.328.545		100

*Beel: Lake, a deeper area or pocket where water remains throughout the year or for a longer period.
**Haor: Big depression or low-lying floodplain area in Northeast Bangladesh which is inundated during monsoon and becomes a vast sheet of water.
***Baor: Oxbow lake.

It is evident from the above figures that the contribution of capture fisheries with respect to the total fish catch of the country is the highest (41%) followed by fish farming (38%), while the contribution of marine fisheries is only 21% although 166.000 square kilometres is under the economic jurisdiction of the country for exploration, exploitation, conservation and management of marine living and non-living resources.

The coastline of the country is about 480 km in length. The area of the sea that makes up the Bangladesh Exclusive Economic Zone (EEZ) is estimated to be about 125.000 sq km. Three major fishing grounds have been discovered in the Bay of Bengal (i) South Patches (6.200 sq km) (ii) Middle Ground (4.600 sq km) (iii) Swatch of no Ground (3.800 sq km). Of these three fishing grounds, the South Patches are found to be the most productive, with an estimated standing stock of 11.4-16.0 mt per sq km, followed by 10.2-14.4 mt in the Swatch of no Ground and 8.4-12.0 mt in the Middle Ground. Potential fish (hilsa and other fin fish) and shrimp grounds have been identified and demarcated within the area of the continental shelf up to the depth of 40 fathom.

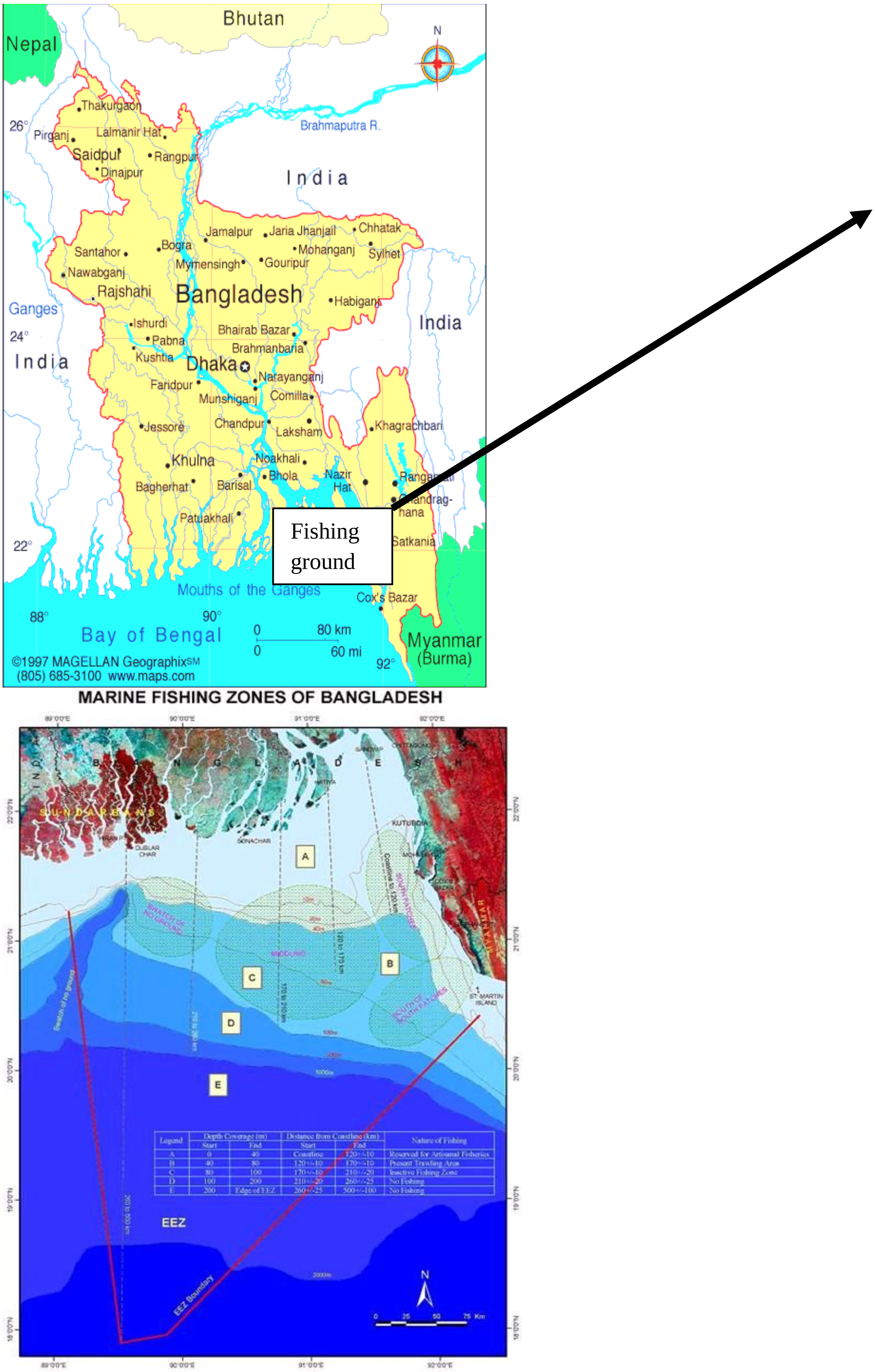

Figure 3: Major fishing grounds in the southern part of Bangladesh

There are two types of Marine fisheries in Bangladesh: (a) artisanal fisheries, which have 22.500 non-mechanised boats and 21.400 mechanised boats used for hilsa and shrimp (post larvae and juveniles) catch, and (b) industrial fisheries which have 122 industrial trawlers engaged in demersal fish and shrimp catching. There is a vast area of the artisanal fisheries sector in Bangladesh. At present, 93% of the catch comes from artisanal fisheries and 7% of the catch comes from the industrial fishery.

2.3 Hilsa fishery in Bangladesh:

2.3.1 Biology of hilsa

The Indian shad, *Tenualosa ilisha,* belongs to the family Clupeidae (herring family). The scientific name of the species, *Hilsa ilisha* has been revised recently to *Tenualosa ilisha* (Fisher and Bianchi 1984), but the popular name "hilsa" has been used for more than a century.

Hilsa has a wide range of distribution and occurs in marine, estuarine and riverine environments. The fish is found in the Persian Gulf, Red Sea, Arabian Sea, Bay of Bengal, Vietnam Sea and China Sea. The riverine habitat covers the Satil Arab, and the Tigris and Euphrates of Iran and Iraq, the Indus of Pakistan, the rivers of Eastern and Western India, the Irrawaddy of Myanmar, and the Padma, Jamuna, Meghna, Karnafully and other coastal rivers of Bangladesh. The major portion of hilsa (about 95%) is caught by Bangladesh, India and Myanmar (Banglapedia 2007).

Figure 4: *Tenualosa ilisha* (hilsa)

Hilsa shad (*T. ilisha*) is anadromous in nature. It is capable of withstanding a wide rang of salinity and travelling great distances up-stream. Hilsa lives in the sea for most of its life but migrates up to 1,200 km inland through rivers in the Indian sub-continent for spawning. Distances of 50-100 km are usually normal in the Bangladesh rivers (Wikipedia 2007). Hilsa may reach up to 60 cm in total length, but commonly found specimens measure 35 to 40 cm. A large-sized hilsa weighs about 2.5 kg. The hilsa is known to be a fast swimmer (Southwell and Prashad 1918).

Some conflicting views have been expressed on the minimum size of hilsa at first maturity. Day (1873) observed that the hilsa may attain first maturity at the end of the first year or at the beginning of the second year. In Bangladesh waters (Meghna River), Shafi *et al.* (1978) observed that, the size at first maturity is 21 cm in the case of males and 32 cm in the case of females.

In Bangladesh, hilsa is available almost throughout the year in the major rivers. Hilsa starts spawning migration to upstream during the southwest monsoon and consequent flooding of all the rivers (Rahman 2005). The eggs are deposited in fresh water and hatching takes place within 23 to 26 hours at an average temperature of 23ºC. The larvae and juveniles make their way downstream to the sea during a period of 5-6 months. They feed and grow on the way. In about 6-10 weeks the fry grow to about 12-20 cm and become known as jatka. At this stage they start migration to the sea for further growth and maturity. After growing for 1 year in the sea, hilsa become mature and undertake their spawning migration towards inland rivers thus the cycle continues (Haroon 1998).

Hilsa is relatively fecund. Numbers of eggs are found to be 144 thousand in 28 cm length fish up to 2.3 million in 44.5 cm length fish. The peak-breeding period of hilsa is placed during the full moon in the month of October (Halder 2004).

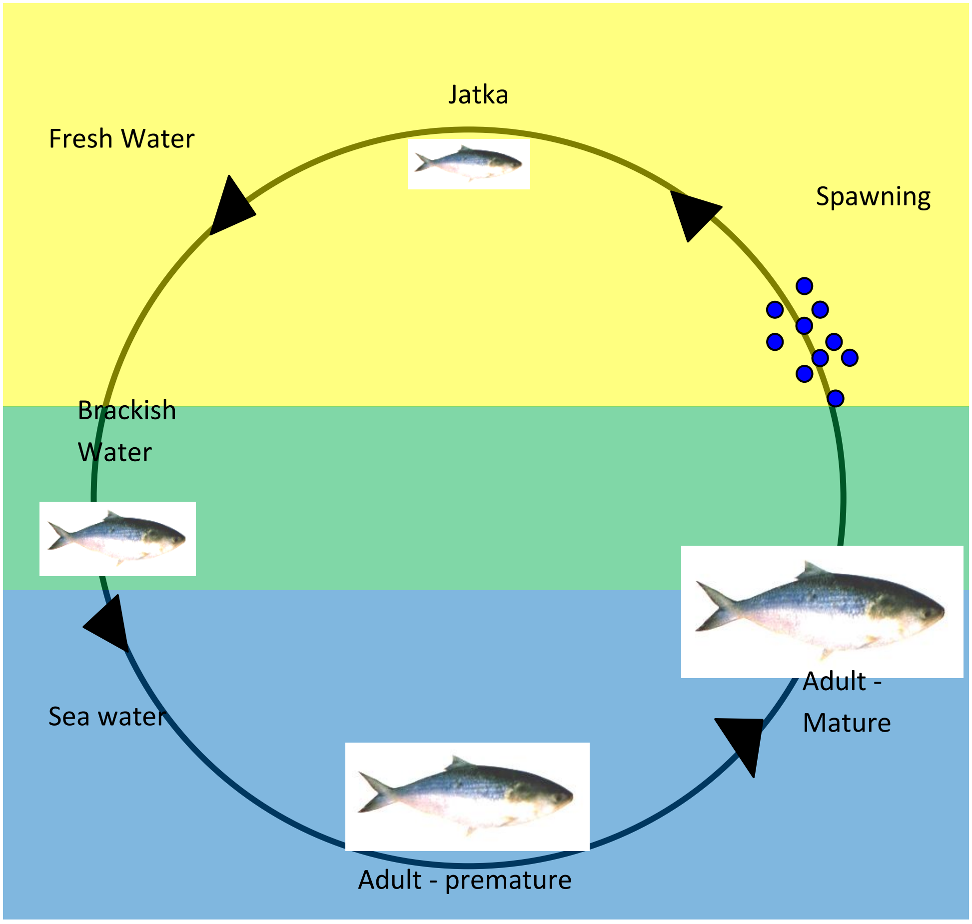

Figure 5: Movement pattern of *Tenualosa ilisha* (hilsa) into different habitats (Haldar 2005)

A major spawning ground of hilsa was determined by catching hilsa larvae/fry by experimental fishing. Earlier studies indicated that hilsa breed year round in almost all the major rivers throughout the country. The BFRI, riverine station studies identified the lower stretches and estuarine of the Meghna River as the major spawning grounds of hilsa (Miah *et al*. 1999, Halder *et al*. 2001). The major spawning ground is shown in the following Figure 6.

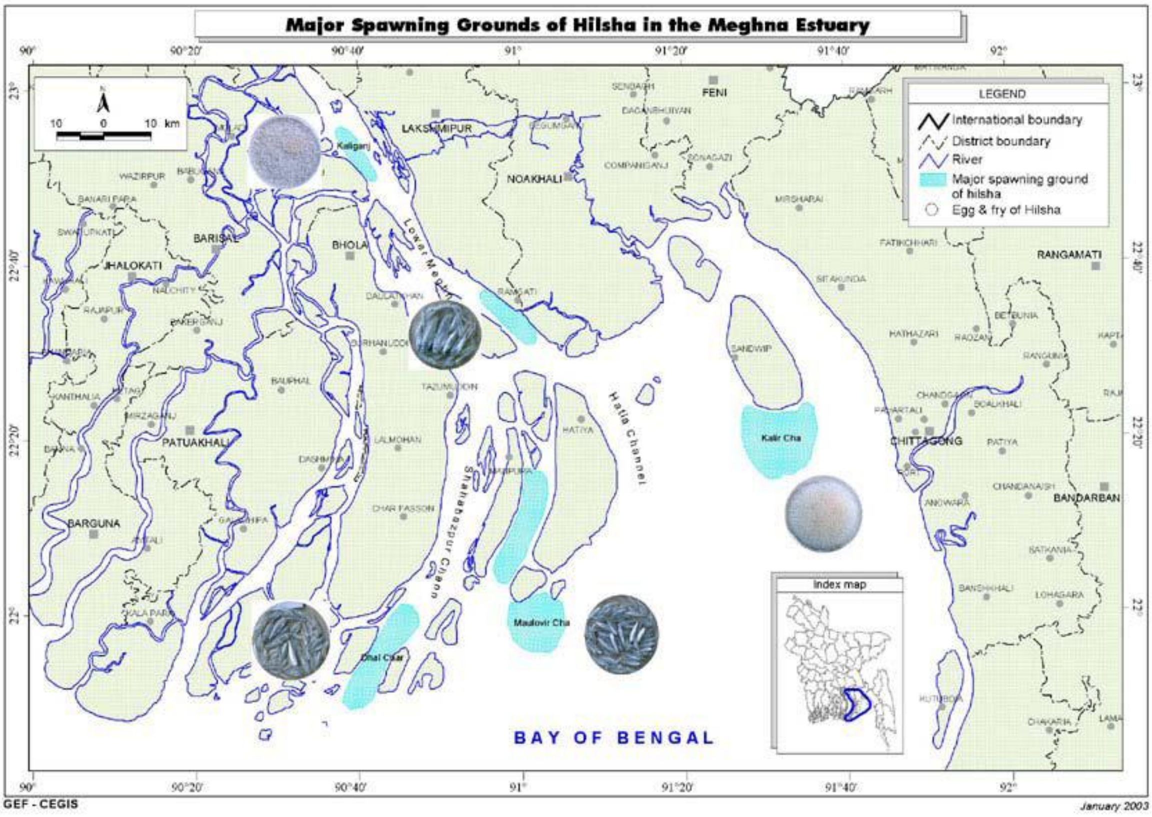

Figure 6: Major spawning ground of hilsa in the southern part of Bangladesh

2.3.2 Economic profile of the hilsa fishery

In Bangladesh, hilsa occurs in inland, marine, and coastal waters and is harvested throughout the year. Hilsa has the highest contribution to Bangladesh fish production as a single species. It is considered the national fish of the country and contributes to the national economy, employment and export. In the year 2005-06, about 11% of the country's total fish production came from hilsa. Average hilsa production is about 215 thousand mt worth US $380 million. It contributes 1.0% to the GDP. On the other hand, the government earned an average of US $630 million by exporting on average 220 mt per year. An estimated 0.46 million people are engaged in hilsa and jatka fishing. About 2% of the country's total population are directly or indirectly involved in the hilsa fishery for their livelihoods (Halder 2002).

<u>Present status of the hilsa fishery</u>

Since the inception of the fish catch assessment survey system by FRSS, DoF, the catch statistics of hilsa are collected systematically and reported in the Fishery Statistical Year Book of Bangladesh from 1983/84 onwards. In the country, national hilsa catch ranged between 194.981 and 280.328 mt with an average of 217.681 mt per year during the last 21 years and seems to be more or less stable over this time. The total production has increased approximately 48% from 1987 to 2007 (Figure 7).

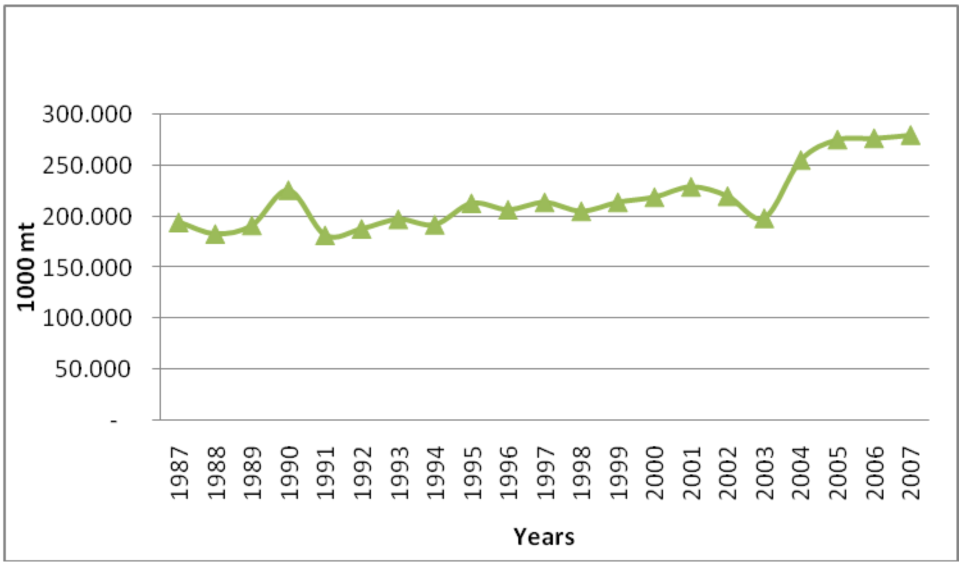

Figure 7: Total hilsa harvest from both marine and inland sectors in Bangladesh (1987-2007)

It is evident that the hilsa fishery is experiencing recruitment over-fishing and growth over-fishing. A study in 2004 pointed out that current fishing is close to the MSY level. In the year 2003, the estimated standing stock size and MSY was 218 thousand tons and 235 thousand tons respectively. The annual catch of hilsa was 229.000 mt in the year 2003, which is very close to MSY level (Department of fisheries (DOF 2005b). This indicates the over-fishing of the hilsa stock. Not only this, the exploitation rate of hilsa was 0.33 (under-exploitation) in 1985 but it has since increased to 0.66 (over-exploitation) in 2002. The present exploitation rate is about 2 times that of 1985, and the hilsa are over-exploited by 0.16 times i.e. 32 % higher than the optimum level (0.5). The length of first capture hilsa has decreased from 38 cm in 1985 to 20 cm in 2002 (Halder 2002). The total inland and marine sectors hilsa landings from 1984 to 2007 are shown in Appendix 1.

Comparison between inland and marine of hilsa landings

In Bangladesh, hilsa exist in inland, marine and coastal waters and are harvested throughout the year. Until the introduction of mechanised boats and nylon twine in early 1980s, the catches of hilsa were mainly concentrated in the inland waters and in the estuaries and very little in the coastal zones. Although the total hilsa harvest is more or less steady, the inland hilsa catches have decreased by about 15% during the period 1987 to 2006. After the introduction of nylon twine and mechanised boats in the marine sectors (Raja 1985 and Hall & Kasem 1994), the intensity of marine hilsa catches have been increased. In spite of this, marine production has been increased by about 26% during 1986 to 2006. During 1986/87 to 2006/07, the catches ranged between 104 thousand to 198 thousand mt with an average of 137 thousand mt since the base year 1986/87, the increase in marine hilsa landings is about 45%. Such a robust increase of hilsa production from the marine sector may be due to increased fishing effort, expansion of fishing areas and may also be due to a decrease in abundance and fishing areas in the inland waters (Figure 8).

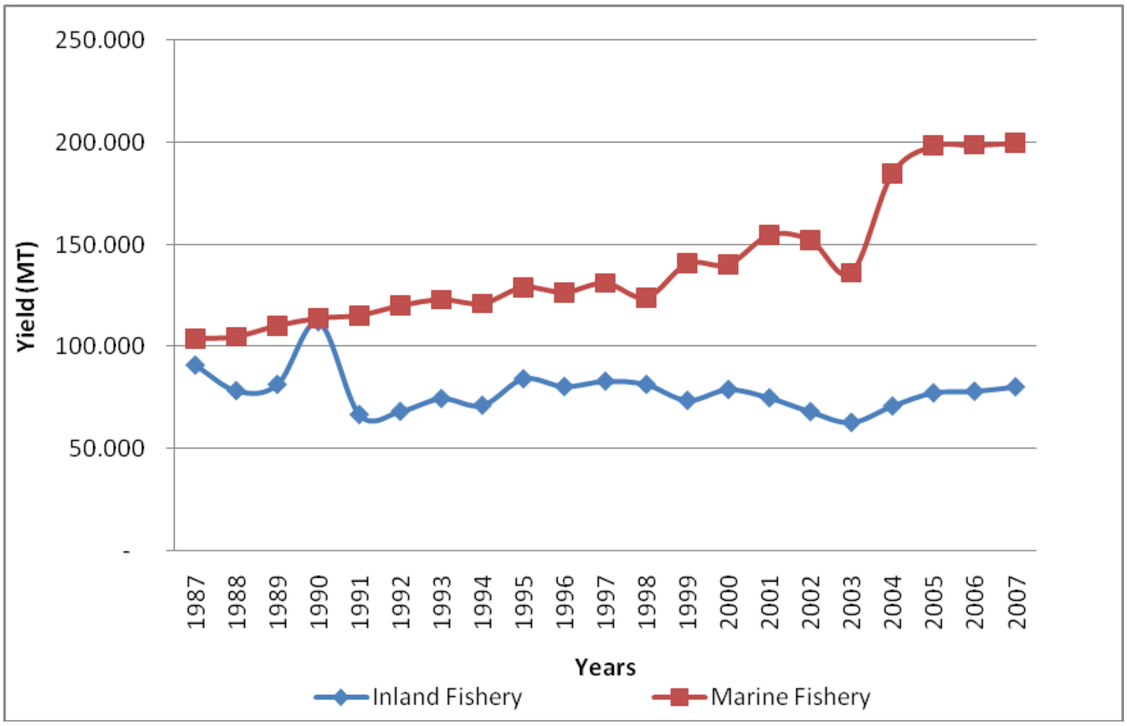

Figure 8: Trends of hilsa harvest both inland and marine sector in Bangladesh (1987 to 2007)

<u>Export of hilsa</u>

A considerable amount of hilsa is exported from Bangladesh. The minimum size of exportable hilsa is about 1.0 kg. Hilsa is mainly exported to West Bengal, India and some other countries in the Far East and Middle-East, European Union, America and Australia. In Europe, USA and some other countries hilsa is available at the Bangladeshi grocery stores. In the year 2002-2003 Bangladesh exported 1148 mt of hilsa, and in 2005-2006 it was increased to 3672 mt DOF (2007) (Table 2).

Table 2: Export quantity and value of frozen and chilled hilsa in the last five years (Department of Fisheries (DoF) 2007).

Year	Export volume (MT)	Export earning (million Tk.)
2002-2003	1.148	15.000
2003-2004	1.930	79.000
2004-2005	3.584	51.950
2005-2006	3.672	63.610
2006-2007	5,20	3.700

From the above Table 2, it could be seen that in 2006-2007 the exports suddenly dropped. The reason is that the Government of Bangladesh banned the hilsa export for this year. The whole year catch both inland and marine are locally consumed.

2.4 The artisanal hilsa fishery in Bangladesh

The artisanal fisheries are by far the most important fisheries in the marine sector of Bangladesh. In the year 2006, about 93% of the catch comes from the artisanal fishery and about 7% comes from the industrial fishery. Among the artisanal sector the hilsa fishery contributes over 41% of the total catch (Figure 9).

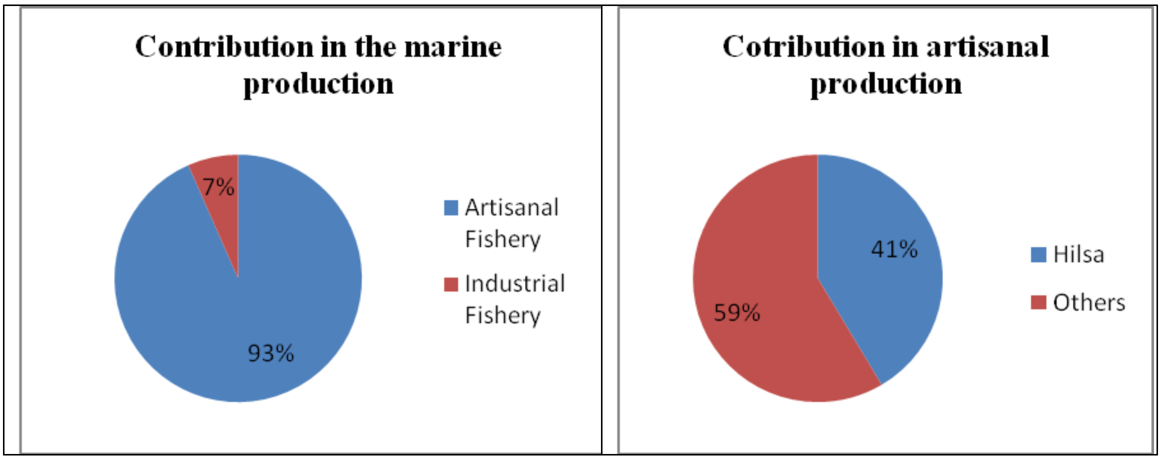

Figure 9: Contribution of hilsa fishery in artisanal fishery in Bangladesh

The artisanal sector is characterised by use of local, traditional and primitive methods of fishing. By implication, the characteristics of the sector are supposed to be low level of mechanisation, labour intensive fishing methods, and the prevalent use of unsophisticated techniques.

The artisanal hilsa fishery is mainly a gill net fishery. Several traditional fishing techniques are employed in this sector. Artisinal fishing for hilsa can be done almost throughout the year. The peak season is September/October, some minor peaks occur in February, April and June. The catch from the estuarine sector was sold mostly at the fishing ground itself to carrier boats; hence the shore landings are poor.

In the artisanal gill net fishery, mechanised and non-mechanised boats are engaged for hilsa fishing. As per statistics of FRSS, the total numbers of mechanised boats (MB) and non-mechanised boats (NMB) and gears were 2.887.380,2 and 6.682 respectively in 1984/85. In 2005/06, these figures had increased to 18.992 6.377 and 106.316 respectively. A survey was conducted by GEF in 2002/03. According to this survey, three types of boats engaged in marine hilsa catching in Bangladesh. These are trawlers (around 15 feet long) and tempo (around 10 feet long) boats used in commercial hilsa fishing. Both types of boats are called trawlers or mechanised boats with around 8-12 HP engine capacities. And the other most important non-mechanised boats used in the artisanal sector are Chandhi boats which have existed for a long period of time.

The hilsa stocks are exploited by a variety of gears, the most common of which are the clap net, gillnet, driftnet, seine net, barrier net, and fixed bag net; the largest contribution, however, comes from gill/drift nets. Mechanised fishing with gillnets accounts for the bulk of the landings from the sea. For this reason the number of fishing vessels and gears increased day by day.

Number of hilsa fisherman in artisanal sector in Bangladesh

Number of fishers involved in a fishery is an important aspect towards sustainable development and management of the fishery. In a country-wide survey, the total number of fishermen involved in hilsa fishing was found to be about 464 thousand belonging to 184 thousand families and of them 68% are full time and 32% are part time (Table 3).

Table 3: Total no. of hilsa fishermen in different areas of Bangladesh (Halder 2004b).

Name of division	Total district	Total fishermen	Total hilsa village	Total hilsa fisher family	Total hilsa fishermen	Occupation	
						Full time (%)	Part time (%)
Dhaka	12	75.687	579	8.902	17.454	26	74
Chittagong	8	257.715	773	66.608	142.649	56	44
Barisal	6	308.270	1.743	100.270	285.001	65	35
Rajshahi	7	27.636	307	2879	6.372	24	76
Khulna	5	78.268	260	4.570	11.783	10	90
Sylhet	2	9.500	41	383	825	10	90
Total	40	757.076	3.706	183..630	464.084	32	68

Among those hilsa fishermen (Table 3) 439 thousand belonging to 171 thousand families are artisanal fishers. From 1987 to 2007, with an increase of boats and gears, the numbers of hilsa fishers have been increased in the marine sector. The number of hilsa fishermen from the inland sector may have decreased because of less abundance of hilsa in the riverine habitats and habitat loss.

Socio-economic conditions of fishermen

Usually, it is told that the fishers are the poorest group of people in the country. But little is known about their poverty level because very little work on the livelihood of the fishers has been done in the country. Like other fishermen, hilsa fishers are poor. There are three major categories of hilsa fishers: the boat owner, head mazhi (skipper) and the crew. Usually the boat owners own the boats and nets and offer their boats and nets for fishing to the head mazhi. The usual share of the above categories of the fishers are that the boat owner gets 50-70% of the total catch, the head mazhi gets 2-3% share, assistant head mazhi and the boat driver get 1.5% share and the crew or labour fishers, deducting the cost of fishing get only 1% shares for the fishing operation. The annual expenditure for livelihood (except capital cost) of the artisanal hilsa fishers was found to average Tk. 76.045 and for consumption it was an average of Tk 38, 300 (BFRI 2000). So the overall socio-economic conditions of the hilsa fisher-folk in both the upper and lower regions are very poor. If the production or CPUE decline, the socio-economic conditions of the hilsa fisher folk will worsen further.

Marketing system of artisanal hilsa fishery

Hilsa is marketed and consumed all over Bangladesh. According to Kleih *et al.* (2003), 88% of hilsa is marketed internally for domestic consumption while the remaining 12% is exported. Most of the catch is consumed locally either processed or fresh. The catch from the artisanal hilsa fishery is sold directly to local agents. There is no effective central marketing agency in the villages. Traders buy fish at low prices from fishers located far from major urban centres. The traders visit different fish landing sites daily buy fish and transport to markets in major towns. The local price is set depending on the demand for fish and distances of villages from the major coastal towns. Hence, the price of fish is attributed to the variable cost of transportation. Prices tend to be lower farther away from the towns. Local agents supply the fish to the town market and some fish are transported to processing factories. The market price of hilsa depends on quality, size and weight, season, market structure, supply and demand. Hilsa prices are known to follow a seasonal pattern, with the demand period around festivals not necessarily coinciding with bumper harvest. Prices also vary from market to market. Prices in town markets tend to be higher than in coastal markets due to a larger concentration of consumers and superior family income (Ahmed 2007). In comparison with the year 1984, the producer price of hilsa has increased about seven times (Tk 20.0/kg in 1984 to Tk 130 in 2003) (Department of Fisheries (DOF) 2007.

Present situation of the artisanal hilsa fishery

The artisanal hilsa sector now a days is characterised by open access with crowding of fishing effort. Hilsa experts now fear that the most productive sites for hilsa remain exploited. The study 2004 also stated that artisanal fishery resources have already reached an upper level of exploitation.This is believed to be due to fishermen fishing in the same areas since time immemorial because of open excess with crowding of fishing effort and due to lack of proper management practices (Halder 2004b). As a result CPUF has been seriously declineing for the last couple of years. The catch of mechanised boats per year is estimated to be 33 mt in 1989/90 and subsequently decreased to only 9 mt in 2005/06. The catch of non-mechanised boats per year ranged from 5.3 to 4 mt from 1989/90 to 2005/06.

For this study the data on the number of boats over time are not reliable. Therefore the number of vessels and CPUE is calculated on an average basis. Such a huge increase of boats and gears in the sector may result in over-exploitation of the fishery, a decrease in catch/unit effort landing to unsustainable conditions of the fishery and ultimately a decrease of hilsa production. The total number of fishing gears and crafts is shown in Appendix 2. The catch per unit effort of mechanised and non-mechanised boats (MB and NMB) in the artisanal hilsa fishery is radically declining (Figure 11).

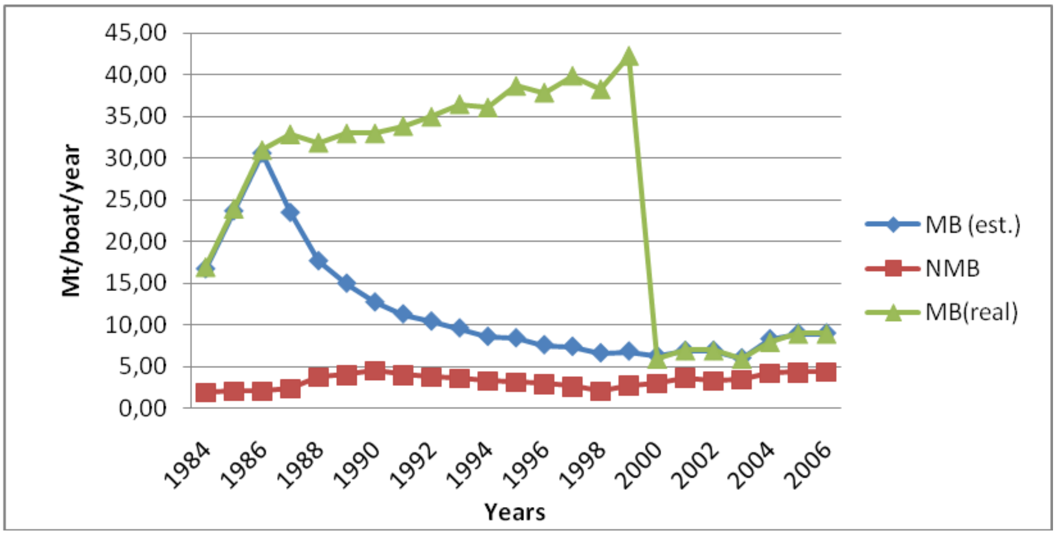

Figure 10: Catch per unit efforts of mechanised and non-mechanised boats

The radical decrease of catches of both MB and NMB also indicates excess fishing effort, which could lead to over-exploitation and vulnerability of the fishery.

2.5 Existing measures for conservation and management of the artisanal hilsa fishery

Nationally, the artisanal fishery is the most important sector as it lands almost all the marine catch and supports the majority of the fishermen. From a management point of view, however, it is the most difficult sector to manage since fishermen are spread out all along the shores, entry into the fishery is free, and normally fishing tends to be their main source of income and employment in the coastal fishing communities. The Bangladesh fisheries authority has taken several measures for conservation and management of the artisanal hilsa fishery in Bangladesh.

Existing policy for marine resources

In the early 1970s to 1990s there was no clear objective for the development of the fisheries sector. This lack led to the development of the “National Fisheries Policy” in 1998. There are five major areas of this policy and one of that is a “policy for exploitation, conservation and management of marine fisheries resource”. To implement and support the National Fisheries Policy the government formulated the “National Fisheries Strategy” (NFS). There are eight sub strategies. One of which is “marine sector sub strategy”. There is no separate segment for management of the artisanal hilsa fishery.

For the conservation of the hilsa fishery some activities and management measures are taken on the basis of this policy and other fishery regulations.

Restrictions on fishing gear

The Fish Act was declared in 1950. Under this act jatka catch was banned in Bangladesh. The use of current jal (monofilament gillnet) under the size of 4.5 cm mesh size was banned in 1988. In the artisanal hilsa fishery, the operation of gill nets of less than 100 mm mesh size is legally prohibited, but fishermen are still using smaller mesh sizes.

Restricting fishing time

In Bangladesh about 60-70% of hilsa are caught during the peak-breeding season and almost 70% of them are sexually mature. For uninterrupted spawning, every year 15 to 24 October (peak spawning season) for ten days catch of brood hilsa has been banned in all major spawning grounds.

Closed fishing area

To achieve the desired development of the hilsa fishery four sites in the coastal areas of the country have been declared as hilsa sanctuaries under the 'Protection and Conservation of Fish Act 1950'. In these four hilsa sanctuaries, all types of fish catches have been banned during certain periods of time in every year. The ban period of three sanctuaries is March to April and the other one is November to January.

Zone restriction

The *Marine Fisheries Ordinance, 1983* made provisions for the management, conservation and development of marine fisheries for water bodies with a depth in excess of 50 metres. This is done to minimise or avoid potential conflict between industrial vessels and artisanal fishers. Any body of water under 50 metres in depth is reserved for small-scale fisheries. All trawlers are allowed to fish within the 200 nautical mile maritime boundary of Bangladesh. Each trawler must be granted sailing permission from the Directorate of Fisheries for every voyage.

Regulation on fishing vessels

Mechanised boats have been brought under a licensing system in accordance with *Amendment 92* of the *Marine Fisheries Ordinance, 1983*. Since January 2000, all non-mechanised boats have also been included under the licensing system. In the artisanal hilsa fishery, all fishing vessels are subjected to registration fees which are paid when vessels are commissioned for the first time and vessel and fishing licences are paid annually. Registration fees are aimed to keep track of how many vessels enter the industry and also to collect revenues, while licence fees are seen as a means to control entry to some extent, keep track of how many vessels are actively engaged in fishing activities each year and also as a way to collect revenue. In the case of the artisanal fishery, the only way to control the vessels (mechanised and non-mechanised boats) is through registration. Registration of the vessels is given by the Mercantile Marine Department. This department also monitors these vessels during the fishing period. In the artisanal gillnet hilsa fishery, every fishing unit needs to get a license after registration, which is renewable each year. If there is failure to renew a license within 2 years of issuing the license, a new license has to be taken. Fishing vessels licence rates vary with vessel size and engine capacity.

All those biological management measures alone are not able to predict the collapse of fishery or to provide the optimum level of the fishery or even any indication about the profit maximising level. Despite all the management measures which have been put in place, fishing effort continues to increase and many more entrants demand to join the fishery. Currently the fisheries authorities are not issuing new licences for artisanal hilsa fishing; however, there is an increasing pressure from those who want to join the fishery. The decision to stop issuing new licences for the hilsa fishery is made due to concerns that the fishery is not sustainable. Therefore, now it is necessary to assess the current status of hilsa and determine the policy that will maximise economic benefits while ensuring sustainable development of the country's hilsa resources.

3 MODELING

The purpose of fisheries management is to find ways to maximise the benefits from the fish resources. Predictive models of the fishery are necessary for fisheries administrators to foresee the evolution of the resource abundance and to predict their response to fisheries management (Garcia and Le Reste 1981). Such models must contain information on the biological processes of the resources as well as the socio-economic processes associated with the utilisation of the resource. Therefore, they are generally referred to as bio-economic models (Clark 1973). Availability of information alone does not guarantee sound management unless the information is prepared in a way that can be used in the decision making process. A bio-economic model of the fishery organises the available information and thus helps to predict the outcome of different management policies.

Bio-economic models generally consist of three main components: (i) the biological part describing the dynamics of the resource stock, (ii) an economic part describing the economic benefits and costs of harvesting and (iii) a link between the biological and economic part describing how fisheries actions generate harvests (and thus impinge upon the stock dynamics as well as the generation of benefits). Every reasonable bio-economic model contains variables which can be directly controlled by humans. Typically, these variables are fishing effort, harvests and investments in fishing capital and so on. The manipulation of these variables constitutes a fisheries policy. According to Padilla and Charles (1994) "the value of bio-economic modelling can be judged both by its generation of useful 'theoretical' insights into the operation of fisheries systems, and by its application to real-world fisheries". Also, "to be truly useful, a bio-economic model must be 'accessible' in that (a) its use must be less demanding of detailed knowledge than its original creation, and (b) it should be directly usable (or easily adapted) to analyse fisheries that differ in their characteristics and their information availability from those for which the model was developed".

In this study, I develop a bio-economic model of the Bangladesh hilsa fishery to explore the bio-economic implications of different utilisation policies. In particular I will be most interested in policies which maximise the flow of economic benefits from the resources. More precisely, I will use my bio-economic model to:

- Calculate the optimal sustainable yield
- Compare the current situation with optimal fishery
- Devise a socially beneficial fisheries policy over time.

3.1 Choice of model

The level of sophistication of a bio-economic model is constrained by the amount of data available. The level of sophistication desired depends on the intended use of the model. In the case of the Bangladesh hilsa fishery, the availability of useable information severely limits my ability to build a complicated model.

The key components of my bio-economical model are set out below: the model consists of a biological part, a harvest function and a profit function. The last component describes the economic benefits from fishing. The harvest function constitutes the link between the economic and biological parts of the model. The control variable, i.e. the item subject to fisheries management and policy is fishing effort:

(1) $\dot{x} \equiv \frac{dx}{dt} = G(x) - Y(e,x)$ $X = \frac{dx}{dt} = G(x) - Y(e,x)$ (Biomass growth function)

(2) $y = Y(e,x)$ (Harvesting function)

(3) $\pi = p \cdot Y(e,x) - C(e)$ (Profit function)

Where $\dot{x}$ is the biomass change, *G*(*x*) is the biomass growth function, *Y*(*e*,*x*) is the harvest function and *C*(*e*) the cost function. The variable *x* represents the stock size, *y* the harvest, *e* fishing effort, π profits (taken to be equivalent to social benefits) and *p* landings price of fish.

There are two types of variables present in this model: endogenous variables and exogenous variables. The main endogenous variables are *x*, y and π Π, , representing biomass, harvest and profits respectively. These variables are determined within the fishery. The main exogenous variables are landings price, which is determined by market conditions outside the fishery, and fishing effort which is a control variable.

The bio-economic model we construct builds on this basic framework. However, as will become apparent, the actual model will considerably extend the above components of this basic framework, especially the biological part on which there is most data. It will also, because of the nature of the data, move to a discrete time presentation.

3.2 Biological part of the model

The biological part the model is based on the theoretical framework set out by Beverton and Holt (1957). This framework is fundamentally cohort disaggregated and dynamic. Since its inception, it has dominated fisheries population studies and is still the main tool in practical fish stock research worldwide.

The key variables in the Beverton-Holt model are:

- n(i,t): number of fish in cohort i at time t
- m(i,t): natural mortality of fish in cohort i at time t

- f(i,t): fishing mortality of fish in cohort i at time t
- w(i,t): average weight of fish in cohort i at time t
- ma(i,t): average maturity of fish in cohort i at time t
- r(t): recruitment of the youngest cohort at time t

The key functional relationships of the Beverton-Holt model are:

Cohort evolution

(4) $$n(i,t+1) = n(i,t) \cdot e^{-z(i,t)},$$

where z(i,t) = m(i,t)+f(i,t).

Biomass measures

Cohort biomass is:

(5) $x(i,t) = \mathrm{w}(i,t) \cdot n(i,t)$.

Total biomass is:

(6) $$X(t) = \sum_{i=1}^{I} x(i,t),$$

where I is the maximum number of cohorts in the stock.

Spawning stock is:

(7) $$S(t) = \sum_{i=1}^{I} ma(i,t) \cdot x(i,t)$$

Relationships (4) - (7) are all logical necessities or tautologies. The Beverton-Holt recruitment function, (8), is an empirical hypothesis.

Recruitment

The Beverton-Holt recruitment function may be written as:

(8) $$r(t) = \frac{\alpha \cdot S(t-\sigma)}{1+\beta \cdot S(t-\sigma)},$$

Where $\sigma \geq 0$ is the lead time from the time of spawning to the time of recruitment. For the hilsa we will take σ=0. (Arnason 1984)

The Beverton-Holt recruitment function is a monotonically increasing function with a maximum at α/β. The coefficient, α, determines the slope of this function at spawning stock zero. Typical shapes of this function for different values of α but the same maximum recruitment are illustrated in Figure 10 (Beverton and Holt 1957).

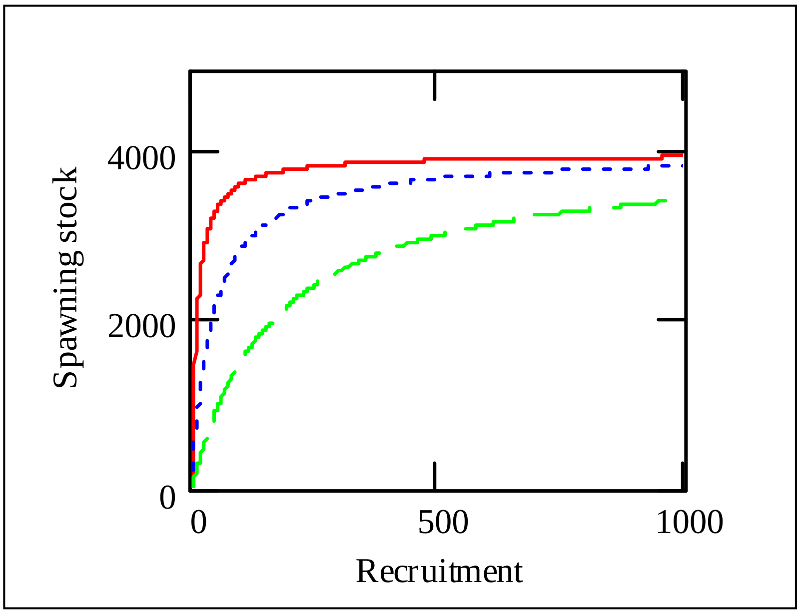

Figure 11: Typical Beverton-Holt recruitment functions (King 1995)

3.3 Economical part of the model

The aggregate costs of fishing effort:

(9) $$C(e) = fk + vc \cdot e$$

C(e) is the cost per effort, fk is the fixed cost and vc is the variable cost. For long run calculation we assumed that fk will become variable so the long run cost function would be:

(10) $$C(e) = (fk + vc) \cdot e$$

The aggregate profits at time t are:

(11) $$\pi(t) = p(t) \cdot y(t) - C(e)$$

$$\pi(t) = y(t) \cdot p - c(e)$$

Here $p(t)$$p$ is the price of landings and $y(t)$ the $y(t)$harvest both at time t. In the empirical implementation of the model price may vary across cohorts.

3.4 The link between the biological and economic parts

Harvesting function

In this bio-economic model, the link between the biological and economic parts is the harvesting function. According to Beverton and Holt (1957) derivations, this harvesting function for a single cohort i over time period $[t, t+1]$ is given by:

(12) $$y(i,t) = w(i,t)\cdot n(i,t)\cdot(1-e^{-z(i,t)})\cdot\frac{f(i,t)}{z(i,t)},$$

where *w(i,t)*, *m(i,t)* and *f(i,t)* are averages over the fishing period.
The total harvest then is just the summation over all the cohorts as:

(13) $$Y(t) = \sum_{i=1}^{I} y(i,t)$$

$$\mathbf{y}(t) = \sum_{i=1}^{8} \mathbf{y}(i,t)$$

Fishing mortality depends on fishing effort and special measures to protect young cohorts. We assume that fishing mortality for year class i at time t is a linear function of fishing effort. In the base year, t*, we have a column in vector of fishing mortality:

$F = [\ f(1,t^*)\ ,\ f(2,t^*),\ldots.f(I,t^*)[f(1,t^{\uparrow}*), f(2,t^{\uparrow}*), f(3,t^{\uparrow}*)\ \ \ldots\ldots..]$

Therefore, fishing mortality for any cohort at any time t is:

(14) $$f(i,t) = f(i,t^*)\cdot\left(\frac{e(t)}{e(t^*)}\right)\cdot pr(i,t)$$

$$f(i,t) = f(i,t^*).\frac{e(t)}{e(t^*)}.\mathrm{pr}(i)$$

Where *pr(i,t)* is the year class protection parameters. pr $(i)\in[0,1]$ 0 means fully protected and 1 means no protection.

4 DATA AND PARAMETER ESTIMATIONS

In order to carry out the study, it was necessary to estimate the parameters of the model outlined above. For that various data are needed. The necessary data are of two types, biological data and economic data.

More precisely, we need estimates of the following:

Variables and parameters	Names of the parameters
Biological	
Maturity rates	$ma(i,t)$
Numbers of fish in base year	$n(i,t^*)$
Average individual weights	$w(i,t)$
Natural mortality	$m(i,t)$
Fishing mortality in base year	$f(i,t^*)$
Recruitment function parameters	α , β
Economic	
Fishing effort in base year	e^*
Fixed costs	fk

Variable costs	vc
Landings price	P

In addition to this we need data on the life span of hilsa (to determine *i*). Obviously also we need to decide on the time interval to use and the base year of the calculations, t*.

•

4.1 Data sources

For estimating the current model secondary and tertiary data will be utilised. The secondary data has been collected from the Fisheries Resources Survey System (FRSS) and Fish Inspection and Quality Control (FIQC) section in Bangladesh and tertiary data from different websites and from various working reports.

FRSS is an important section of the Department of Fisheries under the administrative control of the Ministry of Fisheries and Livestock. In every district of Bangladesh there is a government officer for data collection. Government officers go to fish markets, ponds, lakes (haors, baors) and other water areas for collecting the data. Every month, data are compiled and sent to the FRSS for final compilation. Every year, DoF publishes the Fisheries Statistical Year Book with these data. FIQC is also an important section of DoF. All export products are inspected by this section in different ports (DoF 2005).

All biological data for this study were collected from "Aquatic Resource Management, Development and Conservation Studies" (ARDMCS), GEF component of the Fourth Fisheries Project (FFP) under the administration of the DoF (Halder 2004b).

4.2 Time unit and the base year

We opt to use half-years as our basic time unit. This is because the hilsa grow fast and natural mortality is high. Therefore, added accuracy is obtained by using half years in the calculations rather then whole years.

The year 2005-2006 is considered as the base year for this study. All the necessary data have been collected for this year.

4.3 Biological data and parameters

<u>Life span:</u> Many biological studies have been done on hilsa fish. According to Halder (2004), the maximum length, 58 cm, is attained at 6.5 years of age and indicates that the hilsa are a moderately sized and moderately long-lived fish. But very few fish are left in the stock of more than 4 years. So, for reasons of simplicity, we considered the life span of hilsa to be 4 years with 8 cohorts in a population.

<u>Maturity rates:</u> The minimum size of maturing hilsa is reported to be 19 cm (Halder 2002). Thus, it may be said that hilsa mature at 1 year of age. As basic data for our model it is considered that 1 cohort of hilsa is immature and 2 cohorts of hilsa is 80% mature and the whole population of hilsa mature at age 1.

Numbers of fish in base year: Up-to-date data for the stock of hilsa in Bangladesh is not available. Stock assessment of the hilsa fishery of Bangladesh was introduced in 1983 under the BOBP project; hilsa investigation in Bangladesh (Funded by UNDP and FAO). Later on, the initiative was continued by BFRI until 2000. Under the ARDMCS, GEF component a two-year (2002 and 2003) study was conducted to continue the previous initiatives. (Halder 2004b).

For this study, we estimate the number of fish (*n*) of different year class (*i*) at time (*t*) in the total fish population of hilsa. This estimation is done by the constructed simple hilsa model.

We assumed the model by using the number of fish that will give us an idea about the stock of hilsa. Furthermore, we assumed that landing and biomass in 2005 has been represented as equilibrium ($\dot{x} = 0$). After that we use the model to calculate the corresponding number of fish by cohorts. Of course these are not the true numbers but make a good and possibly best guess.

Table 4: Estimated results for the number of fish at time *t*

Year	Number of fish (*i*) (million)							
	1	2	3	4	5	6	7	8
2005	24.928	456,6	88,6	17,2	3,3	0,6	0,1	0,0

Average individual weight: Age determination of hilsa from their hard parts (scales, otoliths) is not yet developed and adopted in Bangladesh (Halder 2004b) and hence the age of hilsa was determined by inverse von Bertalanffy,s growth equation.

The von Bertalanffy,s equation, in terms of length-frequency, is:

$L_t = L\infty\ (1 - \exp\ [-K\ (t\text{-}t^{o}\ )])$

Where L_t is the length at age t, $L\infty$ is the asymptotic length, and K is a growth coefficient.

As per von Bertalanffy,s growth equation hilsa attains 25-30 cm size at one year of age. According to Haldar (2005), the age-length relationship of hilsa is shown in Table 5. For this study we calculate individual weight, $w(i,t)$ by using the Le Cren (1951) equation.

The formula is as follows:

$W = a\ L^{b}$

Where "a" is a constant and "b" is an exponent, its value is a = 0,01351 and b = 2,974.

Table 5: Relations of individual age, length and weight of hilsa (BFRI 2000).

Age(year)	Length(cm)	Weight(gm)
0.5	15-16	0,051
1.0	27-28	0,272
1.5	36-37	0,623
2.0	42-43	0,974
2.5	47-48	1,351

3.0	51-52	1,714
3.5	53-54	1,918
4.0	54-55	2,137
4.5	55-56	2,144
5.0	56-56,5	2,194
5.5	56,5-57	2,252
6.0	57-57,25	2,282
6.5	57,25-58	2,372

Natural mortality: Several researches have been done for calculating natural mortality of hilsa. In most research, the total mortality rate was estimated using the length-converted catch curve method. Natural mortality rate was estimated using the following empirical relationship of Pauly (1980):

$$\text{Log10 } M = -0{,}0066 - 0{,}279 \text{ Log10 } L\infty + 0{,}6543 \text{ Log10 } K + 0{,}4634 \text{ Log10 } T$$

Where $L\infty$ is expressed in cm and T, the mean annual water temperature in C°, which here is 27 C – 28 C.

The study of natural mortality for juvenile hilsa is not sufficient. For this study, natural mortality of juvenile and adult hilsa was taken from the scientific paper of Amin *et al*. (2002).

According to Amin *et al*. (2002), the annual rate of natural mortality (M) and fishing mortality (F) were found to be 8.39 and 14.13, respectively. The historical mortality rate is shown in the following Table 7.

Table 6: Historical mortality data of hilsa fish in Bangladesh (Halder 2004b).

Year	Natural mortality	Fishing mortality	Total mortality
1986	1,27	0,63	1,90
1995	1,18	1,43	2,61
1999	1,28	2,49	3,77
2002	1,36	2,14	3,50
2003	1,26	1,77	3,03

On the basis of all study it has been observed that natural mortality of the 1^{st} cohort is very high (8.80) and after that it is much lower and almost constant. So for this study we guess the natural mortality based on the above studies.

Fishing mortality in base year: Fishing mortality rate (f) was obtained by subtracting m from z. Results of natural mortality, fishing mortality estimation and total mortality. From the historical mortality data (Table-8), we guess our basic data of natural mortality, fishing mortality and total mortality of different year classes (i) at times (t) for the hilsa model.

Table 7: Natural mortality and fishing mortality at different ages

Age(half year)	Natural mortality	Fishing mortality	Total mortality
0.5	4,00	6,50	10,50
1.0	0,64	1,00	1,64
1.5	0,64	1,00	1,64
2.0	0,64	1,00	1,64
2.5	0,64	1,00	1,64
3.0	0,64	1,00	1,64
3.5	0,64	1,00	1,64

4.0	0,64	1,00	1,64

Note: All mortality rates indicate half years.

Spawning parameters, α and β:

The spawning parameters are determined so as to replicate as closely as possible the available data of the fishery, especially harvest rates, and available estimates of stock size. This, while somewhat adhoc, is equivalent to a simple minded maximise likelihood procedure.

These assumptions are:

$\alpha = 390$
$\beta = 0{,}01$

4.4 Economic parameters estimation

Fishing effort in the base year; $e\,(t^*)$

In this analysis, fishing effort is estimated in horsepower (HP). FRSS data provide the information about mechanised boats and non-mechanised boats that are engaged in the artisanal hilsa fishery in Bangladesh. The total numbers of mechanised boats and non-mechanised boats are 18982 and 6377 respectively (2005-2006). In case of this analysis, base year fishing effort is the summation of MB and NMB.

Total fishing effort = MB+NMB = 18.982 + 6.377 = 25.369

In order to get one measure of fishing effort for the annual total catches, the effort values from individual boat types had to be converted into standard effort units. On the basis of interviews with concerned stake holders, it can be assumed that the average HP of MB use in hilsa fishing is around 10 HP. Though NMBs are manually operated and do not have any engines, for this study I have assumed the capacity of 5 HP for these types of boats on the basis of the efficiency of NMB relative to the MB.

Fishing effort = [10. MB + 5. NMB] = Total horsepower (considered as a fixed proportionate)

Total fishing effort = 189820 + 31885 = 221705 HP (base year fishing effort)

Estimates of cost parameters: $C(e) = fk + vc.e^*$

In the artisanal hilsa fishery both motorised and non-motorised boats are involved. Most of them are not well equipped. The capacity of fishing is not so standard. This is not only for traditional vessels it is also because of unavailability of hilsa stock. According to the Department of fisheries (DOF) 2005-2006, non-mechanised boats/year catch 4.38 mt and mechanised boats/year 9.00 mt of hilsa. For the calculation of total cost, the boat has standardised as horse power. So the annual average catch per HP is 0.90 mt/year.

A new boat fully equipped costs 1.500.000 Tk. The cost of boat and engine (Tk.1.340.000 and 160.000) includes cost price, sales tax or customs duty, and installation charge. The working life of the boat varies between 8-10 years and engine 6-8 years. Every day the fishing time is around 16 hrs. The fishing boats consumed 1 litre of diesel for every 2 hrs running. Average diesel required for each trip is around 24 litres per day.

The number of fishing days, for both motorised and non-motorised crafts has been about 288 days per year (about 24 days per month). Sometimes fishermen can not harvest because of bad weather. In case of calculation of fishing days, it is considered an average of 275 days per year. The number of labours are the same in mechanised and non-mechanised boats. There are 10 crew/fishermen in each boat. For wages of labour, a share system has been calculated for both motorised and non-motorised boats.

Table 8: Cost calculation for non-mechanised and mechanised boats per year hilsa catch (in year 2005-2006).

Item of cost (Tk)	Non-mechanised boats	Mechanised boat
1. Investment cost		
Price of boat	500.000	1.000.000
Price of engine	-	200.000
Price of net	50.000	70.000
Total investment cost	550.000	1.270.000
2. Operation cost		
Fuel and oil (24 liter/days/35Tk)	-	231.000 (275 days)
Food (80 Tk/day/man)	220.000 (10 person)	220.000 (10 person)
Crew share:		
(Gross earning- food)*0.5	174.700	
(Gross earning-food-fuel)*0.375		269.625
Gear repair/replacement	25.000	30.000
Engine repair		80.000
Hull repair	10.000	20.000
Total	439.700	850.625
3. Depreciation cost		
Hull (10 years)	50.000	100.000
Engine (8 years)		25.000
Total cost (Tk)	489.700	975.625

From the total cost we need to separate the fixed cost and the variable cost.

Non-mechanised boat = Depreciation cost of hall and hall repair cost is considered as a fixed cost (50.000 + 10,000= 60.000 Tk)

Mechanised boat = Depreciation cost of hall, engine and hall repair cost is considered as fixed cost (100.000+25.000+20.000 =145.000 Tk)

<u>Wages of boat owner</u>

Generally in Bangladesh the boat owner plays a vital role in managing the boat. In most of the cases they also involve themselves in managing fishing. They actively participate in the maintenance of the boat, monitor the accounts alone, and deal with fishermen for all rental issues, paying the government fees and performing in all other official jobs. If the work of the boat owner might have been done by others, some cost would occur. We assume a salary for the job of a boat owner is US $2.000 (as National Pay Scale, 2005) per year for 25.369 boats. From this number we can derive the calculation for wages of the boat owner for six months. The wages is US $114 per HP regarding the fishing fleet (total HP 221.705) for six months. Since the boat owner does not claim for extra hours, the cost represented here is definitely a fixed cost. This fixed cost is added separately with the total cost as fixed cost.

Cost function $C(e) = fk + vc \cdot e$

For long run calculation we assumed that fk would become variable because we cannot reduce the fleet with effort, so the long run total cost is calculated by:

TC = $(fk + vc) \cdot e$

In this study for determining the adjustment path we calculated fk by the following formula:

$fk(t) = e(t) \cdot fk + a.\ (e(t) \cdot fk - fk(t-1))$

Where a is the adjustment parameter. This means that fixed costs are gradually adjusted to reduce the effort with the speed of adjustment depend on. If a=1 this means no adjustment and if a=0 immediate adjustment.

Result of cost parameter estimation:

Total HP for hilsa fishing per year = 221.705 HP
Total fixed cost of non-mechanised boat = 60.000*6377 = 382,62 million Tk
Total variable cost of non-mechanised boat = 429.700*6.377= 2.740,2 million Tk
Total fixed cost of mechanised boat =145.000*18.982 = 2.752,39 million Tk
Total variable cost of mechanised boat = 830.625*18.982 = 15.766,92 million Tk
Total fixed cost= (NMB+MB) = 382,62+2.752,39 = 3.135,01 million Tk
Total variable cost = (NMB+MB) =2740.2 +15766.92= 18507.12 million Tk.
Annual fixed cost per HP = 14.140 Tk (US $208)
Annual fixed cost for wages of boat owner per HP = 15.562 Tk (US $228)
Annual variable cost per HP= 83.476 Tk (US $1.228)

Price of hilsa at base year, $P(t^*)$

According to the Halder 2002 the landing price of hilsa has increased about 7 times from the year 1985. In 1985 the price of hilsa was 20Tk/kg and 130Tk/kg (US $2 /kg) in 2005-06. (68 Tk = US $1).

For the present study, the weight of fish is shown in metric tons (1 MT= 1000 kg). The landing price shown is only for hilsa of above 6 months. The price of small fish is low considered to big fish. The price of hilsa is US $2 where as jatka (1st cohort) is US $1.

Price of jatka = 1 MT jatka price is 65.000 Tk (US $956).
Price of hilsa = 1 MT hilsa price is 130.000 Tk (US $1912).

5 NUMERICAL ANALYSIS AND RESULTS

In this section we use the hilsa bio-economic model developed in the previous section to identify optimal fisheries policies. First we work out the optimal (profit maximising) sustainable policy and compare it with the current state of the fishery. Then we try to determine an economically efficient adjustment path of the fishery from its current position to the optimal sustainable one. We work out two paths of this kind. One of them simply tries to maximise the present value of economic returns from the fishery. This path is quite dramatic in terms of shifts in fishing effort and harvests. The other path is moderate in the sense that it adjusts fishing effort and catches relatively moderately each year until the optimal sustainable levels are attained.

5.1 Optimum sustainable yield (OSY) for the hilsa fishery in Bangladesh

The sustainable fishery is a steady state or equilibrium stage of any fishery. The optimum means maximisation of the total sustainable output from the fishery. According to King (1995), optimum sustainable yield refers to “a level of yield consistent with the biological capacity of the stock (therefore usually less than MSY), which takes into account economic, sociological and environmental factors”.

Applying this model, we have calculated the optimum sustainable yield of the hilsa fishery. In this optimum yield level, the corresponding harvest is 94,7 thousand mt and the optimum sustainable fishing effort occurs at 0,33 effort level (73.163 HP). It is important to notice that it is less than the maximum sustainable effort level. This catch is lower than the current effort level but not so much. At the same effort level our spawning stock and total hilsa stock (age< 6 months) will be higher than the current situation as 417 thousand mt and 448 thousand mt respectively. At this effort level hilsa stock will be stable up to a long period of time and harvest will also be steady. We can call this yield level optimum sustainable yield of the hilsa fishery. Calculated total harvest of OSY is less than maximum sustainable yield. Sustainable yield is shown in the following Figure 12.

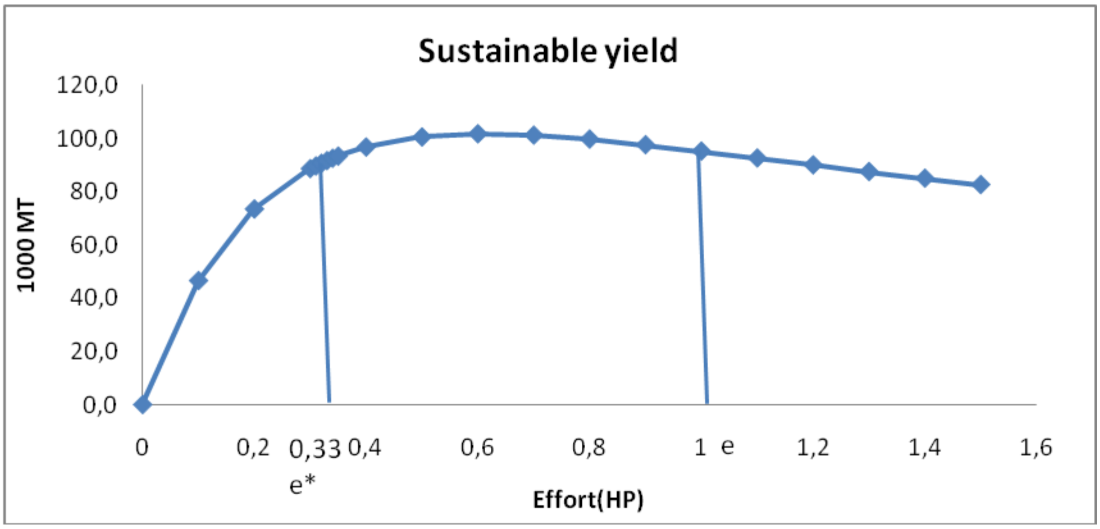

Figure 12: Sustainable yield of the hilsa fishery (per ½ year)

In the above figure e* is the OSY effort level and e is the current effort level. For all calculations the effort level 1 indicates the total number (100%) of fishing vessels as well as horse power. This above figure shows a sustainable yield curve for a six month harvest. The following figure can express the full years sustainable yield more precisely.

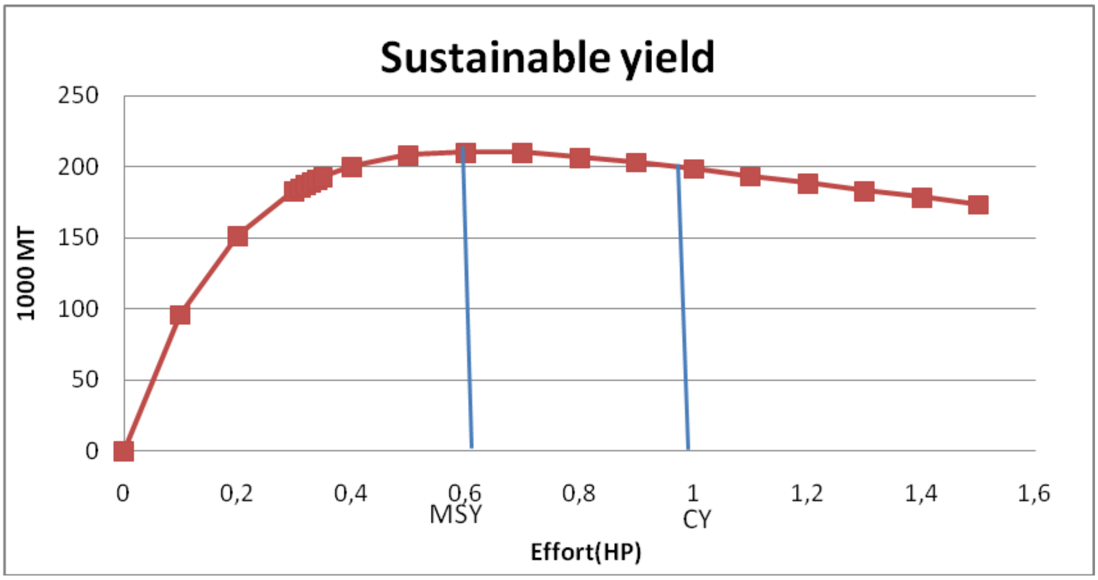

Figure 13: Sustainable yield of the hilsa fishery (per year)

From the above figure (Figure 13) the effort level of maximum sustainable yield (MSY) is 0.6. The current effort level is far from the MSY effort level. The MSY effort level is 40% less than the current effort level. According to the model calculation MSY is 211 thousand mt whereas current harvesting is 199 thousand mt which is very close to MSY. This situation indicates an over-fishing condition of the hilsa stock. So, immediate steps should be taken to control the present level of fishing pressure.

The main purpose of OSY calculation is to find a sustainable policy for hilsa fishery management. The main management objectives are to maximise the economic benefit, maximise the sustainable harvest, sustainable revenue and cost of the hilsa fishery that is calculated after running the model. The sustainable hilsa fishery is shown in Figure 14.

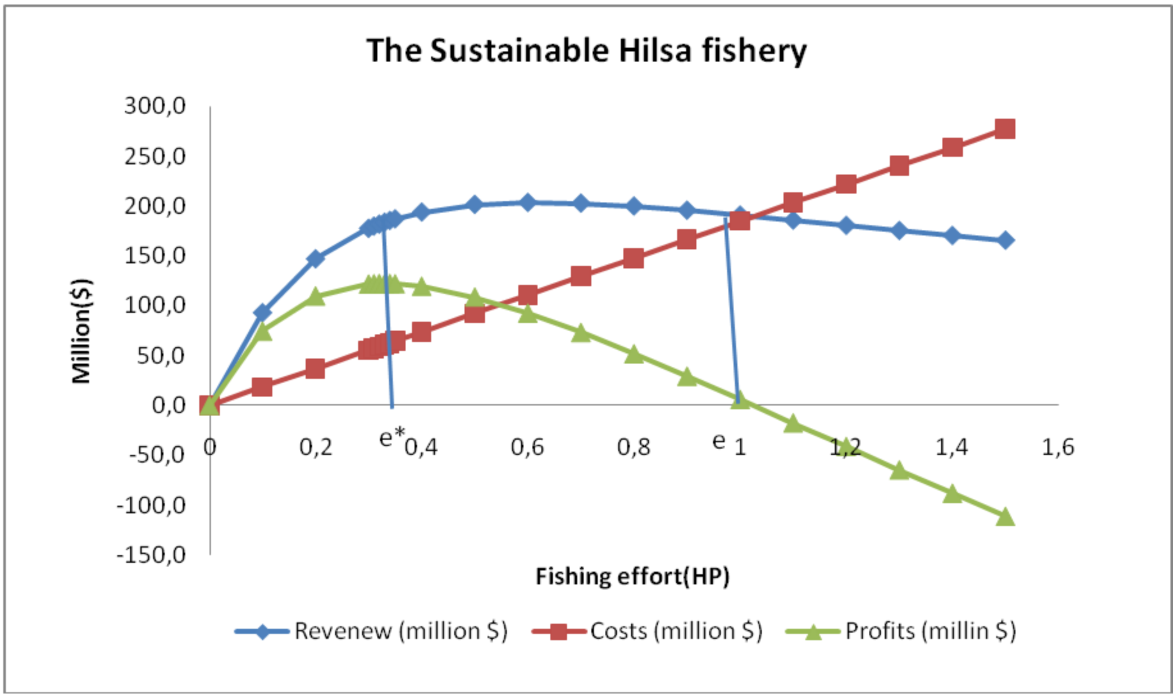

Figure 14: The sustainable hilsa fishery (per ½ year)

The revenue, profit and cost curves are depicted in Figure14. Here e* is expressed as the optimum effort level for maximising the profits of the hilsa fishery. And e is expressed as current effort level where the hilsa fishery is close to equilibrium point. In this diagram profits are defined as the difference between revenues and costs. In terms of the sustainable fisheries diagram, this occurs where the distance between the revenue curve and the cost curve is greatest.

According to the calculation, OSY level of the hilsa fishery in Bangladesh is 94.7 thousand mt and its value is US $189 million for 6 months. From that level of effort the profit will be maximised at up to US $128,5 million also for 6 months. This sustainable resource and economic growth can only be possible when the fishery is properly organised to provide for sustainable growth and maximising economic benefit. One way of achieving this is through managing the fishery at a level where a sustainable level and maximum economic benefit can be obtained. For this purpose we need to find the dynamic path of fishing efforts over time to bring the fishery to an equilibrium point.

5.2 Compare with the current situation

Without proper management policy, the hilsa fishery is generally not expected to make profits even if the fishermen act rationally. Since the net present value of the fishery is small, its contribution to economic growth will be small as well. In base year (2005) total harvested hilsa was 198 thousand mt at current effort level (221.705 HP) and its value was US $190,6 million. But in our study we consider half of the year for all calculation. So at the current effort level our half year harvesting was 99.3 thousand mt. Applying this total harvesting in our model at the same effort level, we got the current situation of the hilsa fishery. At the current situation the spawning stock and total hilsa stock (age < 6 month) are 177 thousand mt and 202 thousand mt respectively. According to Figure 14, fishing cost is relatively high (US $184,7 million) and the distance between revenues and costs is low and its value is US $13.8 million. This outcome should be compared to the maximum attainable profits at the optimal effort level, e*. Clearly, at this level of effort substantial economic profits are generated. The current situation of the hilsa fishery is very close to "0" profit level (competitive equilibrium point). That means this fishery makes little profit. Not only this, the current harvesting is very close to the maximum sustainable yield (MSY) level. If fishing effort expands like previous years, it will eventually lead to zero profit in the industry. So the present situation of the hilsa fishery wastes these rents by applying too much fishing effort.

In an open access fishery or where there is no fisheries management, individualistic competition may run down the stock causing the fishery to collapse. The current situation of the hilsa fishery is very close to open access. If the fishermen act more irrationally by tending to expect profits then the hilsa fishery may lead to resource collapse with the consequence of economic losses which will also lead to no profits in the long run. This may have a negative effect not only on the hilsa industry but also on other supporting industries and may cause large economic losses for the nation as a whole.

Table 9: Numerical comparison between the optimum situation and current situation (6 months).

Hilsa fishery	Fishing effort (HP)	Spawning stock (1000 mt.)	Total hilsa stock (age>6 m)	Total harvest (1000 mt)	Revenues (million US$)	Costs (million US$)	Profits (million US$)
Optimal fishery	0,33	417	448	95	189	61	129
Current fishery	1	177	202	99	199	185	14

5.3 Dynamic adjustment path of hilsa fishery

Once being defined, the optimal sustainable position of the fishery takes place the design of the dynamic adjustment path towards it. While running the model, we may select a path of fishing vessels that may generate fisheries outcomes (biomass, harvest and profits) over time. The objective of the study is to find an appropriate policy for the recovery of the hilsa fishery. For this the selection of a dynamic adjustment path is required. The path for the number of fishing vessels horse power will maximise the economic return from the fishery measured as present value of profits. This incidentally leads to a comparatively large and sustainable biomass. It also maximises the contribution of the hilsa fishery to the GDP and can explore better opportunities of employment for the country.

In the dynamic context the appropriate fisheries objective is to maximise the present value of profits from the fishery forever. Invariably, this implies choosing a time path for the available fisheries controls, e.g. fishing effort or harvest, so as to bring the fishery on to an optimal evolutionary path. In our simple hilsa fishery model we can describe the optimal time paths of fishing effort.

The dynamic adjustment path of the hilsa fishery can be done in two ways: present value (PV) of profits maximising path and a more moderates path. Both the paths are described in the following sections.

5.3.1 Present value (PV) or profit maximising path

The key finding of this exercise illustrates that the number of horse power as well as fishing vessels should be drastically reduced from the current number. This will build up the biomass and also generate substantial profits in the fishery. The PV or profit maximising policy for the hilsa fishery is to reduce fishing effort from the current level of 221.705 HP (25.369 vessels) to 73.163 HP (8372 vessels). This reduction of fishing effort has to be done drastically. It has to be done in five steps and every step will be taken every six months. In this path first six months is our control period. During this period, the first half of the first year we totally cut the fishing effort at 0 effort level. Then from 0 effort level we shall gradually increase the effort level every half year. For the second six months the effort level will be increased up to 0,10, for the third six months to 0,20, the fourth six months to 0,30 and finally in the fifth six months to 0,33 which means the optimal level. The main outcome of this policy is founded in the PV of profit maximising path as shown in the following figures (Figure 15, Figure 16, Figure 17, Figure 18) and detailed numerical outcomes are shown in Appendix 4 for every six months.

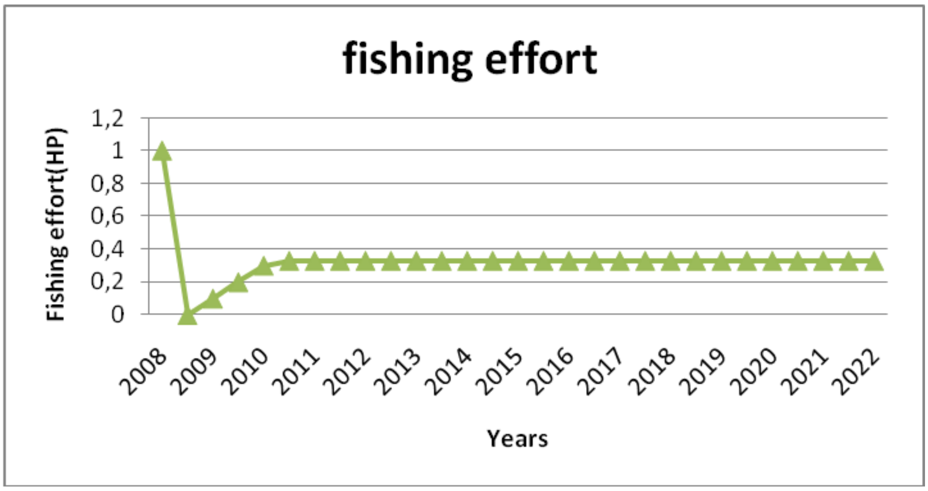

Figure 15: The fishing effort during the PV maximising path for six months.

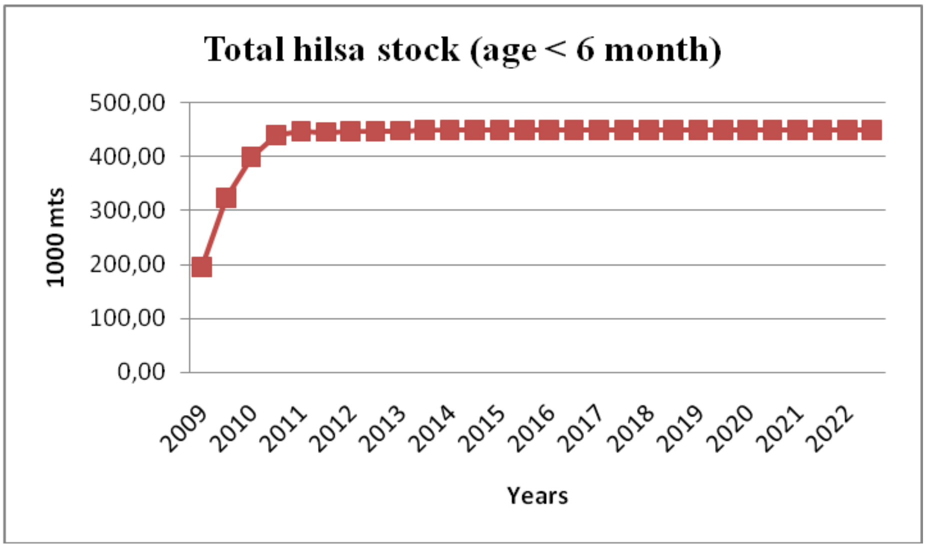

Figure 16: Response of hilsa stock to fishing effort during the PV of profit maximising path for six months.

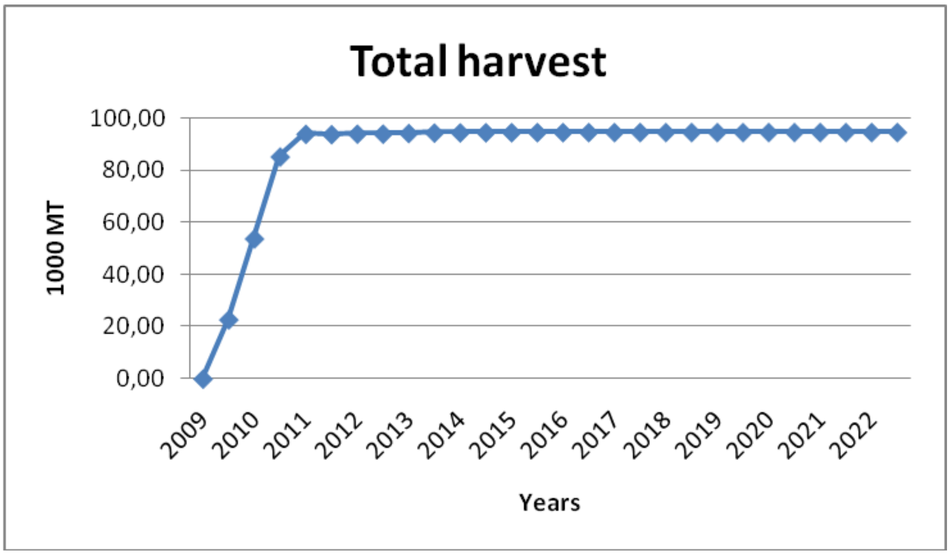

Figure 17: Status of harvest during the PV of profits maximising path for six months

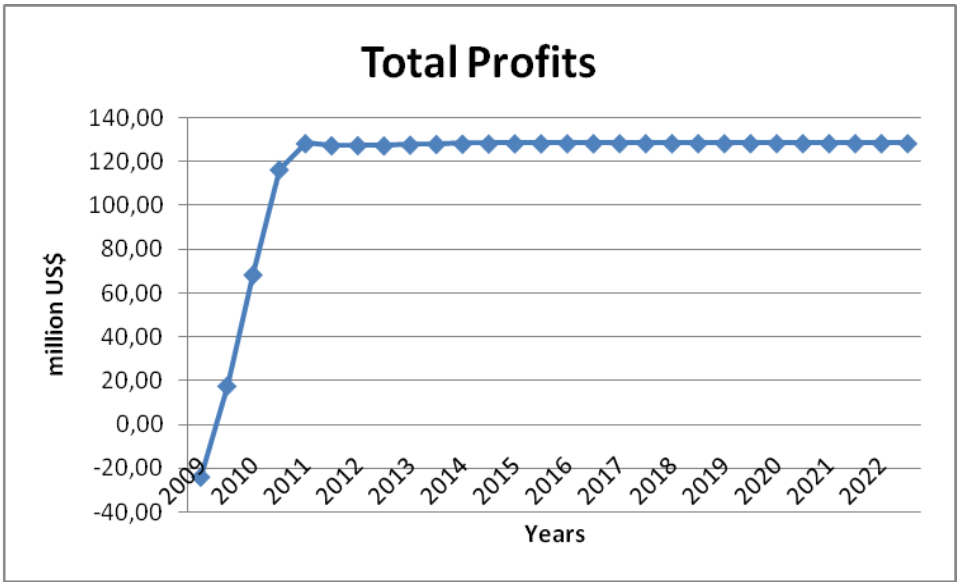

Figure 18: Profit of the hilsa fishery during the PV of profits maximising path for six months

Although the long term harvest rate corresponding to this policy is slightly less than the current level, but the stock of hilsa fish will increase significantly. After the control period the gradual increase of fishing fleets compared to the long run level is to hasten the build up of the hilsa stock (age<6 months) to the long run rent maximising level of around 448 thousand mt compared to the initial level of 194 thousand mt. Within two and half years we will reach to the optimum sustainable fishing effort level as well as the equilibrium hilsa fishery. Within this adjustment period the first six month harvest will be relatively lower and some losses will occur because of fixed cost. By adjusting this fishing effort drastically, the long run net present value of the hilsa fishery will be increased significantly. The present value of this dynamic path is found to be US $3.960 million which brings maximum economic benefits.

5.3.2 A moderate path

The moderate dynamic path for the hilsa fishery is to reduce fishing effort from the current level gradually and smoothly down to the 0,33 level for long run equilibrium of the fishery. In this path the current effort level of 221.705 HP (25.369 vessels) has been reduced to 73.163 HP (8.372 vessels). This reduction has been done in seven steps over a period of three and half years. The first six months of this policy cut the effort of 199,535 HP and then gradually to 177.364 HP, 155.194 HP, 133.023 HP, 110.853 HP, 88.682 HP and finally 73.163 HP which is the estimated optimum level of fishing effort. The main outcome of this policy is illustrated in the moderate path shown in the following figures (Figures 19, 20, 21 and 22) and detailed numerical outcomes half year by half year are shown in Appendix 5.

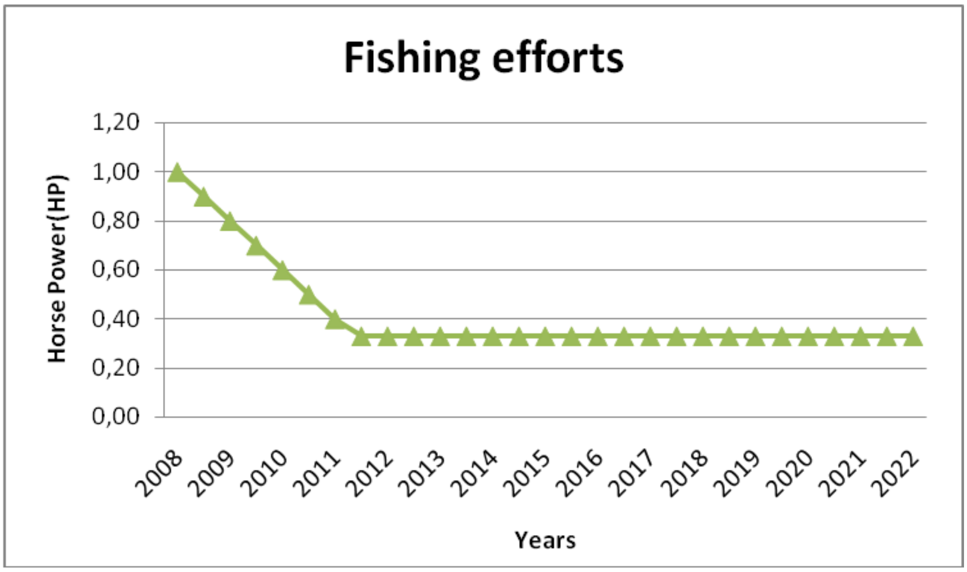

Figure 19: The fishing effort during the moderate path.

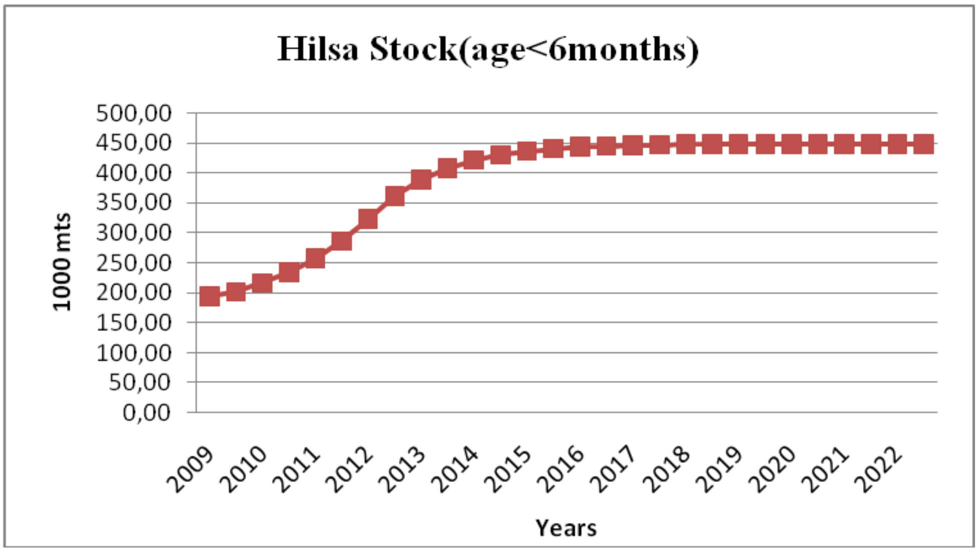

Figure 20: Response of the hilsa stock to fishing effort during the moderate path.

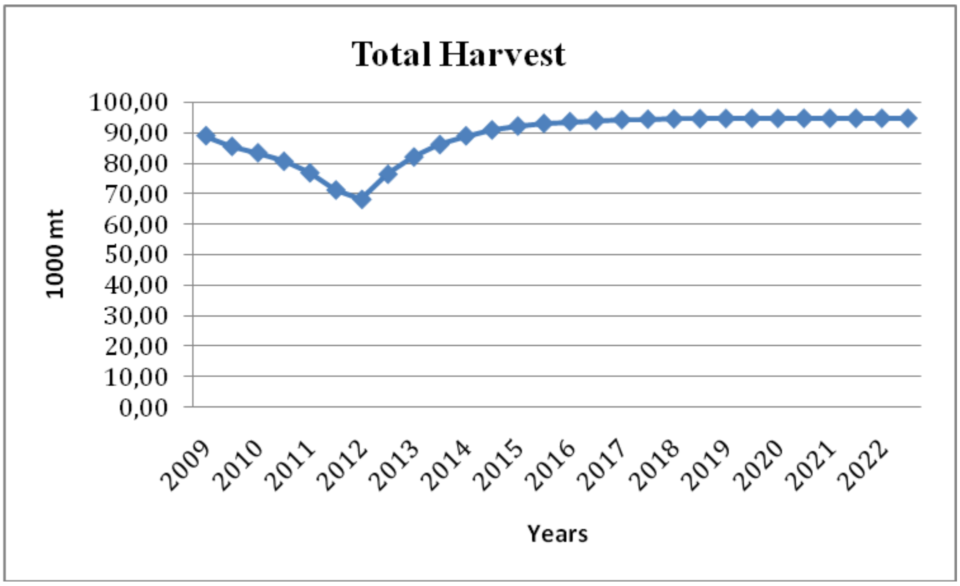

Figure 21: Status of harvest during the moderate path for six months.

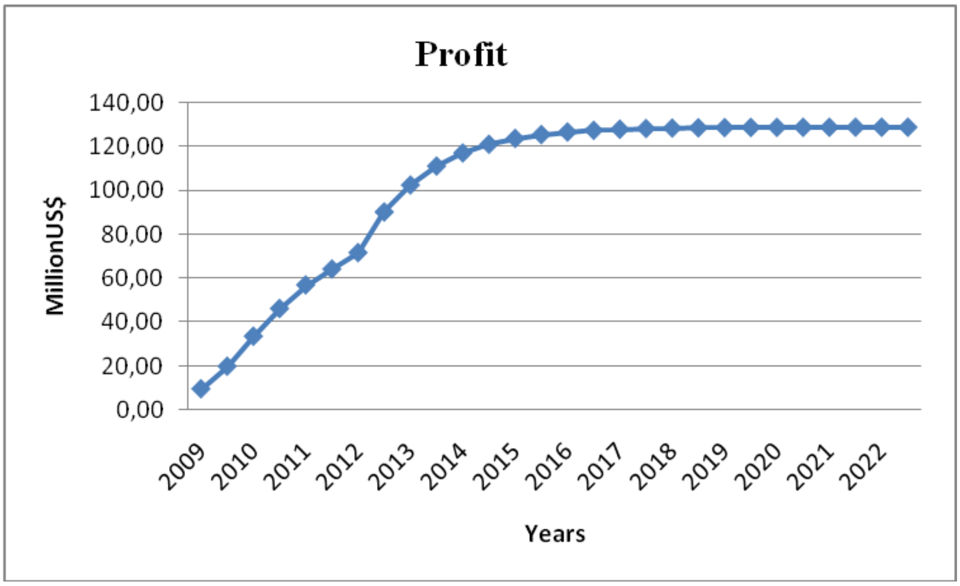

Figure 22: Profit of the hilsa fishery during the moderate path for six months.

The gradual reduction of fishing fleets compared to the long run level is to hasten the build up of the hilsa stock (age<6 months) to the long run economic benefit maximising level of around 448 thousand mt in comparison with the initial level of 194 thousand mt. This increased biomass level will ensure the sustainability of the hilsa fishery. It is observed that by applying this policy the hilsa stock is expected to fluctuate at a low scale along the path toward the long run optimal equilibrium. Under this policy the harvest is also gradually reduced and expected to be 95 thousand mt per six months at a long run optimal equilibrium due to adjusting the fishing fleet. This hilsa recovery policy of gradually reducing fishing effort could also be expected to improve economic benefits from the fishery. These economic benefits will oscillate at a low magnitude and reach an equilibrium state at US $128 million. This policy will also create a long-term net present value of US $3.650 million.

Summary of two dynamic paths

Present value maximising path	**A moderate path**
Drastic reduction of fishing effort	Gradual reduction of fishing effort
It has to be done in 5 steps and each step takes 6 months	It has to be done in 7 steps and each step takes 6 months
1st step our control period (no fishing)	This path does not have a control period
From the second 6 months we introduce fishing boats in the fishery	First 6 months 10% effort decrease from the current effort level
Second 6 months 2.537, third 6 months 5.077, fourth 6 months 7.611, finally 8.372 boats (optimum number) will operate in the fishery.	Then gradually reduce 20%, 30%, 40%, 50%, 60% and finally 66% (optimal level).
At the beginning the policy will give us a loss because of fixed costs.	At the beginning of the policy it will give some profit.
In the control period harvest will be “0” then very slowly go up.	Not much change in harvest during the path.
In this path within 12 years the fishery will reach the sustainable equilibrium level	In this path within 15 years the fishery will reach the sustainable equilibrium level
Net present value – US $3.960 million	Net present value – US $3.650 million
This path is economically superior to the moderate path.	Moderate path is more reasonable for the fishermen as well as society.

5.4 Discussion

According to the above results, the current hilsa fishery suffers greatly from excessive fishing effort and, consequently, overexploited stocks and much reduced flow of net economic benefits. This is not surprising. The hilsa fishery is essentially an open access, common pool fishery. Moreover, it is a well-established mature fishery. Both theory and the experience from numerous real fisheries have established that such fisheries invariably exhibit these features. The only real question in particular cases is the extent of the economic inefficiency and stock over-utilisation.

The model calculations indicate that the optimal equilibrium fishing effort for hilsa is only about one-third of the current fishing effort. This corresponds to a reduction in the number of fishing boats from about 25.000 to 8.400. Moreover, in sustainable equilibrium, all jatka fishing (first half year cohort) should be ended. According to the calculations; if this is not done, the fishery is in serious danger of collapse.

At the optimal sustainable equilibrium, fishing effort the calculations suggest that the total stock of hilsa is more than doubled. The spawning stock increases even more. At the same time the harvest rate is about the same, so downstream activities in the hilsa industry, landings, processing, trading, transportation etc. is largely unchanged. In fact the above calculations ignore the possibility of increased unit prices of hilsa due to higher average landing sizes and therefore prices and wider distribution of landings as the stock extends its range. Most importantly, however, according to the above, the net economic benefits derived from the hilsa fishery will greatly increase from virtually zero to over US $260 million per year. This gain, annually on a sustainable basis, can, if properly used, go a long way towards permanently improving the economic and social situation of the fishing communities.

The model shows that the average annual production of hilsa is 198 thousands mt and the estimated MSY is 210 thousand mt. The current effort level is 33% higher than the MSY effort level. The OSY (optimal sustainable yield) effort level is less than the MSY level and the sustainability of any fishery occurring at this level. From an economic point of view, MSY doesn't imply efficient harvesting relating efficiency to maximise the net benefit from the use of economic resources, i.e. maximising the resource rent (Hartwick and Olwiler 1998). Resource benefit is maximised at a lower level of effort, OSY level (Figure 14).

To move from the current hilsa exploitation level to the long run optimal takes time. Initially, in order to rebuild the hilsa stock, harvest rates will have to be reduced. Dynamic adjustment paths which maximise the present value of economic benefits over time involve quite drastic reductions in fishing effort and harvests during the first two to three and a half years. However, as demonstrated above, it is possible to define more moderate adjustment paths which maintain fairly high catch levels every year while attaining the long run OSY within a reasonable time (i.e. 10 years) and without much loss in the present value of economic benefits (perhaps 10%). Such paths may well be socially more acceptable and, therefore, feasible.

Limitations of the study

- The simple hilsa model that we have built and used for this study is not a true model. It is a supplementary model. This model only considers fishing effort as a factor influencing the hilsa catch. Other determinants of fish catch such as annual changes in weather were excluded. In the future it is necessary to study other factors influencing fishing. Besides this, the model developed here can later be extended and refined by more reliable data.

- It must be pointed out that much of the data used in the model can cause data error. These assumed data and parameters might reflect a false result creating a great concern for the reliability and accuracy of the data. For future study the emphasis should be given to get the real data in a uniform way.

- The benefits and findings of the study will not be static forever. It is not reliable in the course of time as there is a possibility of change in the biological and ecological conditions of hilsa. If such change occurs the outcome will not be reliable. This is the uncertainty of the policy.

- The fishing effort levels and profits generated by the study depend to a large extent on the price of fish and cost of fishing assumed in the analysis. Any fall in price or an increased cost of effort, for instance, may substantially reduce the value of estimated profits. Vice versa the same thing will happen. Similarly the possibility of cost reduction is less rather it will increase. In the future, study that will produce accurate and variable fish and effort prices will be helpful.

Although, the model used here is quite simple and the estimates of the empirical parameters in many respects are not particularly reliable, the overall tenor of these outcomes is quite believable. Because the hilsa fishery is open access, common pool character with over crowding fishing efforts is similar to other artisanal fisheries.

Benefits from the policy implementation

We assume that the model we used to construct the dynamic path is true. The policy which is created through model simulation is implemented in the hilsa fishery, we will get social and economic benefits. The impact of optimum sustainable yield and corresponding dynamic paths with maximising the present value of profits of the hilsa fishery can be described as follows:

Economic benefit: By reducing the fishing effort by two third (66%), we will gain 258 million US$ annually. This profit is nine times higher than the base year (US $28 million). The policy of reducing the fishing effort is not only expected to improve profits of the fishery but also to create a long run net present value of US $3.959 million. The expected net present value can be used by the government or by fishing companies as collateral for loans to meet difficulties during the period of stock rebuilding and to fund investment opportunities. The government can utilise the excess profit for funding management activities such as data collection and storage, management and dissemination, research activities, monitoring, control and surveillance, extension, awareness, quality control and others. The profit can also contribute to the national coffers and social development activities. Giving 8.372 boat owners' registration (license) or individual quotas through their vessel of 12 mt per half year may encourage some companies to invest in processing factories to process hilsa and increase value added to the product for a higher price in the international market or even the local market. Processing companies will create more employment for the community. The labourers who are unemployed by cutting fishing effort can be re-absorbed in the fish processing factories. Thus, economically, there is no net loss to the community and fishing industry. Overall, this policy will stimulate fast development of the fishery. Hence, social welfare and development of the hilsa and jatka fishers' community will be established.

Control the over-fishing of hilsa: A fishery is not sustainable if total catch exceeds the MSY level. In this study the current effort level is 33% higher than the MSY effort level. In the base year, the average catch of hilsa was 198 thousand mt and estimated MSY was 210 thousand mt (Figure 12b) which indicates over-fishing of the fishery. By reducing effort level to the OSY point, the fishery will be sustainable for the long run. Thus control of over-fishing could be possible.

Increase of CPUE: According to the previous description, the hilsa fishery has suffered by serious declining of CPUE in both river and marine sectors. The base year CPUE was around 8 mt per year. By implementing this policy, the CPUE will significantly increase. CPUE at OSY effort level will be 23 mt per year.

Employment impacts of effort reduction: A reduction in fishing effort to attain OSY will raise productivity of the hilsa fishery. On the other hand, it will also result in the unemployment of fishermen. In view of the social and equity considerations people need to be accommodated within the fishing sector. However, withdrawing fishing would mean a reduction in costs as well as an increase in the resource rent, which could be used to compensate the unemployed fishing people. Furthermore, diversification of skills could be done to make them more suitable for non-fishing sectors.

Rehabilitation of fishermen: Through implementation of the policy, the sustainable hilsa fishery will be making a good profit. But at the same time many fishermen will be out of work. We calculated that 253.690 fishermen employed in 25.369 fishing vessels at the present time. When we will reduce the fishing effort to 8.372 vessels, a number of 169.970 fishermen will lose their jobs. With this excess profit, it can be easy to rehabilitate the jobless fishermen. According to the optimum sustainable hilsa fishery, the profit will be US $129 million per year. If the average income of hilsa and jatka fishermen was US $800, we can easily rehabilitate 161.250 fishermen within this sector by creating other alternative jobs.

Utilisation of fishing vessels: A comprehensive plan must be chalked out to make the best use of vessels which will be banned. It can be organised in different ways. A major portion of vessels should be utilised for carrying people and seasonal goods from one place to another. A good number of these vessels must be utilised for tourism. And also some of these vessels should be utilised for research and education. We should always consider keeping people of fisheries in the relevant field. To employ them in the same field will help the industry grow bigger than before exploring many more opportunities for the economy of the country.

6 SUMMARY AND POLICY RECOMENDATIONS

The Government of People's Republic of Bangladesh has taken very effective action plans to stop catch of jatka. But no real effort until now has taken place to reduce the continuous rise in fishing effort. If the number of fishing boats increases as the population grows at an alarming rate, it appears that the biomass will also fall. In the artisanal gill net fishery (hilsa fishery), the major concern is the presence of an oversized effort capacity. Given that effort could be reduced to economically efficient levels (represented by the results of the base model) the existing marine hilsa fishery is capable of generating substantial net present value of economic benefits.

The purpose of this study is to assess the artisanal hilsa fishery of Bangladesh and determine an effective policy that will maximise economic benefits while ensuring the sustainability of the fishery. The bio-economic model developed here shows that the fishing effort required to make the hilsa fishery attain maximum economic benefit and ensure sustainable biomass growth is 73.163 (HP) standard units (8.372 vessels) and also compare it to the current state of the fishery. For this purpose we determined an economically efficient dynamic adjustment path of the fishery. Dynamic adjustment path which maximises the present value of economic benefits is US $3.960 million which over time involves quite drastic reductions in fishing effort and harvests during two and half years. On the other hand, a moderate adjustment path maintains reasonably high catch levels every year while attaining the long run OSY without much loss in the present value of economic benefits. It indicates that the best fishery policy is to reduce the current fishing effort of 25.369 vessels to 8.372 fishing vessels. For the Fisheries Division to achieve its objective, the policy of reducing 16.997 fishing vessel (148.542 HP) from the current 25.369 (221.705 HP) vessels is the best policy for ensuring good biomass growth and maximise the profits.

However, as discussed above the reduction of fishing effort by reducing fishing vessels in most cases does not keep effort down due to inherent behavior of fishers to invest more and more in technology to elude regulations to reduce effort. This policy must, therefore, be supported by other measures to ensure that effort reduction does not translate into increased competition among the remaining vessels.

While effort reduction should be a primary goal in the artisanal fisheries, the impact of such reduction in terms of equity is important. That is, there should be a strong balance between efficiency and equity objectives. An isolated policy to simply lower effort will likely to be more difficult to implement because artisanal fishing is largely subsistence in nature and a matter of survival for the fishermen community (Waters 1991). Forcing them out of their livelihood without an acceptable alternative employment program will be viewed by many as inequitable and morally unacceptable. Hence, retaining an employment program will be necessary.

A potential option is for the government and private sector is to pool their resources and organise such programs as promotion of eco-tourism and dispersion of industrial development into the rural coastal areas where more fishermen are employed in these establishments, the less will be the fishing effort.

The government should chalk out a comprehensive plan for the best use of banned vessels. The best use of the banned vessels will be for transportation of people and seasonal goods from one place to another, tourism and for research and education.

Policies that recognise and incorporate indigenous fishing communities will most likely be successful if sufficient authority and power are delegated to the local level (Charles 2001). These will help the local communities acquire the direct responsibility for management and protection of the hilsa fishery and other marine resources. The emphasis should be placed on educating local fishing communities on the effects of unsustainable fishing and the benefits of managed fishery resources. In this case, a community-based management and conservation approach, where the local people are integrated into the management system and their indigenous knowledge of fishes and other marine resources is utilised in designing management, is a good example. Apart from these, the effective enforcement of existing fishery regulations must be pursued.

To implement the current policy, management measures need to be imposed mainly to preserve the fish stock from depletion and to protect the economic position of the fishing society. To protect the stock and improve the economic performance of the fishery in the longer term, a number of management options are available. The most appropriate options should be taken for a sustainable hilsa fishery. Finally, in order to shed more light on the current traditional exploitation, qualitative and quantitative studies have to be conducted at smaller scales to record more detailed information. In addition, better monitoring of fish landings is necessary for the formulation of viable management. Thorough understanding of the exploitation patterns by regular monitoring of resources provides suitable baseline information which is a vital requirement for rational use, especially at this time when there is a growing gap between population increase and the availability of food (fish supply).

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Appendix 1: Total hilsa harvest from both inland and marine sector of Bangladesh (1987-2006)

Year	Hilsa catch		
	Inland Fisheries	Marine Fisheries	Total
1986-1987	91.167	103.814	194.981
1987-1988	78.551	104.950	183.501
1988-1989	81.641	110.311	191.952
1989-1990	112.408	113.943	226.351
1990-1991	66.809	115.358	182.167
1991-1992	68.356	120.106	188.462
1992-1993	74.715	123.115	197.830
1993-1994	71.370	121.161	192.531
1994-1995	84.420	129.115	213.535
1995-1996	80.625	126.660	207.285
1996-1997	83.230	131.204	214.434
1997-1998	81.634	124.105	205.739
1998-1999	73.809	140.710	214.519
1999-2000	79.165	140.367	219.532
2000-2001	75.060	154.654	229.714
2001-2002	68.250	152.343	220.593
2002-2003	62.944	136.088	199.032
2003-2004	71.001	184.838	255.839
2004-2005	77.499	198.363	275.862
2005-2006	78.273	198.850	277.123
2006-2007	80.453	199.875	280.328

Appendix 2: The total number of mechanized and non-mechanized boats (MB and NMB) operated in the marine sector and catch/boat/year. (FRSS, DoF: 1984 to 2006)

years	Number of boats			Hilsa catch (MT)			Av. Catch/boat/year		
	MB	NMB	Total	MB	NMB	Total	MB	NMB	Total
1983/84	3.347	-	3.347	56.000	0	56.000	16,7	0	16,7
1984/85	3.000	-	3.000	71.050	0	71.050	23,7	0	23,7
1985/86	2.887	3.802	6.682	88.389	7.905	96.294	30,6	2,08	14,4
1986/87	2.887	3.800	6.680	94.851	8.963	103.814	32,9	2,36	15,5
1987/88	2.882	3.509	6.389	91.723	13.227	104.950	31,9	3,76	16,4
1988/89	2.880	3.509	6.389	94.990	15.321	110.311	33,0	4,37	17,3
1989/90	2.880	3.509	6.389	95.285	18.658	113.943	33,1	5,32	17,8
1990/91	2.880	3.509	6.389	97.573	17.785	115.358	33,9	5,06	18,1
1991/92	2.880	3.509	6.389	102.036	18.070	120.106	35,4	3,14	18,8
1992/93	2.880	3.509	6.389	105.128	17.997	123.115	36,5	5,13	19,3
1993/94	2.880	3.509	6.389	103.839	17.322	121.161	36,1	4,94	19,0
1994/95	2.880	3.509	6.389	111,475	17.640	129.115	38,7	5,03	20,2
1995/96	2.880	3.509	6.389	109.282	17.378	126.660	37,9	4,95	19,8
1996/97	2.880	3.509	6.389	114.921	16.283	131.204	39,9	4,64	20,5
1997/98	2.880	3.509	6.389	110.440	13.059	124.105	38,3	3,72	1,40
1998/99	2.880	3.509	6.389	121.909	18.761	140.710	42,3	5,35	22,0
1999/00	18.982	7.177	2.616,9	119.295	21.072	140.367	6,3	2,94	5,40
2000/01	18.982	6.377	2.536,9	131.254	23.400	154.654	6,91	3,67	6,00
2001/02	18.982	6.377	2.536,9	131.619	20.724	152.343	6,93	3,24	5,90
2002/03	18.982	6.377	2.536,9	114.274	21.814	136.088	6,02	3,42	5,36
2003/04	18.982	6.377	2.536,9	157.570	27.268	184.838	8,30	4,28	7,29
2004/05	18.982	6.377	2.536,9	170.756	27.607	198.363	9,00	4,33	7,82
2005/06	18.982	6.377	2.536,9	170.945	27.905	198.850	9,00	4,38	7,84

Appendix 3: Output of the model run for calculation of OSY

Fishing effort (HP)	Spawning stock (1000 mt.)	Total hilsa stock (age>6 m)	Total harvest (1000 mt)	Revenew (Million US$)	Costs (million US$)	Profits (Million US$)
0	806,6	841,2	0,0	0,0	0,0	0,0
0,1	645,3	679,0	48,0	95,9	18,5	77,5
0,2	527,3	559,9	75,8	151,5	36,9	114,6
0,3	439,0	470,7	91,5	183,1	55,4	127,7
0,31	431,5	463,0	92,7	185,3	57,3	128,1
0,32	424,1	455,6	93,7	187,4	59,1	128,3
0,33	417,0	448,3	94,7	189,0	61,0	128,5
0,34	410,0	441,2	95,6	191,3	62,8	128,5
0,35	403,2	434,3	96,5	193,0	64,6	128,3
0,4	371,7	402,3	100,1	200,1	73,9	126,2
0,5	319,4	349,0	104,1	208,2	92,4	115,9
0,6	278,1	306,6	105,1	210,9	110,8	100,1
0,7	244,9	272,5	105,1	210,1	129,3	80,8
0,8	217,9	244,5	103,1	207,3	147,8	59,5
0,9	195,6	221,4	101,6	203,3	166,2	37,0
1	177,1	202,0	99,3	198,5	184,7	13,8
1,1	161,6	185,6	96,7	193,5	203,2	-9,7
1,2	148,4	171,7	94,2	188,3	221,6	-33,3
1,3	137,2	159,7	91,6	183,3	240,1	-56,9
1,4	127,6	149,4	89,2	178,3	258,6	-80,3
1,5	119,2	140,4	86,8	173,6	277,1	-103,4

Appendix 4: Output of the model run for PV of profit maximizing path during the adjustment for hilsa fishery.

Years	Spawning stock	Total hilsa stock (age<6 months)	Fishing effort	Total harves (1000 mt)	Revenues (m. US$)	Fixed costs	Total costs (m.US$)	Profits (m.US$)	PV
2008			1,00			48.40			
2009	170,04	193,88	0,00	0,00	0,00	24,20	24,2	-24,20	-23,49
2009	298,38	322,22	0,10	22,77	45,54	14,52	28,1	17,39	16,39
2010	373,40	397,86	0,20	53,83	107,67	12,10	39,4	68,31	62,51
2010	409,58	438,68	0,30	85,31	170,63	13,31	54,2	116,43	103,45
2011	414,51	445,16	0,33	94,04	188,07	14,64	59,6	128,45	110,80
2011	413,19	444,42	0,33	93,88	187,76	15,31	60,3	127,47	106,76
2012	414,05	445,35	0,33	94,08	188,15	15,64	60,6	127,53	103,70
2012	414,20	445,48	0,33	94,10	188,21	15,80	60,8	127,42	100,59
2013	415,21	446,50	0,33	94,32	188,64	15,89	60,9	127,77	97,92
2013	416,02	447,32	0,33	94,49	188,98	15,93	60,9	128,07	95,30
2014	416,38	447,69	0,33	94,57	189,14	15,95	60,9	128,21	92,62
2014	416,58	447,91	0,33	94,62	189,23	15,96	60,9	128,29	89,98
2015	416,71	448,04	0,33	94,64	189,29	15,97	60,9	128,34	87,39
2015	416,80	448,13	0,33	94,66	189,32	15,97	60,9	128,37	84,87
2016	416,86	448,19	0,33	94,68	189,35	15,97	61,0	128,40	82,42
2016	416,90	448,23	0,33	94,68	189,37	15,97	61,0	128,42	80,03
2017	416,92	448,26	0,33	94,69	189,38	15,97	61,0	128,43	77,70
2017	416,94	448,28	0,33	94,69	189,39	15,97	61,0	128,44	75,44
2018	416,95	448,29	0,33	94,70	189,39	15,97	61,0	128,44	73,25
2018	416,96	448,29	0,33	94,70	189,40	15,97	61,0	128,44	71,12
2019	416,96	448,30	0,33	94,70	189,40	15,97	61,0	128,44	69,05
2019	416,96	448,30	0,33	94,70	189,40	15,97	61,0	128,45	67,04
2020	416,97	448,30	0,33	94,70	189,40	15,97	61,0	128,45	65,08
2020	416,97	448,31	0,33	94,70	189,40	15,97	61,0	128,45	63,19
2021	416,97	448,31	0,33	94,70	189,40	15,97	61,0	128,45	61,35
2021	416,97	448,31	0,33	94,70	189,40	15,97	61,0	128,45	59,56
2022	416,97	448,31	0,33	94,70	189,40	15,97	61,0	128,45	57,83
2022	416,97	448,31	0,33	94,70	189,40	15,97	61,0	128,45	56,14
								3255,99	3959,34

Appendix 5: Output of the model run for calculates the moderate path of adjustment for hilsa fishery.

Years	Spawning stock	Total hilsa Stock (>6months)	Fishing effort	Total (1000 mt)	Revenues (m. US$)	Fixed costs	Total costs (m.US$)	Profits (m.US$)	PV
2008			1.00			48.40			
2009	170,04	193,88	0,90	89,02	178,03	45,98	168,65	9,38	9,11
2009	177,90	201,74	0,80	85,52	171,04	42,35	151,39	19,65	18,52
2010	191,88	216,34	0,70	83,42	166,85	38,11	133,53	33,32	30,49
2010	209,67	234,54	0,60	80,64	161,29	33,57	115,36	45,93	40,81
2011	232,08	257,62	0,50	76,86	153,71	28,89	97,04	56,67	48,88
2011	260,30	286,60	0,40	71,27	142,54	24,12	78,65	63,89	53,51
2012	295,72	322,87	0,33	68,20	136,41	20,05	65,03	71,38	58,04
2012	333,69	361,75	0,33	76,42	152,83	18,01	62,99	89,84	70,92
2013	359,40	388,43	0,33	82,05	164,11	16,99	61,97	102,13	78,28
2013	377,78	407,67	0,33	86,12	172,23	16,48	61,46	110,77	82,42
2014	390,74	421,14	0,33	88,96	177,92	16,23	61,21	116,72	84,32
2014	399,55	430,27	0,33	90,89	181,78	16,10	61,08	120,70	84,66
2015	405,45	436,38	0,33	92,18	184,36	16,03	61,02	123,35	83,99
2015	409,38	440,46	0,33	93,04	186,08	16,00	60,98	125,10	82,71
2016	412,01	443,18	0,33	93,62	187,23	15,99	60,97	126,27	81,05
2016	413,74	444,97	0,33	93,99	187,99	15,98	60,96	127,03	79,16
2017	414,86	446,13	0,33	94,24	188,48	15,97	60,96	127,52	77,15
2017	415,60	446,89	0,33	94,40	188,80	15,97	60,95	127,85	75,10
2018	416,08	447,38	0,33	94,50	189,01	15,97	60,95	128,06	73,03
2018	416,39	447,70	0,33	94,57	189,15	15,97	60,95	128,19	70,98
2019	416,59	447,91	0,33	94,62	189,23	15,97	60,95	128,28	68,96
2019	416,72	448,05	0,33	94,65	189,29	15,97	60,95	128,34	66,98
2020	416,81	448,14	0,33	94,67	189,33	15,97	60,95	128,38	65,05
2020	416,87	448,20	0,33	94,68	189,36	15,97	60,95	128,40	63,17
2021	416,90	448,24	0,33	94,69	189,37	15,97	60,95	128,42	61,33
2021	416,93	448,26	0,33	94,69	189,38	15,97	60,95	128,43	59,55
2022	416,94	448,28	0,33	94,69	189,39	15,97	60,95	128,44	57,82
2022	416,95	448,29	0,33	94,70	189,39	15,97	60,95	128,44	56,14
								2.880,88	3.653,39

Appendix 6: National Legislation for Marine Zones and Fishing

(1) *Territorial Waters and Maritime Zones* Act 1974 (Act no XXVI of 1974).
This Act provides for declaration of various maritime zones:

i. Territorial waters: Territorial waters extend to 12 nautical miles beyond the coast of Bangladesh, and also include all internal waters.
ii. Contiguous zone: The zone of the high seas contiguous to the territorial waters and extending seawards to a line of 6 nautical miles measured from the outer limits of the territorial waters was declared to be the contiguous zone of Bangladesh.
iii. Economic zone: The zone of the high seas extending to 200 nautical miles measured from the baseline is the Exclusive Economic Zone of Bangladesh.
iv. Conservation zone: Through official notification, the Government may establish conservation zones in areas adjacent to the territorial waters.
v. Continental Shelf: The continental shelf of Bangladesh is comprised of (a) the seabed and subsoil of the sub-marine areas adjacent to the coast of Bangladesh, and (b) the seabed and subsoil of the analogous submarine areas adjacent to the coast of any island, rock or any composite group constituting part of the territory of Bangladesh.

(2) *The Marine Fisheries Ordinance, 1983 (Ordinance No. XXXV of 1983)*

(i) *The Marine Fisheries Ordinance, 1983* (Ordinance No. XXXV of 1983, July 19, 1983).
(ii) *The Marine Fisheries Rules, 1983* (No. S.R.O. 349 - L/83, September 8, 1983 of Ministry of Agriculture, Fisheries and Livestock Division).
(iii) *The Marine Fisheries Rules (Amendment), 1992* (No. S.R.O. 275 - Rule/92, December 1992 of the Ministry of Fisheries and Livestock).

This *Marine Fisheries Ordinance, 1983* made provisions for the management, conservation and development of marine fisheries for water bodies with a depth in excess of 50 metres. Any body of water under 50 metres depth is reserved for small-scale fisheries. All trawlers are required to obtain a fishing license for a year, which then allows them to fish within the 200 nautical mile maritime boundary of Bangladesh. Each trawler must be granted sailing permission from the Directorate of Fisheries for every voyage. Mechanized boats have been
brought under a licensing system in accordance with *Amendment 92* of the *Marine Fisheries Ordinance, 1983*. Since January 2001, all non-mechanized boats have also been included under the licensing system. (GOB, 1994).