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TOWARD OPTIMAL USE OF BANGLADESH HILSA RESOURCE: BIOECONOMIC MODELLING

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ABSTRACT

The hilsa shad (*Tenualosa ilisha*) fishery is the largest single species fishery of Bangladesh managed under open access system and was chosen for the study. The purpose of the study was to develop optimal policy to assess the optimal exploitation of the fishery. The objective was to maximize the net benefit of the fishery and rebuilding of hilsa stock. Schafer model was chosen to construct the bioeconomic model and to provide an optimal sustainable fishery. Aggregate harvest and effort data was used. Economic parameter on fishing effort, investment and operation cost was gathered as inputs of the model. Sustainable hilsa fishery model was developed indicating unstable and collapse of the fishery at current effort level. Optimal equilibrium model showed effort can be higher than the sustainable fishery but lower than the biomass. The most efficient effort control time path to traject the fishery to optimal sustainable yield (OSY) by giving the highest present value was calculated showing that moderate adjustment path is more acceptable. The path shows that present value and the sustainable biomass was reasonable within the 20-year management horizon. The path could increase the biomass about 27% and net present value about US $7 billion.

Keywords: Sustainable fishery, Hilsa shad, optimal, moderate, adjustment path.

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ABRREBIATIONS

ARDMCS : Aquatic Resources Development, Management and Conservation Studies
BFRI : Bangladesh Fisheries Research Institute
BBS : Bangladesh Bureau of Statistics
BOBLME : Bay of Bengal Large Marine Ecosystem (project)
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
SMB : Standardised Mechanized Boat
OSY : Optimum Sustainable Yield
NPV : Net Present Value

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1 INTRODUCTION

Bangladesh, one of the emerging market economies has consistently posted positive economic growth during the last three decades. In spite of the global economic crisis an average growth of 6 percent has been monitored in the last three years. More than 5 percent growth in agriculture sector during the last two years and substantial growth in industry and service sector has contributed to this growth performance (Bangladesh Economic Review 2013).

Bangladesh is a riverine country blessed with many rivers-canals, depressions, oxbow lakes, ponds and floodplains, covering an area of 4.699 million hectares. The coast line is 710 km and marine waters within the 200 nm EEZ 111,631 km^2 (DOF 2013). Since time immemorial, these inland, coastal and marine water have been sources of fish for human consumption and fish is the indispensable part in the life and livelihoods of the peoples of this country as well as part of national cultural heritage. Fisheries sector has been playing a vital role in the socio-economic development of Bangladesh. This sector also has high potential for economic development (DOF 2013).

Hilsa (*Ilish*) is the national fish of Bangladesh and contributes about 10% of the country’s total fish production. Hilsa catches in Bangladesh represent about 60% of global hilsa production. It occurs in inland, marine and coastal water and is harvested throughout the year in Bangladesh (Halder 2002). In 2011-12, total hilsa production was about 347 thousand mt worth about US $ 1.4 billion and contributes 1% to the GDP.

Until 1972, the hilsa fishery of Bangladesh was restricted to the upstream rivers, mainly the rivers Padma, Meghna, Krakatoa, 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 in India located 10 km from the border with Bangladesh disrupts the migration route and contributes to the loss of spawning and nursery ground of the species and indiscriminate exploitation of juveniles (Halder 2002). It is established by the existing fish population dynamics study that hilsa fish are harvested at a higher level than the optimum fishing mortality, exploitation rate is higher than the optimal level, fishery is suffering by recruitment over fishing, the exploitation indicating a trend towards a high pressure in the hilsa stock and recommendation was to reduce level of fishing effort or to increase the mesh size (Miah *et al.* 1997, Amin *et al.* 2002, Amin *et al.* 2008). In addition, according to Amin *et al.* (2008), the hilsa stock may collapse near future due to an increase rate of exploitation.

The Bangladesh hilsa is a common property artisanal fishery resource which is exploited by millions of artisanal fishermen. Varieties of fishing gear and fishing boats are used throughout the year in the hilsa fishery (Halder 2004a). The number of fishermen and fishing effort was increased due to the high demand of the fish both in local and export market. In certain upstream areas this process has ended and even reversed itself because of lack of fish. 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 conducted in 2002-03 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 fishery (Halder 2004b).

Fish stocks are renewable natural resources and a comprehensive management approach is essential to maximise the sustainable benefits. The resources must be protected from irreversible damage and management should be on a sustainable level. The present situation of the hilsa fishery suggests that proper assessment of the fishery is necessary and finding a way to stimulate the recovery the fishery and make it sustainable while maximising economic benefits.

The importance of the hilsa fishery in Bangladesh as well as in the Bay of Bengal Region is well known. Millions of people are directly or indirectly involved in this fishery. Any negative changes in the fishery will must effect those people seriously. In spite of the importance of the fishery, still up-to-date biological studies are not available and there are a very few studies of the economics of the fishery. To maintain and enhance the hilsa catch mainly biological management and controls have been implemented. However, according to the hilsa scientist these measures are not enough to prevent over fishing and to generate the flow of net economic benefits by utilising the stock or even informing the managing authority of the socially and economically acceptable optimal fishing effort levels.

Both the marine and river hilsa resources of Bangladesh are equally important. But the reliable effort data for the river fishery is not available. Therefore, this study is restricted to analyse the real catch and effort data of the marine artisanal hilsa fishery and to assume effort data for the river fishery to include both sector’s catch and effort more importantly. However, because of the upstream spawning migrations of the hilsa, management policy will be more or less same for both of the marine and river hilsa fishery.

The overall objective of the study is to develop a bio-economic model for the hilsa fishery resource of Bangladesh that describes the status of the hilsa fishery for current exploitation level and optimal use of the hilsa Resource. More specifically the objectives of the proposed study are:

1) Assessment of the current status of the hilsa fishery.
2) Development of a bioeconomic model to recommend sensible policy for the optimal use of Bangladesh hilsa resource.
3) Propose a theoretical solution for effort controls trajectories in stock rebuilding of hilsa fish.
4) Development of progressive policy recommendations for the implementation of the constructed model.

To achieve these objectives a simple static and dynamic bioeconomic model will be developed. On the basis of the model, a reasonable effort control and sensible profit maximizing policy recommendations will be made for hilsa fishery to manage from the current level to an optimal dynamic level.

The findings will add more baseline information regarding the bio-economics of the hilsa fishery management and it will provide some primary idea concerning the optimal sustainable utilisation of the hilsa stock. Recommendations for regulating the fishing effort over time leading to the hilsa recovery process may be derived and policy makers will be able to design management policy for the optimal use of the hilsa resources which could be useful to prevent social and biological overexploitation of the hilsa fishery.

2 BACKGROUND

2.1 General overview of Bangladesh

Bangladesh emerged as an independent and sovereign country in 1971 following a nine-month war of liberation. The country which has a total area of 147,570 km^2 encompasses one of the largest deltas of the world, the Ganges-Brahmaputra delta, which covers approximately two-third of the country's surface. The country is covered with a network of rivers and canals forming a maze of interconnecting channels (Figure 1).

Figure 1: Geographic location of Bangladesh with major rivers (GraphicMaps.com).

Bangladesh has a population of about 152 million, making it one of the most densely populated countries of the world. It borders with India in the west, north, and east, with Myanmar in the southeast. The Bay of Bengal, a productive and important fishing area, is to the south of the country (Figure 1) (BBS 2014).

2.2 Fisheries Sector of Bangladesh

Fisheries Sector has played a vital role in the socio-economic development of Bangladesh. It contributes 4.4% to the national GDP and almost one-fourth (23%) to the agricultural GDP (Bangladesh Economic Review 2012). About 11% (16.5 million) of the total populations depends directly or indirectly on the fisheries sector for their livelihoods (DOF 2012). In recent years, this sector has exhibited a high growth rate of value-added in comparison to other agricultural sectors. The GDP growth rate of fisheries sector over the last 10 years has been fairly steady, varying between 4. 8 to 7.3 percent with an average of 5.6 percent. Fisheries sector contributed about 2.5% of national export earnings in the year 2011-12. It provides about 60% of the animal protein intake (DOF 2012).

Bangladesh is one of the world's leading fish producing countries with a total production of 3.26 million mt in the year 2011-12 (DOF 2012). According to available statistics, the total fish production of the country has exhibited a consistently increasing trend during the last 25 years (Figure 2). Over this period, it increased almost four times from 0.83 million mt in 1987-88 to 3.26 million mt in 2011-12 (DOF 2012). The fisheries production of the country is traditionally divided into three major groups, i.e.

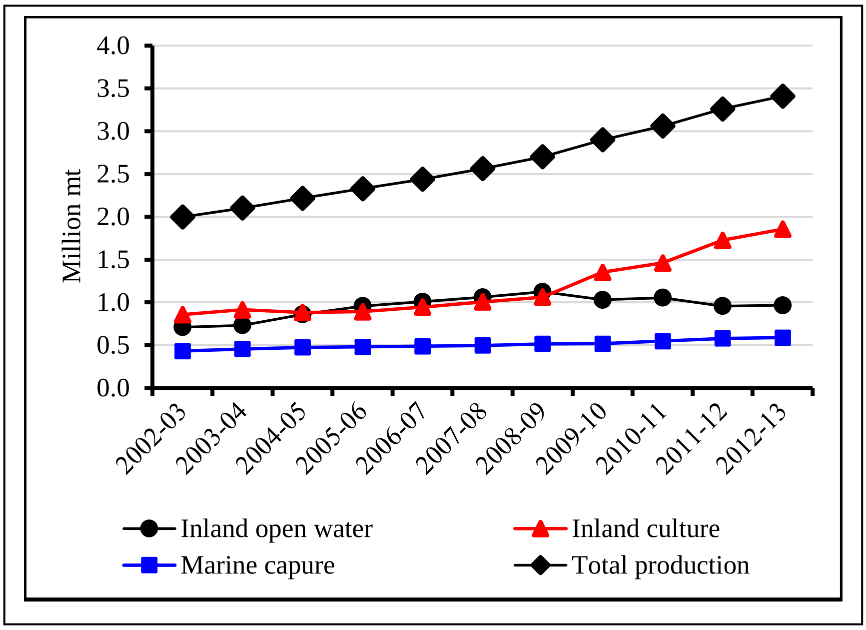


Figure 2. Sector wise fish production trend in Bangladesh for last 11 years.

2.2.1 *Inland aquaculture*

Inland aquaculture includes mainly pond/ditch, baor, shrimp/prawn farm, seasonal cultured water-body covering an area of about 0.741 million ha and produced about 1.73 million mt fish and shrimp in the 2011-12. The utilized area is only 16% of the total inland water-bodies. Nevertheless, about 53% of the total fish production comes from inland aquaculture (Figure 3).

2.2.2 Inland capture fishery

Bangladesh has potential of inland open water capture fisheries, including 853,863 ha of rivers and estuaries, about 177,700 ha of Sundarban mangrove water, 114,161 ha of natural depressions or beels, 68.800 ha of reservoir and about 2.7 million ha of floodplains. Annual flooding during the rainy season inundates up to 60% of the total land surface. After China and India, Bangladesh is the third largest country in the world in inland fisheries (FAO 2012). The inland open water is inhabited by 260 species of fish and 25 species of shrimp. In 2011-12, the total harvest from inland capture fishery was 957.095 mt (29% of total production) (Figure 3).

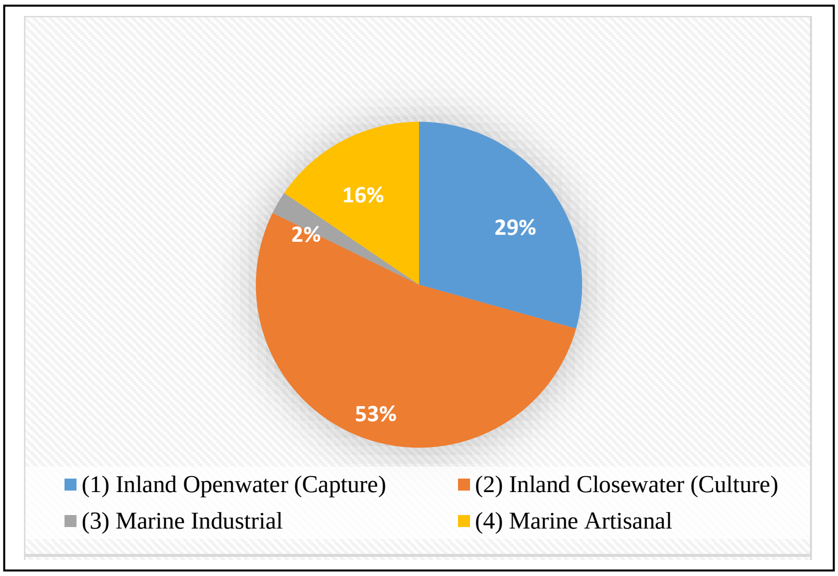


Figure 3. Sector wise fish production contribution (%) in 2012 Bangladesh (DOF 2012).

2.2.3 Marine capture fishery

Only about 18% of country's total fish production is contributed by the marine sector (DOF 2012). Marine capture fisheries are divided into two major group namely Industrial fishing and artisanal fishery. Marine hilsa fishery is included in marine artisanal fishery. Species and total harvest is shown Table 1 below:

Table 1. Comparative production from marine artisanal and Industrial production in 2012.

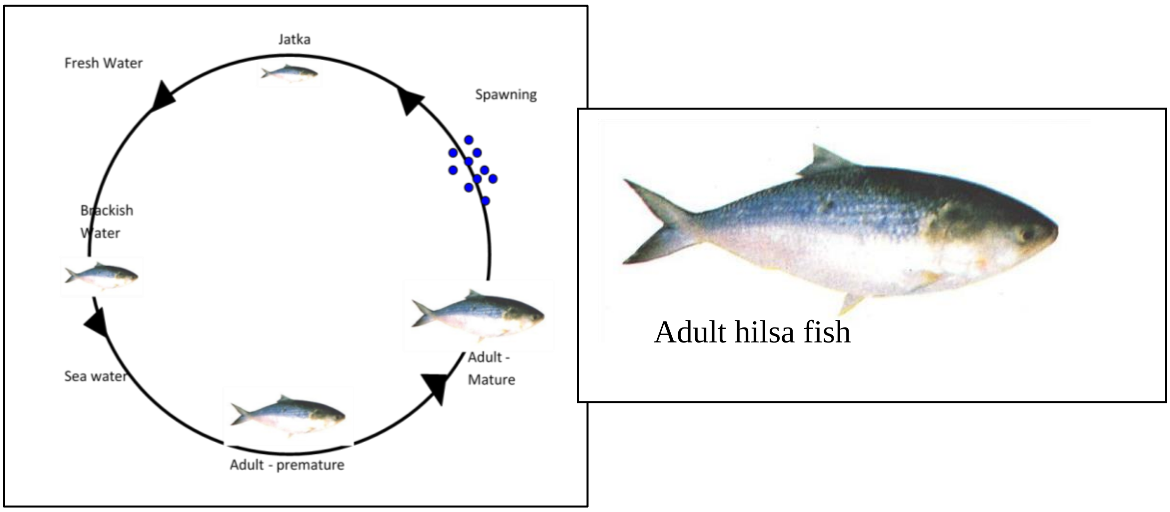
Sector of marine fisheries	Total harvest (mt)	Type of fish
Industrial Trawl	73,386	Sardine, Bombay duck, Indian Salmon, Pomfret, Cat fish, Jew fish, Shark, skate ray, shrimp.
Artisanal	578,620	Hilsa and above mention species.

3 THE HILSA FISHERY

3.1 Biology of hilsa

The hilsa (Indian shad, *Tenualosa ilisha*) (Figure 4), belongs to the herring family (clupeidae). The scientific name of the species, *Hilsa ilisha* has been revised in 1984 recently to *Tenualosa ilisha* (Fisher and Bianchi 1984), but the popular name “hilsa” has been used for more than a century. Hilsa may reach up to 60 cm in total length, but commonly found specimens measure 35 to 40 cm. Hilsa is anadromous and capable of withstanding a wide range of salinity and travelling great distances up-stream. It lives in the sea for most of its life but migrates up to 1,200 km inland through rivers in the Indian subcontinent for spawning. Travelling distances of 50-100 km upriver are typical in the Bangladesh river system (FAO 2014).

Hilsa starts spawning migration during the southwest monsoon and consequent flooding of 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 move downstream to the sea over a period of 5-6 months. They feed and grow on the way. In about 6-10 weeks the fry grows to about 12-20 cm and become known as *jatka* (*juvenile hilsa;* size less than 25 cm). Hilsa spend their juvenile stage in the freshwater environment before heading out to sea to feed and increase in size (Sharma *et al.* 2005). After 1 year in the sea, hilsa become mature and undertake their spawning migration towards inland rivers to spawn again (Figure 4) (Haroon 1998).



Adult hilsa fish

Figure 4. Movement pattern of Tenualosa ilisha (hilsa) into different habitats (Haldar 2005).

Hilsa is a highly fecund species that may reproduce multiple times in its life. Fecundity ranges 0.14 million in 28 cm fish up to 2.3 million in 44.5 cm fish (Halder 2004). Hilsa feed on plankton, mainly by filtering, but apparently also by grubbing on muddy bottoms. The spawning season is during the southwest and monsoon and also from January to March. Gonadal Somatic Index (GSI) indicates that peak spawning occurs in September to October. Nursery areas are both freshwater and estuarine and nursery areas have been established in major parts of the Meghna River (Halder 2002).

3.2 Catch and effort trend

After inception of the Fisheries resource survey system (FRSS) of DOF, the catch statistics of hilsa are collected systematically and reported in the Fishery Statistical Year Book of Bangladesh from 1983-84 onwards. According to FRSS, national hilsa catch ranged between 194,981 and 346,512 mt with an average of 237,936 mt/per year during the last 26 years and it was 217,681 mt/years in 2007 and seems to be more or less stable over that time. The total production has increased approximately 77% from 1987 to 2012 (347 thousand mt) (Figure 5).

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 catch was more or less steady, the inland hilsa catches have decreased by about 15% during the period 1987 to 2006 and again it is increased 26% in 2012.

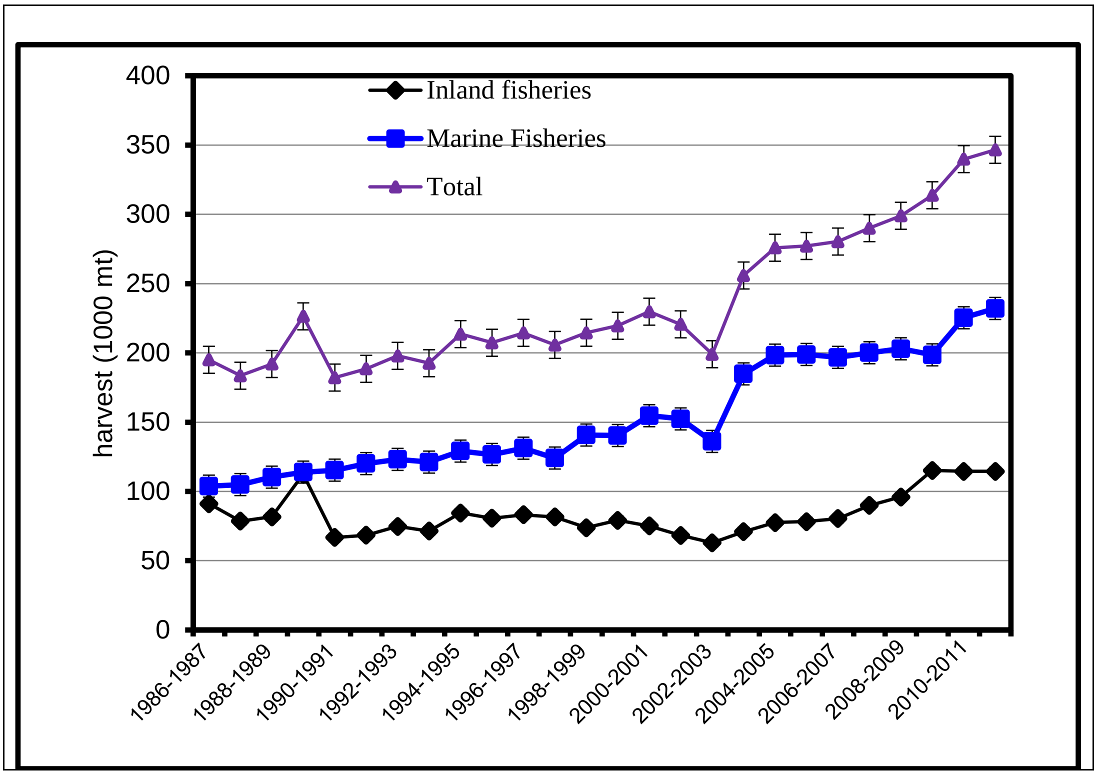


Figure 5. Sector wise hilsa harvest trend (inland, marine and total) from 1986-87 to 2011-12.

The Figure 5 also shows:

(i) The fluctuation in catches since 2005 have brought the fishery to a similar level as it was in the late 80’s.

(ii) There has been a continuous increase in catch for marine hilsa. At the end of period which was almost double comparing 1985.

After the introduction of nylon twine and mechanised boats in the marine sectors (Raja 1985, Hall and Kasem 1994), the intensity of marine hilsa catches have been increased. In spite of this, the increase in marine hilsa landings is about 123% (232 thousand mt) from the year 1987 and contributed 46% marine artisanal production. (Figure 5 and 6).

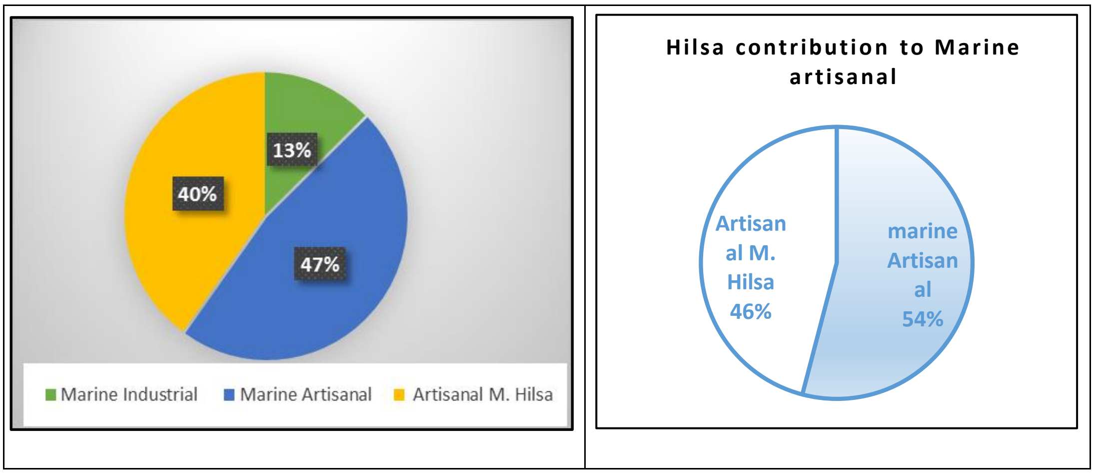


Figure 6. Contribution of hilsa fishery in marine and artisanal production in 2012.

The hilsa artisanal fishery involves a number of different types of fishing gears and crafts which are mostly traditional. Some of the gears are operated by mechanized boats, but mostly with country boats (Islam 2003).

The number of mechanized boats and gears in the marine sectors was recorded as 3,347 in 1983-84. This figure decreased to 2,880 in 1987-88 and remained the same until 1998-99. From a census in1999-00, the number of mechanized boats and gears were found to be 18, 992 and 75,968 i.e., 6.59 and 26.77 times higher than the previous years and indicates that the number of boats and nets were not assessed for the long 11 years. Catch/unit boat over the period did not increased significantly (Figure 7). These numbers of boats and nets are used for marine hilsa catch (Haldar 2004). The catch/non mechanized boat ranged from 2.08 to 5.03 with an average of 4.1 tons/year during 1983-84 to 1988-99 but decreased to 3.0 tons at the beginning of 2000 when the updated effort data were used (Haldar 2004).

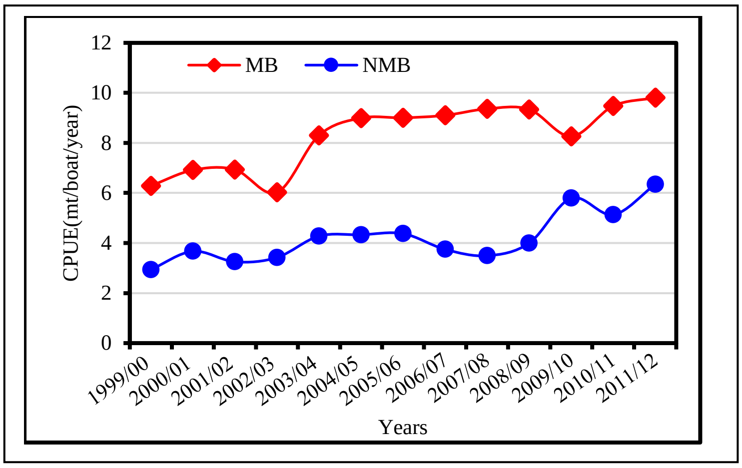


Figure 7. Average catch per unit of of mechanised (MB) and non-mechanised boat (NMB) (1999-2012).

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 and increasing fishing pressure on the hilsa stock.

3.3 Stock and current status of the hilsa fishery

Hilsa is generally thought to be a single stock in the region shared by Bangladesh, India and Myanmar. However, some Bangladesh scientists are of the opinion that a sub-stock structure may exist (BOBLME 2010). Although the harvest has increasing trends and stock is known to be annual, the exploitation level as reported by Amin *et al.* (2002) appear to be much higher than the estimated maximum sustainable yield (MSY). For example, in the year 1999, the MSY was estimated to be 162,400 but a total of 214,500 mt were landed (Amin *et al.* 2002) translating into more than 30% catch over and above MSY. In addition, the annual stock assessment expedition conducted in 2002 estimated more than 20% catch above the MSY. However, estimates of exploitation levels between 1999 and 2008 ranged were in the range 0.53 – 0.66 (Amin *et al.* 2002, Ahmed 2008). They all point to the hilsa population in Bangladesh being overexploited and fishing mortality needs to be reduced by reducing the fishing effort. Controlling fishing effort would require a major change in DOF practices (BOBLME 2010).

The fishery is primarily overexploited through an open access artisanal fishery. Habitat destruction and overfishing are major factors affecting the abundance of hilsa. It has disappeared from 35 out of 235 rivers. Other anthropogenic effects such as pollution and poor floodplain management are affecting the hilsa population in a negative way.

Since the hilsa fishery is a valuable open access fishery, basic fisheries economics theory (Gordon 1954) imply that the fishery should be economically overexploited, i.e. subject to excessive fishing effort and dissipation of potential net economic benefits. The general poverty of the fishermen suggests that this is indeed the case. In fact, it appears that the fishery may be in the neighbourhood close to what has been referred to as open access equilibrium where there are virtually no net economic benefits and stock levels are greatly suboptimal and may not even be sustainable.

A study (Amin *et al.* 2002) 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, catch per boat has been seriously declining for the last couple of years for instance the catch of mechanised boats per year is estimated to 33 mt in 1989-90 and subsequently decreased to only 9 mt in 2005-06 and 9.81 mt/year in 2012. The catch of non-mechanised boats per year ranged from 5.3 to 4 mt from 1989-90 to 2005-06 and 6.34 mt in 2012.

There are some other distinctive signals of overexploitation from the fishery. While total catch trends show an increase over time, the average size of fish seems to have declined. Results using the FISAT program indicate a large variation in exploitation on the stock between 1992 and 2003. However, this analysis did not estimate what the spawning biomass targets should be and this could be one area of possible improvement in an integrated assessment. A study conducted in 2009, indicates that the exploitation levels have not dropped over the period. Based on the assessment conducted using data up to 2005 the

Bangladesh scientists arrived at the following conclusions which was presented in the hilsa fish working group meeting in 2011 in Dhaka, Bangladesh:

(i) Hilsa fishery is suffering by serious recruitment over-fishing (indiscriminate catching of juvenile hilsa)
(ii) There is growth over-fishing (indiscriminate killing of mature female hilsa)
(iii)The fishing mortality has increased due to fishing pressure with decrease in size at first capture (BOBLME 2012).

In Bangladesh, the average catch in the past six years (2007-2012) has been over 209 thousand mt/year in the marine sector and 101 thousand mt/year in the freshwater sector. Again, it is not clear whether the current level of catch is sustainable.

Bangladesh scientists also believe that the *jatka* closures are the primary reason for the continuous increases in catch in Bangladesh waters. It was concluded that the status of hilsa is still uncertain. Hilsa is a fast growing highly productive species and this may protect it somewhat from overfishing, yet pollution and loss or degradation of habitats are affecting both the distribution and the productivity of the stock (BOBLME 2012). Therefore, in spite of increasing trends of the catch it is established by several stock assessment study that hilsa fishery is overexploited and immediate measures is needed for sustainability of the fishery.

3.4 Export of hilsa

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 1 thousand mt of hilsa, and in 2011-2012 it was increased to 6 thousand mt DOF (2012) (Table 2).

Table 2. Export quantity and value of frozen and chilled hilsa in the last 7 years (Department of Fisheries (DOF) 2012).

Year	Total production (thousand MT)	Export volume (Thousand MT)	Export earnings (Million USD.)
2004-2005	256	3.58	9.11
2005-2006	276	3.67	10.96
2006-2007	277	0.52	0.63
2008-2009	290	3.68	19.86
2009-2010	299	3.11	17.73
2010-2011	313	8.54	45.95
2011-2012	347	6.17	35.88

From Table 2, it could be noticed that in 2006-2007 the exports suddenly decreased. The reason is that the Government of Bangladesh partially banned the hilsa export for this year. The catch both inland and marine were locally consumed.

3.5 Marketing system of hilsa fish

The hilsa marketing chain is from fishermen to the eventual consumers of the fish. It may be divided into primary, secondary and retail markets, involving sales agents, suppliers, wholesalers and retailers. Fishermen are the primary producers in the fish marketing chain. Hilsa is marketed and consumed all over Bangladesh. Hilsa is marketed internally for domestic consumption and also exported. The fish marketing systems are traditional, dominated by small organizations and complex. Judging from hilsa prices at the point of landing and in consumer markets, the processing and distributional system seems to contribute significantly in the 'value adding' process. A large number of people, many of whom live below the poverty line, find employment in the coastal hilsa fish marketing chain as fishermen, assemblers, processors, traders, intermediaries, transporters and day labourers, including women.

Fishermen rarely communicate with wholesalers, retailers and consumers. They tend to sell their catch at the landing centres to suppliers (locally known as *baperies*) with the help of commission-based sales agents (known as *aratdars*). As soon as the fishermen land the fish in the primary market, the sales agent takes care of landing, handling, sorting and auctioning by size-groups. It is the most competitive form of auctioning and ensures better prices for fishermen. Auctioneers call out the bid loudly in the presence of the buyers. Sales agents get commission at different rates of the sale proceeds, normally 2 to 5% of the auction price, for their services and costs involved (Ahmed 2007).

Existing fish marketing systems, the auctioneers and suppliers play a crucial role in determining prices for hilsa at the landing centre. Communication between the sales agents and suppliers is generally strong and takes place by mobile phones. Suppliers are a form of intermediaries who supply fish from primary markets to wholesale markets. In general, suppliers are tied to a limited number of sales agents. Suppliers commonly use boats, trawlers, micro-buses, buses and trains to transport hilsa from coastal areas to the wholesalers at urban fish markets who then sell to retailers.

Hilsa prices are known to follow a seasonal pattern, with high 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). According to the Department of Fisheries (DOF) Bangladesh 2012, the average price of hilsa has increased about 15 times (Tk 20.0/kg in 1984 to Tk 300/ 4 US$ in 2012).

3.6 Fishermen involved in the hilsa fishery

In a country-wide survey in 2002-03, the total number of fishermen involved in hilsa fishing was found to be about 0.46 million belonging to 184 thousand families and of them 68% are full time and 32% are part time in different areas of Bangladesh (Halder 2004b). An estimated 0.46 million people are full time engaged in hilsa and jatka fishing and about 3 million (2%) of the country's total population are directly or indirectly involved in the hilsa fishery for their livelihoods (Halder 2004, DOF 2013). From 1987 to 2012, with an increase of boats and gears, the numbers of hilsa fishers have 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 (Mome 2007).

3.7 Socio-economic aspects of hilsa fishery

Most of the fishers are so poor that they are unable to upgrade their boats so they can fish in the marine environment. Most of these fishers are illiterate, and their children cannot attend school because they must help their fisher parents. The fishers who are prevented from catching jatka under the conservation program come from the poorest segments of the community. Their monthly income ranges from 1,200 to 1,500 BDT (US$17–20). Most of the adult and jatka/hilsa fishers live below the poverty line, and most work in teams as labourers/fishers. The wealthier people own the boats and nets (Siddique 2009). The people belonging to fishing communities in the coastal region of Bangladesh are, by and large, economically weak in terms of earning and availability of work (Pal *et al.* 2011).

3.8 Livelihoods of the hilsa fishermen

Millions of artisanal fishers are engaged throughout the year in the hilsa fishery in Bangladesh. The rivers and hilsa are their only means of survival because the people do not possess any land for crop cultivation so. Ignoring the intense heat of the sun, the lack of security and safety measures during monsoons and tidal waves, and having little or no food during fishing, these fishers struggle for their livelihood. Some fishers are happy with a catch of just one average-sized fish per day, as it provides them with money needed to feed their family or repay a boat loan (Siddique 2009).

Hilsa fishers earn their livelihood by catching and selling hilsa even if they have no other sources of income. There are three major categories of hilsa fishers: the boat owner, head mazhi (skipper) and the crew. Usually the boat owners 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 about 50% of the total catch, the head mazhi gets 8% share, assistant head mazhi and the driver get 6% share and the crew or labour fishers 36%. The annual expenditure for livelihood (except capital cost) of the artisanal hilsa fishers was found to average Tk. 76,045 (about US$ 1000) and for consumption it was an average of Tk 38,300 (Data collected by interviewing 2013). If the production or CPUE decline, the socio-economic conditions of the hilsa fisher folk will worsen further (Mome 2007).

3.9 Current Management of Hilsa fishery

The current Management policy for hilsa fishery in Bangladesh is mainly based on some biological conservation and subsidizing to the hilsa fishers. The current management objectives are to facilitate safe and unhindered breeding and conserve juvenile hilsa to ensure the yield of hilsa in a sustainable manner. After ensuring the peak breeding September period of hilsa and detecting major nursery grounds of jatka, government of Bangladesh framed rules and regulations to conserve and protect habitat of jatka in five sanctuaries and ensure successful breeding of hilsa in the natural breeding ground during peak spawning period. Moreover, hilsa research has been done by BFRI. During the banned period of jatka catch, government provides alternative income generating (AIG) opportunities and vulnerable group feeding (VGF) to the poor fishers. Necessary measures are being taken to continue the present success with necessary future action plan through coordinated effort to conserve hilsa in Bangladesh (DOF 2012).

The government has adopted a coordinated programme to protect jatka in the fiscal year of 2003-2004. Since 2007, Jatka Conservation Week has been being observed in coastal hilsa area as a national program to protect jatka and ensure its growth to adult size hilsa and to aware all stakeholders. Every year, the government has executed comprehensive programme for the protection of this fishery resource with the active participation of all stakeholders including local-public representatives, local government administration, Coast Guard, Bangladesh Navy, DOF, fishermen and mass people residing on the bank of rivers and coastal belt.

During ban period, the hilsa fishers are being provided with food-grain at the rate of 30 kg per household (164.740 thousand/family) for 4 months since February to May each year. Government provided financial incentives and distributed trade materials of about 50 million taka to 14.73 thousand fishers as AIG in the year of 2009-10 for not catching jatka during the ban season. Jatka/hilsa fishers were provided with financial support to run small businesses like rearing of poultry and livestock, operation of rickshaw, van, cart, fruit and vegetables business, running of grocery and tea stall, use of pump and sewing machine, net making etc. (DOF 2012).

Protection and conservation of fish act 1950 and rules were amended to make restrictions on some fishing gear, fishing time and to establish some sanctuary and the marine fisheries ordinance 1983, has been using for zone restriction and regulation on fishing vessels.

From the background information of the hilsa fishery it can be summarised that hilsa stock information is not up-to-date, though catch has been increasing but all the scientist points out that the hilsa fishery is over exploited. Millions of people depend on the fishery for their life and livelihoods. So present study will attempt to assess the current fishery on the basis of the available information and to develop a socio economically sustainable fishery model. Model will be used mainly to maximize the net benefit from the fishery by sustainable maintaining the stock over time.

4 A BIO-ECONOMIC MODELLING OF HILSA FISHERY

Fisheries management involves a complex and wide-ranging set of tasks, which collectively aim at the achievement of optimal benefits from the 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 incorporate an understanding of the biological processes of the resources as well as the socioeconomic 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 predicting the outcome of different management policies.

In this section, we have constructed a bio-economic model of the Bangladesh hilsa fishery to explore the bio-economic implications of different utilisation policies. In particular, we will attempt to identify policies which maximise the flow of economic benefits from the resources. More precisely, bio-economic model will be used to:

- Calculate the optimal sustainable yield, effort and stock
- Compare the current situation with optimal sustainable fishery

- Examine stock rebuilding trajectories over time
- Devise a socially beneficial fisheries policy over time.

4.1 General theory of the bio-economic model

To explain the hilsa fishery and study improvements in its utilisation, we construct a simple bio-economic model of the fishery. The main components of this model are (i) a biomass growth function, (ii) a harvest function and (iii) a fisheries profit function. The first function represents the biology of the model. The second function constitutes the link between the biological and economic part of the model and the third function represents the economic part. The control variable, i.e. the item subject to fisheries management, is fishing effort. In an unmanaged fishery, fishing effort will follow a certain evolutionary path. To determine this path, we have our fourth modelling component: (iv) the effort evolutionary function.

The essentials of the model are as follows:

Biomass growth function

$$\dot{x} = G(x) - y \qquad (1)$$

Where $G(x)$ denotes the biomass growth function of biomass, y is is the yield or the level of harvest from fishing and $\dot{x} = \frac{dx}{dt}$ represents the changes in biomass over time. This function is assumed to follow the usual biological specifications (Clark 1973).

Harvest function

The volume of harvest is taken to depend positively on fishing effort as well as the size of the biomass to which the fishing is applied. This harvesting function can be written as follows:

$$Y(e,x) = q \cdot e \cdot x^{\delta} \qquad (2)$$

where q is the catchability coefficient, e fishing effort and δ the schooling parameter.

The profit function

Profit function (π) are obtained by subtracting total costs (TC) which include; (i) costs associated with fishing effort and harvest and (ii) costs independent of fishing effort and harvest or fixed costs fk, from the marginal revenues (R) thus obtaining the following:

$$R = p \cdot y$$

$$TC = C \cdot (y \cdot e) + fk$$

Therefore, profits are (Profit function):

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

The four variables of this model, i.e. x, y, π and e represent biomass, harvest, fishing effort and, respectively. The first three, x, y and π are endogenous determined within the model. The fourth, fishing effort, e is a natural control variable for the fishery, which the fisheries authorities can influence. Note that the price of fish, p, is an exogenous parameter determined by market conditions outside the fishery.

The above model comprises three elementary functions; the natural growth function, $G(x)$, the harvesting function $Y(e,x)$, and the cost function, $C(e)$. As already mentioned, I adopt widely used specific forms for these functions.

4.2 The biomass growth function

Populations of organisms cannot grow infinitely. Growth of organisms is constrained by environmental conditions and food availability. It has been shown that populations of organisms strive to stabilise at the highest possible population size for a given set of conditions (Schaefer 1954). Marginal growth of a population typically increases when the size of the population decreases and vice versa. This type of density dependent growth has been called compensatory growth (Clark 1973). The opposite type, when marginal growth increases with biomass, is called depensation (Clark 1973). Obviously, depensatory growth cannot exist but over an interval of biomass.

A very common biological growth function for exclusively compensatory growth is the logistic biomass growth function (Lotka 1910):

$$G(x) = rx(1 - \frac{x}{k}) \qquad (4)$$

Where x is population size, r is the growth rate of the population and k is the carrying capacity of virgin biomass. This is the parabolic equation also referred to as Verhult’s equation or the logistic growth equation (Schaefer 1954).

By adding harvest to the equation and the variable of time we obtain the effect of fishing on population dynamics expressed in (1) above.

$$\frac{\partial x}{\partial t} = rx(t)\left(1 - \frac{x(t)}{K}\right) - y_t$$

where: y_t is the harvest at time t. We may write (1) more simply as follows:

$$\dot{x} = \alpha \cdot x - \beta \cdot x^2 - y_t \qquad (5)$$

where: $\alpha = r$ and $\beta = \frac{r}{K}$.

The change in biomass in discrete time will be approximately by following equation

$$x_t - x_{t-1} = \alpha \cdot x_t - \beta \cdot x_t^2 - y_t \qquad (6)$$

where: the change in biomass over one priod is equal to the biomass growth less the harvest.

The equilibrium (or sustainable) state of the biomass, defined by $\dot{x} = 0$, in continuous time and x_t-x_{t-1}=0 in discrete time. Therefore, in equilibrium:

$$y = x_t - x_{t-1} = \alpha \cdot x_t - \beta \cdot x_t^2 - y_t = 0 \qquad (7)$$

4.3 The harvest function

Assuming that each unit of effort harvests equal amounts from the targeted stock, harvest may be described by (Schaefer 1954):

$$Y(e,x) = q \cdot e \cdot x^{\delta} \quad (8)$$

where: q is the catchability co-efficient.

Equation (8) implies that harvest, y is proportional to the stock size, x at a given fishing effort e. δ is the schooling parameter, usually taken to be in the interval [0,1].

Obviously, on the basis of (8), the equilibrium stock size, $x\,, q, e$:

$$\hat{x} = \left[\frac{y}{e \cdot q}\right]^{\frac{1}{\delta}} \qquad (9)$$

Incidentally, expression (9) shows that the common approach to regard *CPUE=y/e* as proportional to biomass only holds in the special case of the schooling parameter being equal to unity.

4.4 The cost function

Fishing effort is really a combination of economic inputs in the form of labour, investment, fuel, maintenance and supplies, fixed costs and overhead that is devoted to the fishery on an annual basis. The variable e must be regarded as the appropriate aggregate of these inputs. Naturally fishing costs increase in e.

For the aggregate costs of fishing effort, we choose:

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

where: $C(e)$ is the cost per effort, fk represents fixed costs and vc is the variable cost. For the long run calculation, we assume that fk will become variable so the long run cost function would be $C(e) = (fk + vc) \cdot e$.

4.5 Profit function

The profits from the fishery are defined as the total revenues ($R = p \cdot y$) less the total costs (TC) defined above. We, therefore, obtain the profit function:

$$\pi = p \cdot y - fk \cdot e - vc \cdot e \quad (12)$$

where or, by substituting in for y.

Profit function:

$$\pi = p \cdot q \cdot e \cdot x^{\delta} - (vc + fk) \cdot e \qquad (13)$$

4.6 The complete model

The complete model under those functional specifications becomes:

$$\dot{x} = \alpha \cdot x - \beta \cdot x^2 - y \qquad (14)$$

$$Y(e,x) = q \cdot e \cdot x^\delta \text{ (Harvesting function)} \quad (15)$$

$$\pi = p \cdot q \cdot e \cdot x^\delta - (vc + fk) \cdot e \text{ (Profit function)} \quad (16) .$$

4.7 Fishery equilibrium

Using the bio-economic model defined above, we can now calculate maximum sustainable yield (MSY), maximum economic yield (MEY) and the bionomic equilibrium (BE) and equilibrium profits and other statistics of interest.

Biomass at MSY may be obtained using the formula:

$$MSY = \frac{\alpha}{2\beta}$$

while the associated harvest is obtained as follows:

$$Y_{MSY} = \frac{\alpha^2}{4\beta} = \frac{r \cdot K}{2}$$

The corresponding static equilibrium effort levels at MSY (E_{MSY}), or for any other equilibrium effort (E_{eq}) level for that matter, may then be calculated by combining the biomass growth and the harvest functions and solving for effort thus obtaining the expression:

$$E_{eq} = \frac{y}{q \cdot x^\delta} = \frac{\alpha - \beta \cdot x}{q \cdot x^{\delta - 1}} = \frac{\alpha \cdot x^{1-\delta} - \beta \cdot x^{2-\delta}}{q} \quad (17)$$

Equation (17) is extremely useful in any sustainable equilibrium calculations. Note that if $\delta = 1$, (17) reduces to a linear function of biomass.

The E_{MSY} can be calculated from (17) by substituting y_{MSY} or x_{MSY} in.

The bionomic equilibrium (*BE*) is derived from the condition that

$$\pi = R - TC = 0,$$

in other words, where total revenues and costs are equal. Using (17) from above this may be written as:

$$\pi = p \cdot q \cdot e \cdot x^\delta - (vc + fk) \cdot e = 0$$

Clearly, substituting in for e from (17) in this equation yields and expression for the bionomic equilibrium biomass as:

$$\mathrm{p}\cdot(\alpha\cdot x-\beta\cdot x^2)-b.(\frac{\alpha\cdot x-\beta\cdot x^2}{q\cdot x^\delta})-fk=0 \qquad (18)$$

This equation will in general have to be solved by numerical means. Once the x_{BE} has been found from (18), it is straight forward to find the corresponding effort level from (18) and subsequently the harvest.

The profit maximizing MEY biomass(x_{MEY}) static reference point may be obtained by maximizing the profit function (12) with respect to biomass, i.e.

$$\text{maximize } \ p\cdot(\alpha\cdot x-\beta\cdot x^2)-b\cdot(\frac{\alpha\cdot x-\beta\cdot x^2}{q\cdot x^\delta})-fk \qquad (19)$$

The solution to this maximization problem will in general have to be found by numerical means.

4.8 Dynamic reference points

Static or equilibrium analysis is useful but since fisheries are inherently dynamic, their static nature diminishes their utility as fisheries management tools. This is especially true since it is unlikely that any fishery is in complete equilibrium at any given time (Seijo *et al.* 1998). Dynamic representations which take into consideration changes in biomass, effort, costs and benefits (profits) over time are much more realistic and therefore superior in determining the optimal fisheries management policy.

Optimal dynamic equilibrium reference points (*) for a given discount rate have been developed in fisheries economics (Arnason 1990, Clark and Munro 1975). For our general model (1) to (3) above optimal dynamic equilibrium is given by the expressions:

$$G_x(x)+\frac{C_e(e).Y_x}{\pi_{e(e,x)}}=d \qquad (20)$$

$$G(x)=Y(e,x), \qquad (20b)$$

where d is the rate of discount and the functions are defined in (20) above. Substituting the Schaefer model discussed above into 20 we find:

$$(\alpha-2.\beta.x)+\left(\frac{b.\delta.(\alpha-\beta.x)}{p.(1-a).q.x^\delta-b}\right)=d. \qquad (21)$$

$$\alpha\cdot x-\beta\cdot x^2-q\cdot e\cdot x^\delta=0$$

From this equation the optimal sustainable biomass level, (x^*) can be obtained by numerical means. Note that for a discount rate equal to zero, $d=0$, $x^*=x_{MEY}$ (Clark 1985). The optimal equilibrium effort e^* may then be obtained from expression (17) as:

$$e^*_{eq}=\frac{\alpha\cdot x-\beta\cdot x^2}{q\cdot x^\delta} \qquad (22)$$

Maximisation of the present value,PV, is the usual objective of a dynamic fisheries policy. The present value of a future flow of benefits may be defined as the amount of benefits at year zero that is equally desirable to the future flow of benefits (Clark 1985). This is dependent on the rate of discount, d. A high discount rate will lead to a lower present value, while a low discount rate will lead to higher present values for net benefits in the same time period (Seijo *et al*. 1998). The present value of profits, π in year t is expressed as:

$$PV_{\pi} = \frac{\pi_t}{(1+d)^t} \qquad (23)$$

The NPV of a flow of profits over a time interval [0, T] is obtained as:

$$NPV_{\pi} = \sum_{t=0}^{T} \frac{\pi_t}{(1+d)^t} \qquad (24).$$

4.9 Profit maximization problem:

The dynamic optimization problem is to find the time path of fishing effort that maximizes the present value of the profits from the fishery from the current time onwards. This present value is dependent on the rate of discount, *r*. A high discount rate will lead to a lower present value, while a low discount rate will lead to higher present values for net benefits in the same time period (Seijo *et al*.1998)

The profit maximizing MEY biomass(x_{MEY}) static reference point may be obtained by maximizing the profit function (12) with respect to biomass, i.e.
The statement of the problem for discrete time expressed as:

$$Maximize \int_0^{\infty} \left(p \cdot (\alpha \cdot x - \beta \cdot x^2) - b \cdot \left(\frac{\alpha \cdot x - \beta \cdot x^2}{q \cdot x^{\delta}}\right) - fk\right) \cdot \frac{1}{(1+r)^t}$$

Where r is the discount rate, optimality problem is linear in the control variable of effort *e* (*t*), 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. Therefore, the optimal dynamic path is of the so-called bang-bang variety (Clark and Munro 1975). This means that the most rapid approach to the dynamic MEY is optimal.

The solution to this maximization problem will in general have to be found by numerical means.

5 DATA

5.1 Necessary Data, sources and collection

To construct the current bioeconomic model, the following data were used: 1) Aggregate landing data, 2) Effort data and 3) Economic data. The aggregate landings and effort data was collected from the Fisheries Resources Survey System (FRSS) section of DOF Bangladesh. Tertiary data for instance some biological parameter and related information have been collected from various, research journal, working reports and websites.

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 survey and data collection. Government officers visit fish markets, ponds, lakes (haors, baors), rivers 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. This is the only source of fisheries and aquaculture data in Bangladesh. Export data was collected from annual report of DOF 2012. All biological data for this study has been 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) and any other related publications.

Data on the economic aspects of the hilsa fishery, including estimates of costs, revenues and profits, was collected mainly through interviews with boat owner, persons involved in the catching and marketing chain of the of hilsa fishery, including fish depot owner, whole seller and fishers. Twenty fishers from separate non mechanised and mechanised boats were interviewed by an appointed data collector for the 2012-13 season. The data collector visited the three different hilsa fishery area (Barisal, Coxsbazar and Chandpur district) of Bangladesh and randomly selected the fishermen from mechanized boats and non-mechanized boats. Additional data and comparative information were obtained from both public and private data sources such as the Department of Fisheries (marine fisheries section) as well as current available literature.

5.2 Biological parameter data collection and comparison

For estimation of the model parameter we need historical catch and effort data as well as some important biological data for the fishery such as Virgin stock or carrying capacity (K), schooling parameter(δ), catchability (q) etc. But the up-to-date data on the fishery is not available. FRSS is the only source of the catch and effort data. Biological data from some article of fish population dynamics study on the fishery.

The method of data (Figure 8) collection is shown in the above figure data quality and use of these data will be discussed in the estimation section.

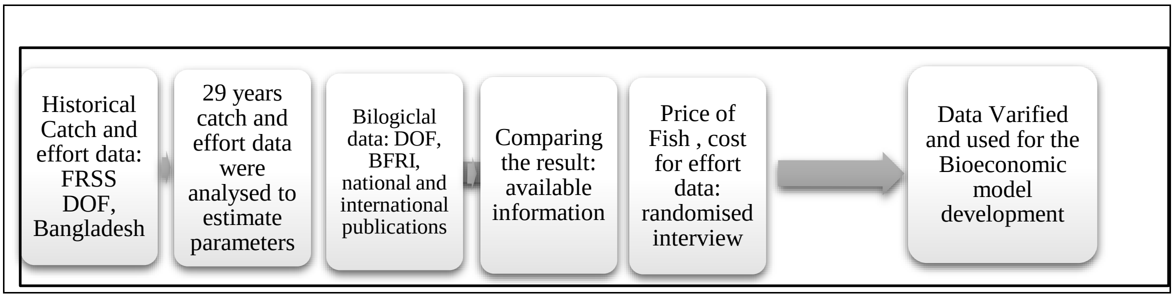


Figure 8. Method and types of data collection.

6 ESTIMATION

6.1 Biological parameters estimation

Collected catch and effort data analysis shows that the data quality is very poor because in the year 1999-00 the number of boat increased at a times about 9 times than previous year 1988-99. Data were used to calculate the catch per unit of effort (CPUE) /standardised mechanised boat/year. Result shows that increased efforts create a sudden decreased in CPUE from 22.02 mt/boat to 5.37 mt/boat. And after that the changes in CPUE is more or less stable for instance it varies around 6 to 9 mt/boat. Then we did regression analysis and estimated MSY 157,235 mt. and $\alpha = r$=2.887 and β=0.0000091 by using these CPUE data. And compared our result with others research findings mentioned in Table 3.

Table 3. Comparison of the findings of some fish population dynamics/bioeconomics studies regarding MSY, annual stock/biomass, standing stock, exploitation rate.

Scientist and year	**MSY (1000 mt)**	**Annual catch/yield (1000mt)**	**Annual stock (1000mt)**	**Carrying capacity (K) (1000mt)**	**Standing stock (1000mt)**	**Exploitation level**
Amin et.al 2002	162	215	335	Not studied	86	0,66 Max.0,59
Amin et. al. 2008	210	257	-	Not studied	148	0,55-0,66
Sm Ahmed 2008	-	-	-	Not studied	-	0,53
Mome 2007	211		379		-	-
The Sunken Billions: The World Bank	286	-	-	K=1.084	-	-

So according to the findings of the earlier study mentioned above, we find the MSY ranges from162 to 286 thousand metric tonnes. The last population dynamics study for hilsa fish was done in the year 2002 and that found the MSY 210 thousand metric tonne. But the government has been implementing the conservation method for gravid hilsa, banning on peak spawning season and spawning ground and protection and conservation of Juvenile hilsa activities from 2003-04. From the Impact of the project, it is assumed that hilsa harvest increased 347 thousand in 2012 from 255 thousand in 2004. So on the basis of above information it would be better to assume the MSY of hilsa fish around 286.000 for the current model. That's why we have accepted the MSY 286.000 MT and the carrying capacity of hilsa fish $K = 1.084.000\ mt$ (The World Bank 2009). Then some parameters are calculated (Table 4) on the basis of that data by using empirical modified logistic Schaefer-Gordon model.

Table 4. Biological parameter estimates for the Bangladesh hilsa stock.

Parameter	**Symbol**	**Value**
Intrinsic Growth rate/alpha	$r\ (\alpha)$	1.05
Beta	β	0.001
Carrying Capacity/ Virgin Biomass	K	1,084,000

6.2 Harvest function parameters

The schooling parameter (δ) value 0.5 was taken on the known biological data of the species from 'The Sunken Billions' (The World Bank, 2009). The catchability coefficient (q) was estimated (Table 5) by using the above harvest function:

$$Y(e,x) = q \cdot e \cdot x^{\delta} \text{ Therefore,}$$

$$q = \left(\frac{y_t}{e_t.\cdot x_t}\right)^{\frac{1}{\delta}}$$

Table 5. Harvest parameter estimates for hilsa fishery.

Parameter	**Symbol**	**Value**	Ref
Catchability Coefficient	q	0.00045	On the basis of Arnason-Sharma fisheries program. Using the above equations.
Schooling Parameter	δ	0.5	The Sunken Billions(The World bank 2009)

6.3 Cost function estimates

In this model, total costs (TC) are defined as the sum of the fixed costs (fk) and variable costs (vc) as explained in the cost function (section 4.4). Fixed costs are those incurred independent of fishing activity and will include (i) capital costs consisting of (a) depreciation of vessel value and equipment and (b) the lost interest on the vessel and equipment value, (ii) average annual licensing and registration fees, (iii) average maintenance fees per year and (iv) management and overhead costs.

Fishing effort in the base year; $e(t)^*$ was standardised on the basis of Horse Power of the engine and then horse power was converted to Standardised Mechanised Boat (SMB) for better understanding.

FRSS data provide the information about mechanised boats and non-mechanised boats that are engaged in the marine artisanal hilsa fishery in Bangladesh. The total numbers of mechanised boats (MB) and non-mechanised boats (NMB) are 19,223 and 6,861 respectively (2011-12). In case of this analysis, base year fishing effort is the summation of MB and NMB.

Total fishing effort = MB+NMB = 19,223 + 6,861 = 26,084

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 and comparing the secondary data (Mome 2007) 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 = 162,230 + 34,305 = 226,535 HP

Then I converted all the horsepower as a Standardised Mechanized Boat for better understanding. Dividing total effort (horse power) by 10 hp, I calculated total number of Standardised Mechanized boat is 22654, which will be termed as a SMB in this report.

Effort data is not available for the inland hilsa catch. FRSS (Department of Fisheries, Bangladesh, 2012) only provided the total inland catch of hilsa which is 114,475 mt in 2012. According to our calculation single SMB's average catch 10 mt/year. So we can assume effort (SMB) by the following way:

$$\text{Total effort needed for inland (SMB)} \frac{114{,}475}{10} = 11447.5$$

So total effort for the base year as

(SMB) 2012=22654+11447=34101

Estimates of cost parameters:

$$C(e) = fk + vc \cdot e(t)^{*}$$

Both mechanised and non-mechanised boats are involved in the artisanal hilsa fishery. Most of these 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) 2011-12, non-mechanised boat was catch 6.34 mt and mechanised boat catch was 9.82 mt hilsa. For the calculation of total cost, the boat has standardised as standardised MB. Thus, the annual average catch per SMB is 10 mt/year.

A new boat fully equipped costs 1.500.000 Tk. The cost of boat and engine (Tk.1.340.000 and 220.000) 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. The price of net

80,000-300,000. Every day the fishing time is around 10-12 hrs. The fishing boats consumed 1-1.5 litre of diesel for every 2 hrs running. Average diesel required for each trip is around 15-20 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). Due to bad weather and banning period (11 days) no of fishing days are considered an average of 200 days per year. The number of labours are involved 10 people in mechanised and 6 persons in 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.

Details cost calculation data for non-mechanised and mechanised boats per year hilsa catch (in year 2011-2012) is given in Annexure 3.

Fixed cost calculation:

Non-mechanised boat = Depreciation cost of hull and hull repair, gear repair cost is considered as a fixed cost (35,000+52,335 + 12,000= 99,335 BDT

Mechanised boat = Depreciation cost of hall, engine, crew share, hull repair cost, net cost, (5% of total Investment cost) and interest payments (@8.5% of investment cost) is considered as fixed cost (80,000+90,000+150,000+101,280+171,700) =597,980 (BDT).

Variable cost calculation:

Non-mechanised boat = Food and Supply, fuel and Lubricant, license fee/license renewal fee, docking charge and landing charge is considered as variable Cost (200,000+300,000 + 600.671= 900,881 BDT

Mechanised boat = Food and Supply, fuel and lubricant, license fee/license renewal fee, docking charge and landing charge is considered as

variable cost=195,000+5000,000+843,000= 1,538,350 BDT

Wages of boat owner

According to our data collection we can see that a share system is established for hilsa artisanal fishery. Boat owner get the about 50% of the catch after deducting all of the operational cost. So we did not consider any salary for the boat owner.

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:

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

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 = 226.535 HP and Standardised Mechanised Boat SMB=22654+11,448 for Inland river catch=34.101 SMB
Total fixed cost for 1NMB+1MB = 99,335 +597,980 = 697,315 BDT
Total variable cost = (1NMB+1MB=15 HP) =900,881+1,538,350=2,439,231BDT.
Annual fixed cost per SMB = 464,876BDT =US $ 6,037 (1NMB+1SMB=1.5 SMB)
Annual variable cost per SMB= 1,626,154BDT =US $ 21,119.

Based on the above estimate the cost function for the Bangladesh hilsa fishery will be calculated by the following mixed cost function $TC = (vc + fk) \cdot e$

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

The average landing price was considered for the calculation. The price of small fish is low compared to big fish. The average price of hilsa for the base year was BDT 300/kg= about US $ 4/kg (@77BDT=1US $).

So average price of hilsa for 2011-2012 was 1 MT =US $ 4,000

So this is a mix of cost function estimates and price (Table 6).

Table 6. Economic parameter estimates for the Bangladesh hilsa fishery.

Parameter	Symbol	Value	Brief Description
Price	p	4,000	US$/mt, based on 2012 average market price
Fixed cost/SMB*	fk	6,037	E=34.101 SMB. For Inland river hilsa catch we assumed effort 11,448 SMB on the basis of average catch calculated for single SMB
Variable cost /SMB*	vc	21,119	Fuel lubricants, food, supplies
Crew share	a	0.375	Percent average given in interviews and included as a variable cost.

*SMB-Standardised Mechanized Boat

6.4 Profit function estimates:

In summary, based on the harvesting function, profit function may be expressed as:

(Profit) $\pi = p \cdot q \cdot e \cdot x^{\delta} - (vc + fk) \cdot e = 0$

$$\pi = 4000 \cdot q \cdot e \cdot x^{\delta} - (6{,}037 + 21{,}119) \cdot e$$

Profits per boat

$$\pi(i) = 4000 \cdot q \cdot e(i) \cdot x^{0.5} - (6{,}037 + 21{,}119) \cdot e(i)$$

In what follows the effort unit, e, correspond to one standardized vessel.

7 STATIC ANALYSIS OF THE BANGLADESH HILSA RESOURCE

The sustainable view on the fishery plays an important role in fisheries management. Although not theoretically appropriate, a great deal of fisheries policy is in reality formulated on the basis of sustainable fisheries models. It should be noted that sustainability may occur at many levels of biomass. Thus, the question is which of these sustainable biomass levels is most desirable. In this section we use the hilsa bio-economic model developed according to the previous section to formulate optimal fisheries models. First we work out on Static analysis the fishery to find the optimal sustainable yield then unmanaged competitive dynamics, optimal (profit maximising) sustainable path and compare it with the current state of the fishery. We work out two paths of this kind. One of them simply tries to maximise the present value (bang bang) of economic returns from the fishery. The other path is moderate in the sense that it adjusts fishing effort considering the social reality.

7.1 The sustainable Hilsa fishery and its reference points

7.1.1 Sustainable yield

Applying the modified Logistic Schafer model mention above (section 4.1), the following diagrammatic summary (Figure 9) of the sustainable yield has been calculated. In this calculation the MSY level harvest is 278 thousand mt and the corresponding effort 27,111 Standard Mechanised Boat (SMB). The maximum sustainable economic yield (MEY) is calculated about 258 thousand mt and corresponding effort is 22,146 SMB.

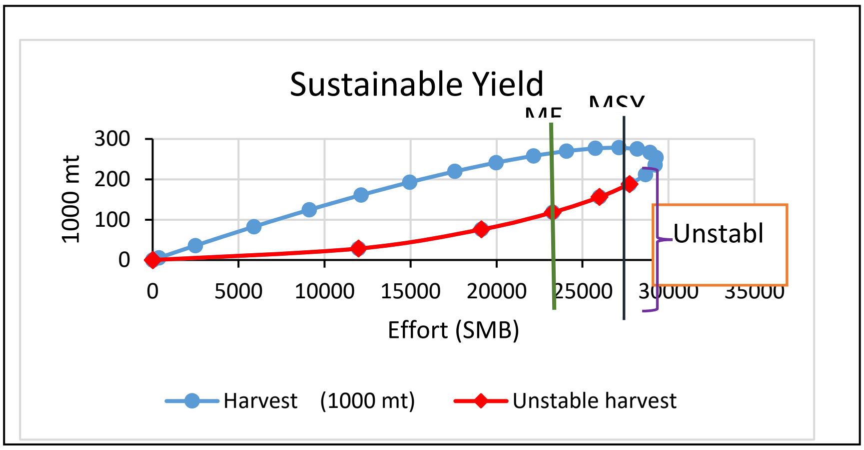


Figure 9. Sustainable yield (MSY/MEY) for the Bangladesh hilsa fish.

The current (2012) level of effort, however, is 34,101 SMB and the harvest is about 347 thousand mt which is far greater than the MSY harvest and MSY effort level. This suggests that the current situation is unsustainable and if maintained will lead to a fishery collapse. To avoid that immediate measures to reduce fishing effort are required.

7.1.2 Sustainable hilsa Fishery

The following Figure 10 illustrates the static sustainable fisheries model for the hilsa fishery. Drawn in the diagram are sustainable revenues, costs and biomass curves as functions of fishing effort. Since the cost curve intersects the revenue curve in the unstable region, the open access equilibrium is unstable (Clark 2005).

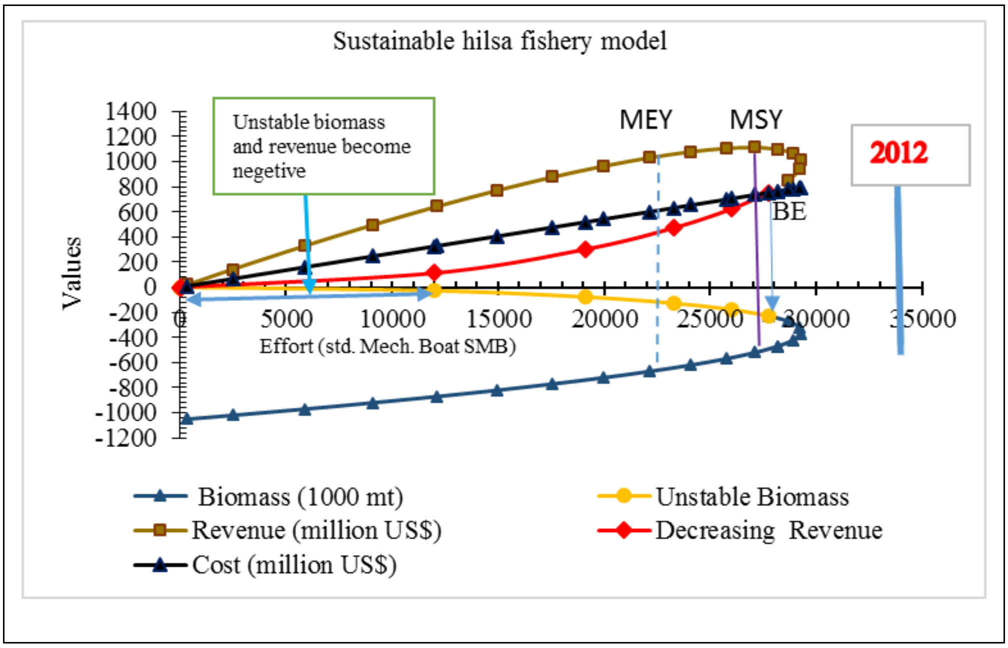


Figure 10. Sustainable fishery model for the Bangladesh Hilsa.

On the basis of this model, we have calculated several equilibrium fisheries management reference points. These reference points include the current (2012) situation as well as the calculated bioeconomic equilibrium (BE), i.e. where costs curve hits the revenues curve (profit zero), the maximum sustainable yield (MSY) and the maximum economic yield (MEY). Table 7 presents a summary of these reference points for the Bangladesh hilsa fishery and the corresponding economic outcomes and biological conditions.

Table 7. Sustainable equilibrium and current 2012 fishery reference point for the Bangladesh hilsa fishery.

	Biomass (1000 mt.)	Effort (Std.Mech.Boat-SMB)	Total Harvest (1000 mt)	Revenue (million US$)	Cost (million US$)	Profit (million US$)
2012	510	34,101	346	1386	928	458
MEY	670	22,146	257	1032	601	430
MSY	520	27,111	278	1113	736	377
BE	228	27,736	188	753	753	0

MSY, MEY and current (2012) harvest, cost and profit for a standard mechanised boat for the Bangladesh hilsa fishery is given Table 8 below:

Table 8. The harvest and profit level per SMB at the same reference points.

year	**Biomass**	**Harvest (mt /Per SMB /year)**	**Profit ((US$ / SMB /year)**
2012	510	10	13,431
MSY	520	10	13,890
MEY	670	12	19,436
BE	228	7	0

As indicated in Figure 9 and Tables 7 and 8, current fishing effort is hugely excessive and harvest levels considerably higher than can be sustained. Costs associated with excess effort have also dissipated potential profits from the fishery; in fact, biomass and harvests are well below the respective X_{MEY} and Y_{MEY} levels. However, due to low costs and high unit price of the fish, the fishery seems to have achieved a profit but that is not significantly higher that which is attainable at the MEY level. The MEY option presents the most efficient sustainable outcome for the fishery. Here sustained profits would be about 20% higher than the MSY profits level. This MEY condition would however require a positive investment in the fishable biomass over a period of time to allow for an approximately 30% more biomass than the current level. To accomplish this and to reduce fishing costs, fishing effort would have to be greatly reduced or by roughly one third (1/3).

The present management situation of the hilsa fishery is very close to open access. If this situation continues, the above equilibrium analysis suggests the resource will collapse with the consequence of very little or no catches, high economic losses It will have a negative effect not only on the hilsa fishery but also on other backward and forward industries and may cause wide ranges of economic losses for the nation as a whole.

8 DYNAMICS OF THE HILSA FISHERY

In order to gather sufficient understanding of fisheries for management purposes we must study their dynamic evolution. In this chapter we will attempt to describe the competitive or unmanaged dynamic path for the hilsa fishery as well as the optimal dynamics.

8.1 Competitive dynamics

Heavy fishing in the current period generates higher catches but at the expense of a smaller fish stock and smaller potential catches in the future. In the dynamic context, the appropriate fisheries objective is to maximise the present value from the fishery forever. Without management, the fishers themselves determine the path of the fishery over time.

In this section we consider the evolution of the hilsa fishery over time as if there was no management. This may not be too far from the truth because the fishery has been essentially open access, with some technical restriction on gear, size of fish, area and time but virtually no controls on effort. Under those circumstances, it is reasonable to expect that new vessels will enter and exit the fishery according to the profits the fishers are able to make. More precisely we postulate the following:

The evolution of the competitive fishery over time is qualitatively different from the optimal one. The biomass dynamics $\dot{x}$, is the same as before. For our model this is defined as:

$$\dot{x} = (\alpha \cdot x - \beta \cdot x^2 - e) \cdot x = 0$$

The fishing effort dynamics, $\dot{e}$ however, will be different. The reason is that in the competitive fishery, effort will expand whenever there are positive profits in the fishery and contract whenever profits are negative. So, for the competitive fishery, there can be no economic equilibrium unless profits are zero. This then is the economic equilibrium in the competitive fishery, i.e. all the combinations of biomass and fishing effort that results in zero profits (Arnason 2008). We specify this behaviour in a simple way as:

$$\dot{e} = 0 = (p \cdot x - c \cdot e) \cdot e,$$

The economic equilibrium curve traces out the combinations of biomass and fishing effort that maximize present value of profits. Thus it is optimal to use high fishing effort in a high biomass level, to harvest a great deal. On the other hand, at a low biomass level, it may be optimal to employ no fishing effort at all. Everywhere off the fishing effort equilibrium curve, optimal fishing effort is changing. It is growing above the curve and declining below it (Arnason 2008).

The above two equations define two difference equations in the space of effort and biomass. Thus from any starting point, they will trace out the evolution of the biomass. To understand these dynamics, it is helpful to start with the equilibrium curves, and the graph of these curves in biomass-effort space is drawn in Figure 11 and Figure 12 presents a possible competitive dynamic path for the Bangladesh hilsa fishery.

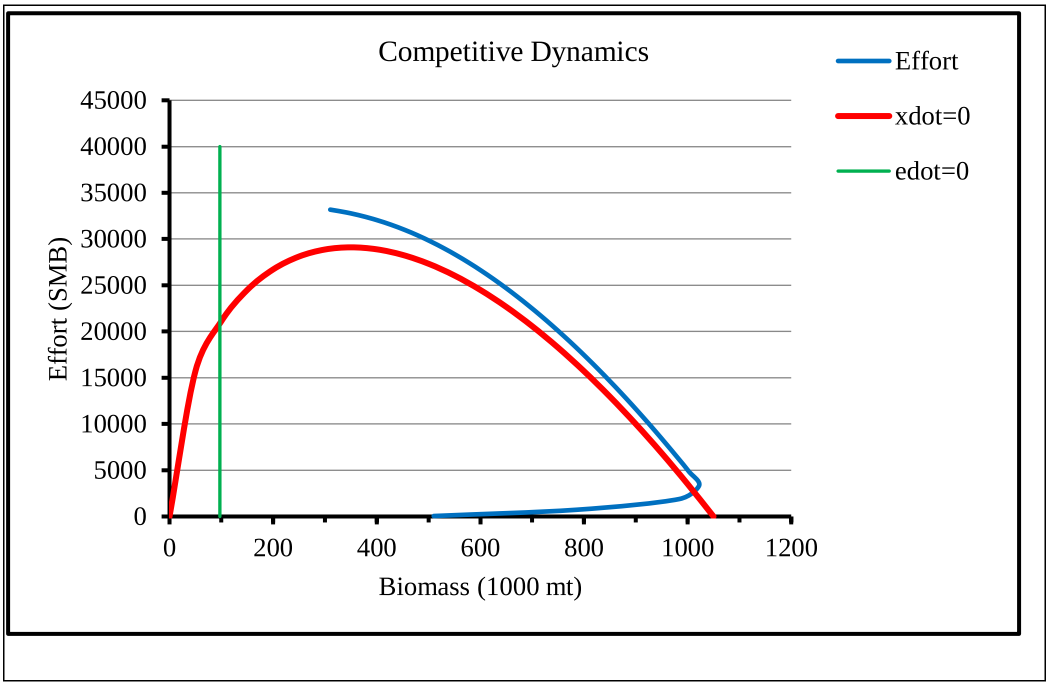


Figure 11. Biomass effort-space equilibrium situation of the hilsa fishery.

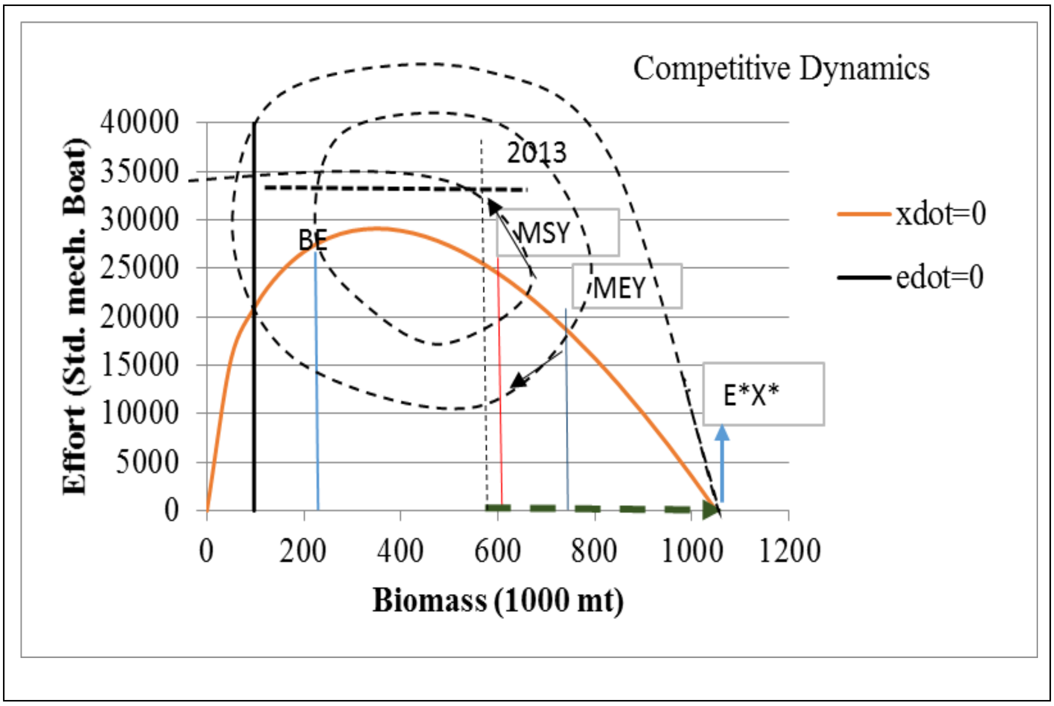


Figure 12. Possible competitive dynamic evolutionary path of the Bangladesh hilsa fishery from the initial exploitation stage. The base year 2012 and the fishery reference points; BE, MEY, MSY and the optimal fishery (E*, X*) also given for comparative reference.

8.2 Optimal Dynamics

The appropriate management policy for the Hilsa fishery must recognize that the stock level cannot be immediately moved toward its sustainable MEY level. Therefore, the real question is how to move from the initial biomass level to the optimal long run sustainable level in the optimal way.

The optimal level of effort in a static sense is where the difference between sustainable revenue and cost curves is maximized. This static state occurs at e_{MEY} and x_{MEY}. More formally, the static maximum economic yield occurs at that level of fishing effort e, where the total sustainable net returns are maximized (Anderson and Seijo 2010).

It is important to recognize that the optimal dynamic MEY level is not the same as the static MEY level. The latter is defined by:

$$\text{Static MEY}\ G_x(x) + \frac{Y_x(e,x)\cdot C_e}{p\cdot Y_e(e,x) - C_e} = 0,$$

where the variables and functions are defined above (section 3).

The former is defined by

$$\text{Dynamic MEY} \qquad G_x(x) + \frac{Y_x(e,x)\cdot C_e}{p\cdot Y_e(e,x) - C_e} = r\,,$$

where *r* is the rate of time discount.

It follows that the dynamic MEY biomass is smaller than the MEY biomass (Arnason 1990).

The dynamic optimization problem is to find the time path of fishing effort that maximizes the present value of the profits from the fishery from the current time onwards. This present value is dependent on the rate of discount, *r*. A high discount rate will lead to a lower present value, while a low discount rate will lead to higher present values for net benefits in the same time period (Seijo *et al.*1998)

The present value (PV) of a flow of profits over a time interval [0, T] is obtained as:

$$PV_\pi = \sum_{t=0}^{T} \frac{\pi_t}{(1+r)^t},$$

where π_t denotes profits in year *t* and *r* the rate of discount.

The dynamic optimization problem is to find the time path of fishing effort that maximizes the present value from the fishery.

A formal statement of the dynamic maximization problem for discrete time may be expressed as:

$$\max_{e(t)} \sum_{t=0}^{\infty} \left(p\cdot Y(e(t),x(t)) - C(e(t)) \right) \cdot \frac{1}{(1+r)^t}$$

$$\text{Subject to } x(t+1) - x(t) = G(x(t) - Y(e(t),x(t))$$

Sustainable hilsa fishery model shows that since the cost curve intersects the revenue curve in the unstable region, the open access region is unstable. The optimization problem is to find the effort which will maximize the economic benefit from the fishery. It should be noted that in our case (see section 7.1), both the harvest function and the cost function are linear in the control variable, e(t), i.e. fishing effort. This implies that the optimal control is of so-called bang-bang variety (Clark and Munro 1975). This means that the most rapid approach to the dynamic MEY is optimal.

8.2.1 Optimal adjustment path

The objective of the study to rebuild the hilsa fish stock and find the optimal adjustment path toward the long-run optimal sustainable equilibrium. This will vary depending on the biological and harvest characteristics of the fishery (Arnason 2008).

It is difficult to solve dynamic maximization problems exactly. In this case we have employed numerical methods to approximately find the optimal solution. Our method was the following:

Combining biomass growth, harvest and profit we got the optimal equilibrium condition as:

$$\psi = (\alpha - 2 \cdot \beta \cdot x + \left(\frac{b \cdot \delta \cdot (\alpha - \beta \cdot x)}{p \cdot (1 - a) \cdot q \cdot x^{\delta} - b}\right) = r,$$

where r represents the discount rate. Note that for a discount rate equal to zero, $r = 0$, $x^{*} = x_{MEY}$ (Clark 1985).

The optimal sustainable biomass level, (x^{*}) according to the above equation can be obtained by numerical means.

The corresponding optimal equilibrium effort e* may then be obtained from expression as

$$e_{eq} = \frac{\alpha \cdot x - \beta \cdot x^{2}}{q \cdot x^{\delta}}.$$

The approximately optimal dynamic equilibrium, biomass, fishing effort and harvest for r=0.05 (5%) are given in the following Table 9.

Table 9. Approximate optimal dynamic biomass, fishing effort and harvest for 5% discount rate:

	Optimal equilibrium
Biomass	647 thousand mt
Effort	22,783 SMB
harvest	261 thousand mt

The approximately optimal path to the optimal equilibrium was found by numerical means. The approximately optimal effort (SMB) is illustrated in Figure 13 and the corresponding biomass path in Figure 14. Then the Figures 15 - 17 show the corresponding optimal outcomes in terms of harvest, revenue and profits.

The key findings of this optimal path shows that the number of fishing boats (SMB) should be rapidly reduced from the current level. It will rebuild the hilsa stock and also maximize the net benefits from the hilsa resources. The optimal adjustment path for the hilsa fishery is to reduce the fishing effort from the current level of 34,101 SMB to zero in the first managed year (2015). Comparatively in the moderate path of adjustment the reduction of effort is applied gradually to the optimal level by considering social reality. In our calculation the effort reduction for moderate path was done as 31,500 in 2015, 25,000 in 2016 and 22,783 SMB in 2017. In this most rapid optimal path the fishery will be closed for one year and from the second year effort will increase and within three years (from 2015 to 2017 the attempted effort will (0, 23,000 and 22,783 SMB) reach up to the optimal effort level 22,783 SMB. The result output from the moderate path will be discussed in the section 8.3. For both of the path a constant 5% discount rate assumes that the value of future benefits (profits) over time does not change.

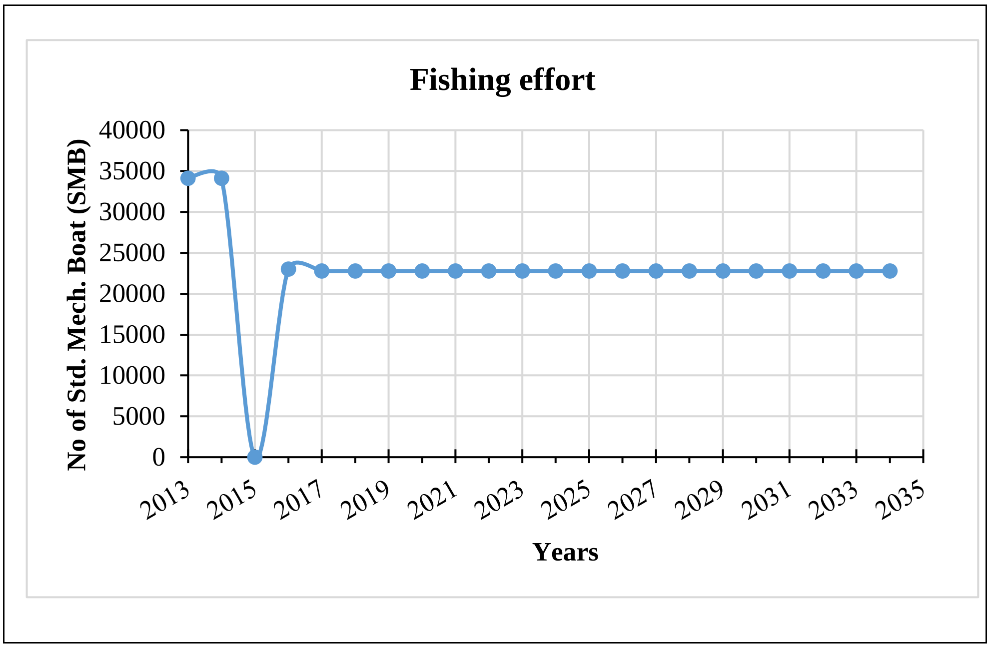


Figure 13. Fishing effort for the optimal adjustment path for 2013 to 2034.

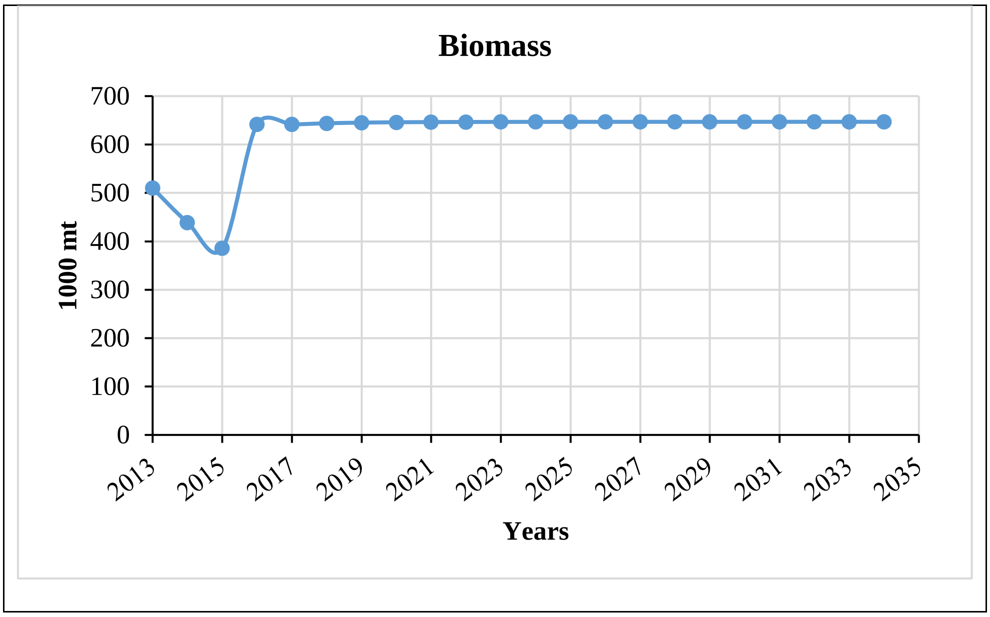


Figure 14. Estimated optimal dynamic projection of hilsa fish biomass for the period 2013 to 2034.

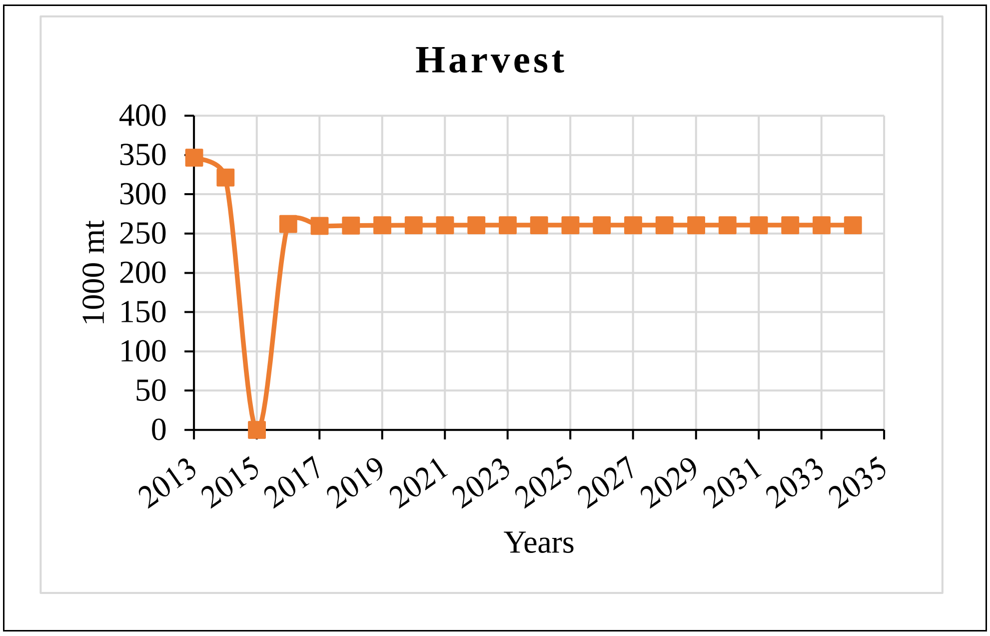


Figure 15. Optimal dynamic harvest projections for the period 2013 to 2034.

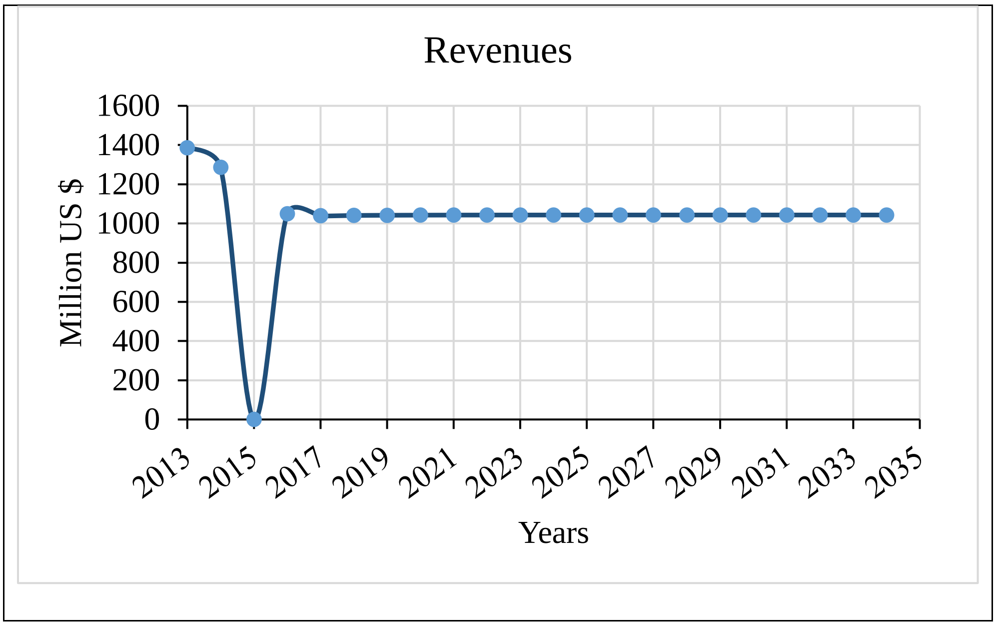


Figure 16: Optimal dynamic revenue projection of hilsa fishery for the year 2013 to 2034.

Figure 17. Estimated profits for hilsa fishery during the optimal path from 2013 to 2034.

Optimal adjustment path indicates that long run sustainable harvest (about 260 thousand mt) is lower (25%) than the current level (347 thousand mt) but hilsa stock will increase remarkably (from 510 to 647 thousand mt) within 3 years the fishery will reach up to the equilibrium level.

Implementation of the optimal adjustment path will significantly increase the net present value of the fishery. The estimated maximum NPV was found about 7,545 million. The nature of the path will depend on the initial stock size relative to the long run optimal stock size. This approach represents an extreme (and possibly impractical) path to optimal sustainability but the fundamental principle of this approach can still be appreciated from a management point of view.

As already discussed, the optimal long run equilibrium of the fishery as well as the optimal adjustment paths depend on the rate of discount, *r*. So, does the maximum present value of the fishery. The following Table 10 gives the maximum present value of the fishery as a function of the rate of discount.

Table 10. Estimated NPV at various discount rates.

Discount Rate (d)	NPV of Profits (billions US$)
10%	4.4
8.5%	5.3
5%	9.7
0%	10.4

8.2.2 Optimal dynamic equilibrium

The dynamic optimization model is important to find the suitable path of fishing effort that maximizes the present value of profits from the fishery. The optimal Dynamic policy will vary depending on the rate of discount. To compare discount rate effect, optimal bioeconomic a range of reference points (*) were estimated. The following Table 11 presents a summary of optimal bioeconomic outcomes for various discount rates.

Table 11. Optimal dynamic equilibrium solutions for various discount rates (*r*).

Discount rate(d)	x* (1000 mt)	Effort (Std. Mech. Boat	Harvest (1000mt)	Revenue (m.USD)	Cost (m.USD)	Profit m.USD
0.10	486	27,641	282	840	636	204
0.085	635	23,239	208	832	631	201
0.05	646	22,783	201	804	618	186

The discount rate determines the future value of future benefits from the fishery. The effect of increasing the discount rate is to encourage fishing effort *Ye* and harvests *Yx.* This will reduce the optimal biomass *X**. An increased discount rate reflects a higher return on investments which can make harvest more feasible for instance less investment in fish stock.

8.3 Moderate/Reasonable adjustment path for the hilsa fishery

Though the optimal adjustment is the best way to rebuild the fish stock and maximize the net present value from the fishery but it is also true that the implementation of the policy may not possible due to the socio economic reality, for instance, unemployment and livelihoods problem. That’s why we would like to find a more moderate adjustment path for the management for the fishery which will not entail as rapid reduction in fishing effort while still saving the fish stock and generating a high present value. Such a path will be more acceptable to the fishermen and easier to implement for the managers. We refer to this path as the moderate adjustment path.

The moderate adjustment path for the hilsa fishery that is specified is to reduce fishing effort from the current level (some 34,101 boats) gradually toward the estimated optimal long run equilibrium level (22,783 SMB) of the fishery. In our simulation, this reduction has been done in 3 steps. The first control year (in 2015) of this policy will cut the effort to 31,500 SMB and then to 25,000, and finally 22,783 SMB. The main outcome of this policy is illustrated in the moderate path shown in the following figures (Figures 18-22) and detailed numerical outcomes are shown in Appendix 7.

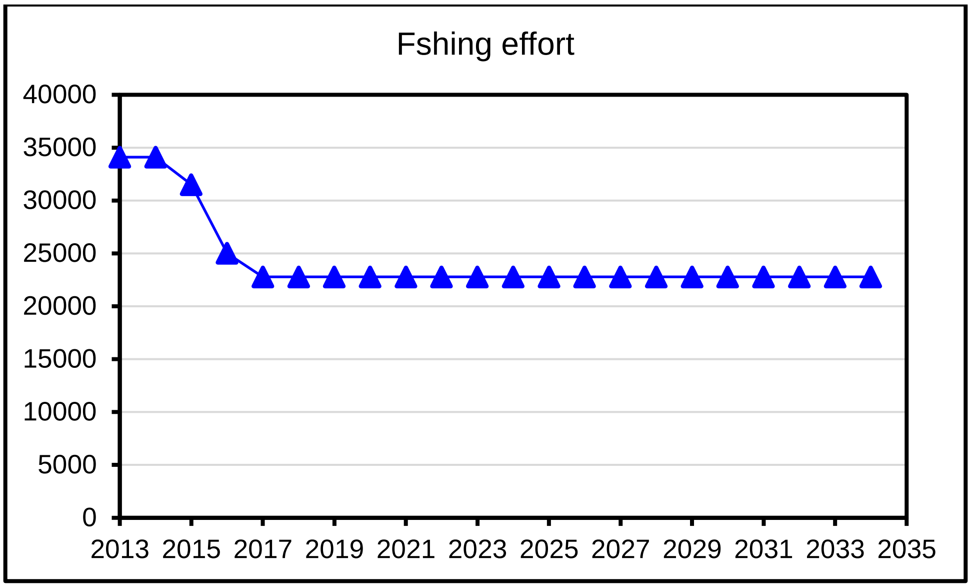


Figure 18. Fishing effort trends during the moderate adjustment path for the years 2013 to 2034.

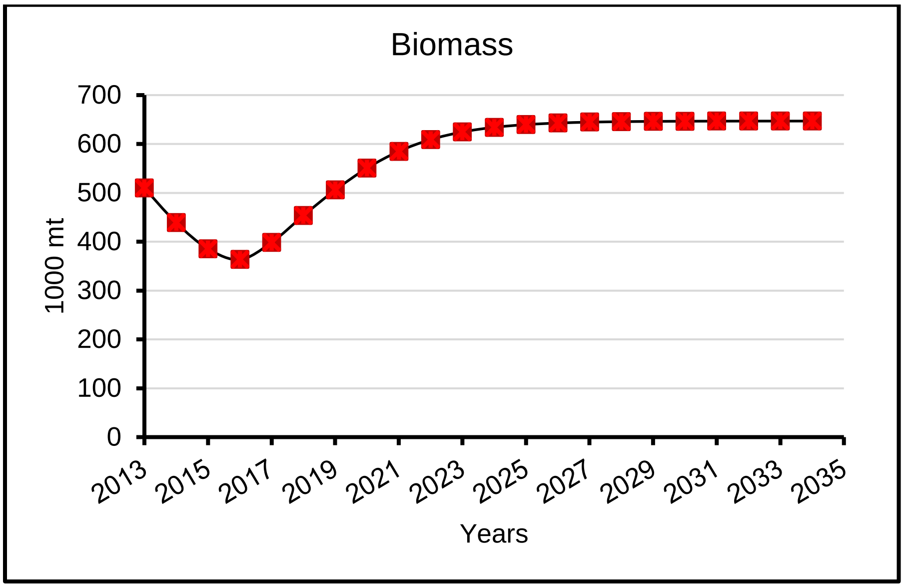


Figure 19. Response of hilsa biomass during the moderate adjustment path from the year 2013 to 2034.

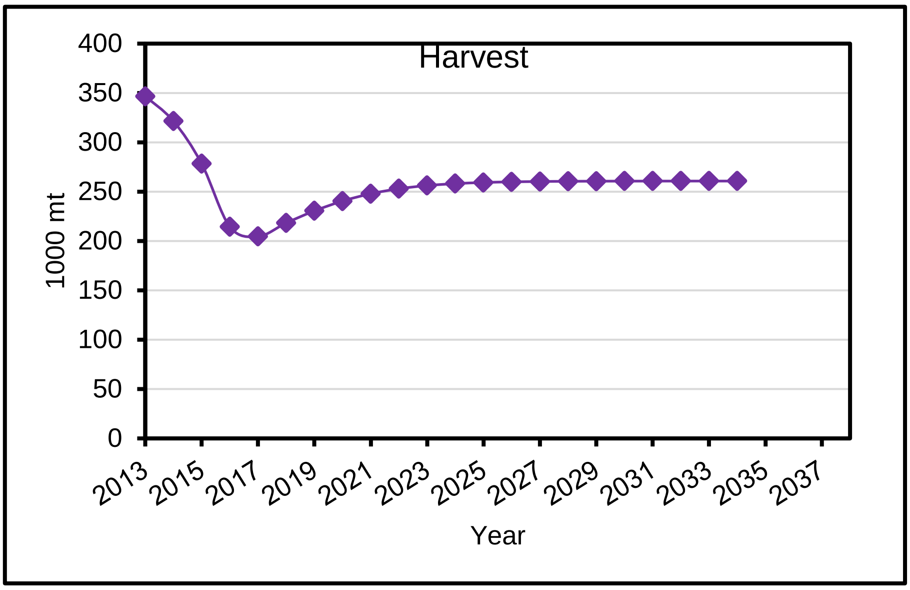


Figure 20. Harvest trends of hilsa fishery during moderate path of adjustment.

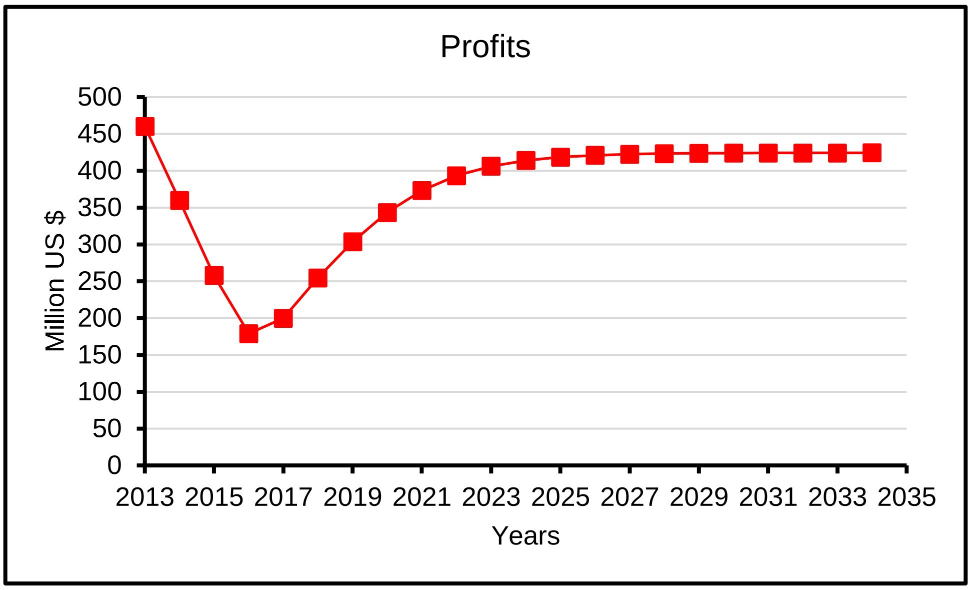


Figure 21. Revenue projection during moderate path of adjustment.

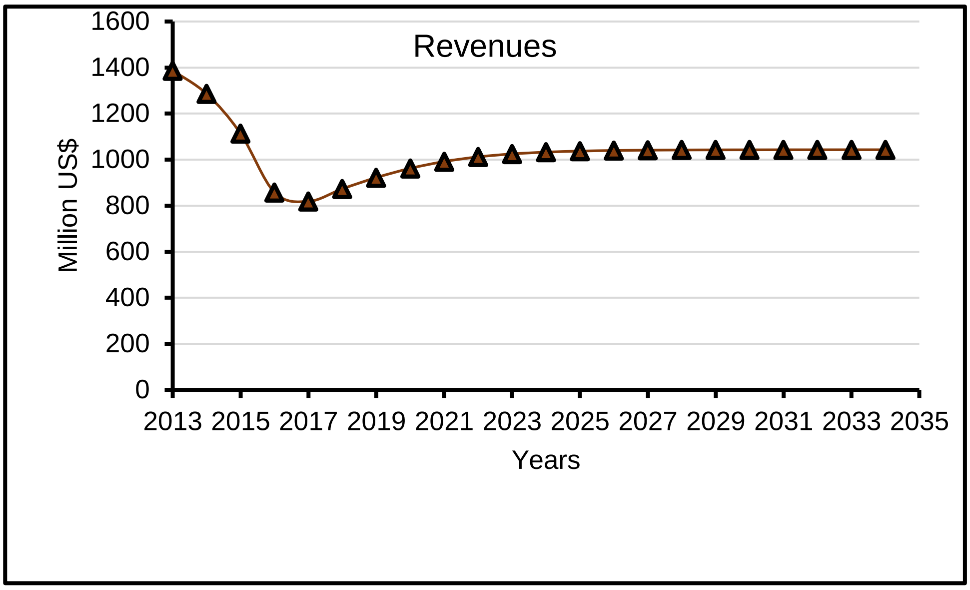


Figure 22. Profit projection of hilsa fishery during moderate path of adjustment.

The gradual reduction of fishing boats compared to the PV maximizing optimal path will not attain the long run optimal economic benefit maximising level as fast as the most rapid approach (bang-bang) but it may be more socially acceptable. According to our calculation the initial level of biomass is around 510 thousand mt. This moderate path will increase the biomass level to 647 thousand mt annually (27% higher than the present biomass). This optimal biomass level will increase the sustainability of the hilsa fishery, reduce the likelihood of the fishery collapsing and, perhaps most importantly, maximize the long term economic benefits from the fishery.

This policy will create a net present value of US $ 7,030 million whereas the optimal policy generates NPV of US$ 7,545 million. Thus the loss in present value is comparatively small. A comparative summary of the adopted optimal dynamic (bang-bang) and moderate adjustment paths on present value, effort, harvest and biomass is given Table 12 below.

Table 12. A comparative summary of the adopted optimal dynamic (bang-bang) and moderate adjustment paths on present value, effort, harvest and biomass.

Path.	Present value of profit (PV) (million US$		Effort (SMB)		Harvest (1000mt)		Biomass (1000 mt)		Total PV (Million US$)
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
Optimal Path	366	0	23,000	0	262	0	647	386	7,545
Moderate path	254	152	3,150	22,783	278	233	647	363	7,030

9 DISCUSSION

9.1 Static and Dynamic equilibrium fishery

Applying the model, the static (or sustainable) and dynamic projections analysis indicate that the current hilsa fishery suffers greatly from excessive fishing effort and, consequently, overexploited stocks and much reduced flow of net economic benefits. There is a great deal of instability in the hilsa fishery which is not surprising. The hilsa fishery is an open access, common pool fishery by nature. 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. Now the real question in particular cases is the extent of the economic inefficiency and over-utilisation fish stock.
According to the static analysis, the fishery currently finds itself at a critically depensatory situation in terms of management with most bioeconomic criteria are at unstable situation. This current state may however represent an opportunity for management. According to the optimal management solution, the fishery has a potential for sustained profits at the rate of US$ 424 million annually. This would however require an adjustment of biomass up to 647 thousand metric tons in addition to dynamic adjustments in fishing effort.

The dynamic equilibrium calculations indicate that the optimal equilibrium fishing effort for hilsa is only about 2/3 of the current fishing effort. This corresponds to a reduction in the number of fishing boats from about 34,101 to 22,783 equivalent SMB. Moreover, in sustainable equilibrium, all fishing for the first managed year should be ended. According to the calculations; if this is not implemented, the stock may be critically reduced and fishery may collapse over time.

One in four (25%) of the world fisheries is in a rapid depletion because of over exploitation. Many cause have been found for the collapse of some fishery including a lack of political will impose adequate harvest, overoptimistic stock assessment by the fishery scientist, exceptional mortality from natural predators, climate changes and subsidies to fishers (Roughgarden & Smith, 1996). To find real idea about the current fishery, the comparison between a collapsed fishery (the sustainable BE) and the MEY fishery is described in Table 13 below.

Table 13. The comparison between collapsed and MEY fishery.

A collapsed fishery (the sustainable BE)	The MEY fishery.
1. Stock under rapid depletion level	1. Long run sustainable biomass
2. An unstable equilibrium condition	2. Surplus of some biomass
3. Trends of increasing harvest	3. A stable equilibrium condition
4. Increasing of effort	4. Optimal effort level
5. Sudden fall of after a relatively long stable and persistence of high level catches	5. Optimal harvest for long time
6. Profit level zero for unstable catches.	6. Sustainable profit level over time

The cost estimates a fishery managed at MEY is 601 million US$ and and MSY cost is 736 million US$ higher than MEY cost 601 million US$. Notably there is small overall profit to be made using the BE static option. This is important as it will have significant implications for any management strategy developed.

The estimated stock of hilsa at optimal sustainable equilibrium is about 27% higher than the current level. At the same time the harvest rate should be decreased by 25% from the current harvest. So backward and forward 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 be very close to present situation which is US $ 424 million per year. This gain of the profit, on a sustainable basis per year, can, if properly used, go a long way towards permanently improving the economic and social situation of the fishing communities.

Catch information of Bangladesh hilsa from 2007 to 2012 confirms an increasing trajectory in yield (Figure 5) have shown large, unsustainable peaks in harvests due to excessive effort which has resulted in a unstable equilibrium for biomass levels. Profits also peaked with these harvests but then fell sharply in the next year as biomass apparently declined.

The bioeconomic model indicates the average annual production of hilsa is 260 thousands mt and the estimated MSY is 278 thousand mt. The current effort level is 25% 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 (section 7.1, Figure 10).

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 rapid reductions in fishing effort and harvests during the first 2-5 years. However, as demonstrated above, it is possible to define more moderate adjustment paths which maintain reasonable catch and effort levels every year while attaining the long run Optimum sustainable yield within a reasonable time (i.e. 5 years) and without much loss in the present value of economic benefits (about 7%). Such paths may well be socially more acceptable and, therefore, feasible.

9.2 Optimal Dynamics

NPV analysis of profits for a simulated 20-year management period toward the long-run optima at varied discount rates obtained values ranging between US$ 4 to US$ 10 billion for discount rates from 0-10% (table 9) Using the 2013 discount rate as a reference however, a more likely range of values possibly lie between discount rates of 0% to 5% therefore obtaining the range US $ 9 to 10 billion.
These NPVs represent the value of pure profits from the fishery over the period and may also provide a benchmark from which an appropriate management strategy may develop, particularly with regards to the cost of management (or net benefit). It may be important to keep the net costs of any management initiative below the NPV for this or any management period in order to avoid a net loss to the national economy.

Based on the model specifications the “most rapid approach” or “bang-bang” adjustment path (Arnason 2008) is optimal. It may be recognized however that this policy may not be applicable in a strict sense to this or, indeed, most other fisheries and may need to be modified for practical application. This policy however addresses the problems of the competitive dynamic path and other sub-optimal management objectives by reducing fishing effort in the short term, rebuilding the stock in the short to medium term, and then adjusting fishing effort and harvests to their respective optima based on the available biomass.

10 POLICY IMPLEMENTATION AND ITS BENEFITS

If we assume that the constructed model for dynamic path is true, the practical question then arises as what type of fisheries management system and what social and economic benefits may be achieved. Impact of the policy implementation on sustainable yield, biomass and corresponding dynamic paths with maximising the present value of profits of the hilsa fishery can be described as follows:

<u>Control the over-fishing of hilsa:</u> Any fishery is not sustainable if total catch exceeds the MSY level. This study shows that current effort level is 26% higher than the MSY effort level. In the base year, the total catch of hilsa was 347 thousand mt and estimated MSY was 278 thousand mt (Figure 1 section 5.1) which indicates not only over-fishing but also indicates the instability of the fishery. By reducing effort level to the OSY point, the fishery will be sustainable for the long run. Thus the stock rebuild can be possible by controlling over-fishing.

<u>Economic benefit:</u> Fishing effort must be reduced by one fourth (26%). Thus will gain about 424 million US$ annually. This profit is close to the base year profit 458 and moreover it will make this profit sustainable. 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 $ 7,030 million. If it is not reduced to the optimal level, the model shows that the fishery may eventually collapse. 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 social development activities. Giving 11,318 boat owners registration (license) or individual quotas through their vessel of 10 mt per 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 fishers“ community will be established.

<u>Sustainable CPUE:</u> According to our analysis, the base year CPUE was around 10 mt per year but our calculation shows that the CPUE is 11 mt/SMB. By implementing this policy,

The estimated CPUE will be sustainable. CPUE at optimal effort level will be 11 mt per year.

Impacts on Employment: Reducing fishing effort to attain OSY will raise productivity of the hilsa fishery. But 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 341,010 fishermen employed in 34,101 fishing vessels at the present time. When we will reduce the fishing effort to 22,783 vessels, 113,180 fishermen will lose their jobs. With the excess profit, it can be easy to rehabilitate the jobless fishermen. According to the optimum sustainable hilsa fishery, the profit will be US $600 million per year. If the average income of hilsa and jatka fishermen was US $1000, we can easily rehabilitate fishermen for alternative jobs.

Utilisation of fishing Boats: An alternative plan can be find out to make the best use of boat which will be removed from the fishery. It can be organised in diversified ways. These boat can be utilized for carrying people and seasonal goods from one place to another place, tourism, research and education. Or they can be employed in the same field that will help the hilsa industry grow bigger than before exploring many more opportunities for the economy of the country.

Limitations of the study

The simple hilsa model that we have built and used for this study is simplifications. 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 variation in weather were excluded. In the future it is necessary to study other ecological and environmental factors influencing fishery. 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. 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 reliable 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. A 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 overcrowding fishing efforts is similar to other artisanal fisheries.

- Bangladesh hilsa is a common fish stock shared by the Bangladesh, India and Myanmar but for this study we considered only the Bangladesh context which may differ from our estimation.

11 SUMMARY AND POLICY RECOMMENDATIONS

The Government of People's Republic of Bangladesh has been implementing a project to prevent catch of jatka and gravid hilsa. But no real effort until now has taken place to reduce the continuous rise in fishing effort and catch. If the number of fishing boats/fishing effort continuous to increase or it is not decreased as the catch grows at an alarming rate, it appears that the biomass will also fall. In the artisanal hilsa fishery, the major concern is the presence of an over effort capacity. Given that effort could be reduced to economically efficient levels (represented by the results of the base model) the existing both marine and inland hilsa fishery is capable of generating substantial net present value of economic benefits.

The purpose of this study is to assess the present status of artisanal hilsa fishery of Bangladesh and determine the exploitation level, rebuild the fish stock and to recommend a 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 22,783 standard mechanized boat units 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 $ 5,899 million which over time involves quite drastic reductions in fishing effort and harvests over 3 years. On the other hand, a moderate adjustment path maintains reasonably high effort and 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 34,101 (SMB) vessels to 22,783 fishing vessels.

The reduction of fishing effort by reducing fishing boats in most cases does not keep effort down due to inherent behaviour of fishers to invest 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 boats. 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. So, alternative employment program will be necessary.

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

The government should develop comprehensive plan for the best use of decommissioned vessels. The best use of these 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.

Additional requirements to implement the current policy include in-depth biological and economic programmes to assess the stock and determine total allowable catch (TAC and to determine the fishery's present position along the optimal adjustment path. 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. It appears that the fishery has the potential for substantial profits and therefore an investment in an optimal-oriented management system may be worthwhile. Reduction of effort needs a big investment, so Bangladesh could also look to solicit funds from global development partners such as the Global Environment Facility (GEF) and the World Bank as well as other bodies having an interest in conserving biological resources and achieving economically efficient and sustainable development. Better monitoring of fish landings is necessary for the formulation of viable management. Regular monitoring of resources provides suitable baseline information which is a vital requirement for rational use. Especially long term optimal use of the hilsa resource is very important at this time when there is an increasing demand of fish supply and the livelihoods of the millions.

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APPENDICES

Appendix 1. Total hilsa harvest from both inland and marine sector of Bangladesh 1987-2013

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	196.744	280.328
2007-2008	89.900	200.100	290.000
2008-2009	95.970	202.951	298.921
2009-2010	115.179	198.574	313.753
2010-2011	114.520	225.325	339.845
2011-2012	114.475	232.037	346.512
2012-2013	119.340	231.660	351.000

Appendix 2. No of Boats and Average catch per boat from 1983 to 2011-12

Years	Number of boats		Total No of Boat	Hilsa catch (MT)		Total	Av. Catch (Mt)/boat/year		Total
	MB	NMB		MB	NMB		MB	NMB	
1983/84	3.347	-	3.347	56.000	-	56.000	16,73	-	16,73
1984/85	3.000	-	3.000	71.050	-	71.050	23,68	-	23,68
1985/86	2.887	3.802	6.689	88.389	7.905	96.294	30,62	2,08	14,40
1986/87	2.887	3.800	6.687	94.851	8.963	103.814	32,85	2,36	15,52
1987/88	2.882	3.509	6.391	91.723	13.227	104.950	31,83	3,77	16,42
1988/89	2.880	3.509	6.389	94.990	15.321	110.311	32,98	4,37	17,27
1989/90	2.880	3.509	6.389	95.285	18.658	113.943	33,09	5,32	17,83
1990/91	2.880	3.509	6.389	97.573	17.785	115.358	33,88	5,07	18,06
1991/92	2.880	3.509	6.389	102.036	18.070	120.106	35,43	5,15	18,80
1992/93	2.880	3.509	6.389	105.128	17.997	123.125	36,50	5,13	19,27
1993/94	2.880	3.509	6.389	103.839	17.322	121.161	36,06	4,94	18,96
1994/95	2.880	3.509	6.389	111.475	17.640	129.115	38,71	5,03	20,21
1995/96	2.880	3.509	6.389	109.282	17.378	126.660	37,95	4,95	19,82
1996/97	2.880	3.509	6.389	114.921	16.283	131.204	39,90	4,64	20,54
1997/98	2.880	3.509	6.389	110.440	13.059	123.499	38,35	3,72	19,33
1998/99	2.880	3.509	6.389	121.909	18.761	140.670	42,33	5,35	22,02
1999/00	18.982	7.177	26.159	119.295	21.072	140.367	6,28	2,94	5,37
2000/01	18.982	6.377	25.359	131.254	23.400	154.654	6,91	3,67	6,10
2001/02	18.982	6.377	25.359	131.619	20.724	152.343	6,93	3,25	6,01
2002/03	18.982	6.377	25.359	114.274	21.814	136.088	6,02	3,42	5,37
2003/04	18.982	6.377	25.359	157.570	27.268	184.838	8,30	4,28	7,29
2004/05	18.982	6.377	25.359	170.756	27.607	198.363	9,00	4,33	7,82
2005/06	18.982	6.377	25.359	170.945	27.905	198.850	9,01	4,38	7,84
2006/07	18.992	6.377	25.369	172.852	23.892	196.744	9,10	3,75	7,76
2007/08	18.992	6.377	25.369	177.828	22.272	200.100	9,36	3,49	7,89
2008/09	18.999	6.377	25.376	177.471	25.480	202.951	9,34	4,00	8,00
2009/10	19.223	6.861	26.084	158.860	39.724	198.584	8,26	5,79	7,61
2010/11	19.223	6.861	26.084	182.152	35.211	217.363	9,48	5,13	8,33
2011/12	19.223	6.861	26.084	188.527	43.510	232.037	9,81	6,34	8,90

Appendix 3. Cost and profit calculation for base year 2012

			Base Year 2012-13				
	Item of cost	Non mechanised Boat (BDT)	Remarks	Mechanised boat (BDT)	Remarks		
	1. Investment Cost						
	Price of Boat						
	License fee/License renewel fee	3.000		5.000	2000-5000BDT/year		
	docking charge	400		600	400-600BDT/year		
	Price of Engine	-		220.000			
	Price of net	80.000		300.000			
	Total Investment cost	619.100	61.910	2.025.600	202560,00		
	2.Operational Cost	-	52.335	-			
	landing charges (35 tk/mt)	210		350			
	Fuel and Oil	-	114.245	195.000	12hr*65tk*8litre*250day		
	Food (6-10 people*200BDT/day*200 day)	300.000	6pers*200*200	500.000	10 pers*200tk/day*200fd		
	Crew Share	-		-			
	(Gross earning - Food)*	600.671	0,3750	-			
	(Gross Earning-food-fuel)*	-		843000			
	Gear repair/ replacement	35.000	20000-50000	150.000	100000-500000	-	
	Engine repair	-		90.000			
	Hull repair	12.000	15000-40000	80.000			
	Total operational Cost	947.881		1.858.350			
	3, Depreciation cost	30.785	5 percent of investment	101.280			
	Hull(10 Years)	52.335	8,5 percent interest payments	171.700			
	Engine(8years)						
	Total cost	1.031.001		2.131.330	1NMB+1MB		USD/SMB
					BDT	US$	
	Fixed cost (fk)	99.335	Fixed Cost for MB	597.980	697.315	9.056	6.037
	(19223 MB+ NMB 6861)	681.534.005	For 19223	11.494.969.540	464.876	6.037	
						US$	

	Variable cost (vc)	900.881	variable cost MB	1.538.350	2.439.231	31.678	21.119
	for 19223 MB+ NMB 6861	6.180.946.256	19.223	29.571.702.050	1.626.154	21.119	27.156
		900.881					0,22
				1.538.350			
	Revenue Base year	Cost Base year		Profit			
	1351948052	926054949		425893102,9			

Appendix 4. Sustainable Hilsa fishery model calculations

Biomass (1000 mt.)	Effort (Std.Mech .Boat)	Biomass	Total Harvest (1000 mt)	Revenue (million US$)	Cost (million US$)	Profit (million US$)	
1050	360,0411	-1050	5,25	21	9,777277	11,22272	
1020	2484,023	-1020	35,7	142,8	67,45613	75,34387	
970	5882,911	-970	82,45	329,8	159,7563	170,0437	
920	9099,451	-920	124,2	496,8	247,1047	249,6953	
870	12126,04	-870	160,95	643,8	329,2946	314,5054	
820	14954,17	-820	192,7	770,8	406,0954	364,7046	
770	17574,29	-770	219,45	877,8	477,2473	400,5527	
720	19975,54	-720	241,2	964,8	542,4558	422,3442	
670	22145,51	-670	257,95	1031,8	601,3834	430,4166	MEY
620	24069,81	-620	269,7	1078,8	653,6396	425,1604	
570	25731,59	-570	276,45	1105,8	698,7671	407,0329	
520	27110,84	-520	278,2	1112,8	736,2219	376,5781	MSY
470	28183,33	-470	274,95	1099,8	765,3465	334,4535	
470	28183,33	-470	274,95	1099,8	765,3465	334,4535	
420	28919,17	-420	266,7	1066,8	785,329	281,471	
370	29280,53	-370	253,45	1013,8	795,142	218,658	
320	29217,95	-320	235,2	940,8	793,4428	147,3572	
270	28664,15	-270	211,95	847,8	778,4036	69,39642	
227,5	27736,15	-227,5	188,2563	753,025	753,2029	-0,17791	BE

Appendix 5. Optimal Dynamic Equilibrium Calculation Results

x	Gx	e	Ye	Yx	p*Ye-fk-vc	MSE	Rhs	roi	Diff
0	1,05	0	0	0	-27,156	0	0	0,05	0
50	0,95	15713	0,003182	0,5	-14,428078	-0,94108	0,008918	0,05	-0,04108
100	0,85	21111	0,0045	0,475	-9,156	-1,40881	-0,55881	0,05	-0,60881
150	0,75	24495	0,005511	0,45	-5,1105923	-2,39115	-1,64115	0,05	-1,69115
200	0,65	26713	0,006364	0,425	-1,7001559	-6,78838	-6,13838	0,05	-6,18838
250	0,55	28109	0,007115	0,4	1,30449894	8,326875	8,876875	0,05	8,826875
300	0,45	28868	0,007794	0,375	4,02091454	2,532633	2,982633	0,05	2,932633
350	0,35	29102	0,008419	0,35	6,51891648	1,458003	1,808003	0,05	1,758003
400	0,25	28889	0,009	0,325	8,844	0,997931	1,247931	0,05	1,197931
450	0,15	28284	0,009546	0,3	11,0277662	0,738753	0,888753	0,05	0,838753
500	0,05	27330	0,010062	0,275	13,0932236	0,570364	0,620364	0,05	0,570364
550	-0,05	26058	0,010553	0,25	15,0577418	0,450864	0,400864	0,05	0,350864
600	-0,15	24495	0,011023	0,225	16,9348154	0,360801	0,210801	0,05	0,160801
646,9	-0,2438	22783	0,011445	0,20155	18,625612	0,293858	0,050058	0,05	5,84E-05
696,9	-0,3438	20714	0,011879	0,17655	20,3619545	0,235458	-0,10834	0,05	-0,15834
746,9	-0,4438	18408	0,012298	0,15155	22,0370483	0,186753	-0,25705	0,05	-0,30705
796,9	-0,5438	15877	0,012703	0,12655	23,6569511	0,145268	-0,39853	0,05	-0,44853
846,9	-0,6438	13134	0,013096	0,10155	25,2267834	0,109316	-0,53448	0,05	-0,58448
896,9	-0,7438	10189	0,013477	0,07655	26,7509198	0,077709	-0,66609	0,05	-0,71609
946,9	-0,8438	7050	0,013847	0,05155	28,2331325	0,049583	-0,79422	0,05	-0,84422
996,9	-0,9438	3726	0,014208	0,02655	29,6767019	0,024295	-0,91951	0,05	-0,96951
1046,9	-1,0438	223	0,01456	0,00155	31,0845014	0,001354	-1,04245	0,05	-1,09245
1096,9	-1,1438	-3452	0,014904	-0,02345	32,4590652	-0,01962	-1,16342	0,05	-1,21342
1146,9	-1,2438	-7292	0,01524	-0,04845	33,8026417	-0,03892	-1,28272	0,05	-1,33272
1196,9	-1,3438	-11294	0,015568	-0,07345	35,1172366	-0,0568	-1,4006	0,05	-1,4506
1246,9	-1,4438	-15451	0,01589	-0,09845	36,4046482	-0,07344	-1,51724	0,05	-1,56724

Appendix 6. Optimal Dynamic Adjustment path calculations results

Time	Bio-mass	Growth	Attempted fishing effort	Actual fishing effort	Attempted Harvest	Test Biomass	Real Biomass 31.12	Actual harvest	Revenues (m usd)	Costs (m. US$)	Profits	PV of profits
2013	510	275	34101	34101	347	439	439	347	1386	926	460	460
2014	439	268	34101	34101	321	386	386	321	1286	926	360	343
2015	386	256	0	0	0	642	642	0	0	0	0	0
2016	642	262	23000	23000	262	642	642	262	1049	625	424	366
2017	642	262	22783	22783	260	644	644	260	1039	619	420	346
2018	644	261	22783	22783	260	645	645	260	1041	619	422	331
2019	645	261	22783	22783	260	646	646	260	1042	619	423	316
2020	646	261	22783	22783	261	646	646	261	1042	619	424	301
2021	646	261	22783	22783	261	647	647	261	1043	619	424	287
2022	647	261	22783	22783	261	647	647	261	1043	619	424	273
2023	647	261	22783	22783	261	647	647	261	1043	619	424	260
2024	647	261	22783	22783	261	647	647	261	1043	619	424	248
2025	647	261	22783	22783	261	647	647	261	1043	619	424	236
2026	647	261	22783	22783	261	647	647	261	1043	619	424	225
2027	647	261	22783	22783	261	647	647	261	1043	619	424	214
2028	647	261	22783	22783	261	647	647	261	1043	619	424	204
2029	647	261	22783	22783	261	647	647	261	1043	619	424	194
2030	647	261	22783	22783	261	647	647	261	1043	619	424	185
2031	647	261	22783	22783	261	647	647	261	1043	619	424	176
2032	647	261	22783	22783	261	647	647	261	1043	619	424	168
2033	647	261	22783	22783	261	647	647	261	1043	619	424	160
2034	647	261	22783	22783	261	647	647	261	1043	619	424	152
									PV=			4644
									PV after that			2901
									Total PV=			7545

Appendix 7. Moderate adjustment path calculations results

Time	Biomass	Growth	Attempted fishing effort	Actual fishing effort	Attempted Harvest	Test Biomass 31.12 xt+1	Real Biomass 31.12	Actual harvest	Revenues (m usd)	Costs (m. US$)	Profits	PV of profits
2013	510	275	34101	34101	347	439	439	347	1386	926	460	460
2014	439	268	34101	34101	321	386	386	321	1286	926	360	343
2015	386	256	31500	31500	278	363	363	278	1113	855	258	234
2016	363	250	25000	25000	214	398	398	214	858	679	179	155
2017	398	260	22783	22783	205	453	453	205	819	619	200	164
2018	453	271	22783	22783	218	506	506	218	873	619	255	199
2019	506	275	22783	22783	231	550	550	231	922	619	303	226
2020	550	275	22783	22783	241	585	585	241	962	619	343	244
2021	585	272	22783	22783	248	609	609	248	992	619	373	252
2022	609	269	22783	22783	253	625	625	253	1012	619	393	254
2023	625	266	22783	22783	256	634	634	256	1025	619	406	249
2024	634	264	22783	22783	258	640	640	258	1033	619	414	242
2025	640	262	22783	22783	259	643	643	259	1037	619	418	233
2026	643	262	22783	22783	260	645	645	260	1040	619	421	223
2027	645	261	22783	22783	260	646	646	260	1041	619	423	213
2028	646	261	22783	22783	261	646	646	261	1042	619	423	204
2029	646	261	22783	22783	261	647	647	261	1042	619	424	194
2030	647	261	22783	22783	261	647	647	261	1043	619	424	185
2031	647	261	22783	22783	261	647	647	261	1043	619	424	176
2032	647	261	22783	22783	261	647	647	261	1043	619	424	168
2033	647	261	22783	22783	261	647	647	261	1043	619	424	160
2034	647	261	22783	22783	261	647	647	261	1043	619	424	152
									PV=			4129
									PV after that			2901
									Total PV=			7030