Hilsa Fisheries Research and Development in Bangladesh

Editor

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BFRI Received Ekushey Padak 2020

Bangladesh Fisheries Research Institute (BFRI) received the prestigious National Award **Ekushey Padak 2020** for outstanding contribution in fisheries research. Hon'ble Prime Minister Sheikh Hasina handed over the award to the Director General of the Institute Dr. Yahia Mahmud at a ceremony held on 20 February 2020 in Dhaka.

Ekushey Padak Recipients with Hon'ble Prime Minister Sheikh Hasina.

Foreword

Hilsa Shad, (*Tenualosa ilisha*) is the largest single species fishery of Bangladesh which contributes about 12% of the total fish production and 1.0% of national GDP. Of the current total fish production of 4.27 million tonnes (2017-18), hilsa alone contributes 0.52 million tonnes. Hilsa production has increased by 78% in last 11 years from 2007-08 in Bangladesh due to various conservation measures taken by the Government. Bangladesh is the world top hilsa producing country and accounts for about 75% of the world hilsa landings. Hon'ble Prime Minister Sheikh Hasina, Government of the people's Republic of Bangladesh has paid the highest attention to hilsa conservation and development and increased allocation for research and alternate employment for improving the livelihood of hilsa fishers.

Although hilsa is an important fish in Bangladesh, not much research was done on hilsa in the country until the mid-1980s. Some Universities and the Department of Fisheries (DoF) earlier carried out some research on the species, but they were mostly fragmentary, scattered and not comprehensive enough for sustainable development of hilsa fisheries.

Bangladesh Fisheries Research Institute (BFRI) since its establishment in 1984 has been conducting continuous research on hilsa fisheries and generated a large volume of information and knowledge covering all aspects of the fishery. Ministry of Fisheries and Livestock, Govt. of the People's Republic of Bangladesh and many international organizations like IDRC, ACIAR/CSIRO, Fourth Fisheries Project of DoF, WorldFish Center supported BFRI research on hilsa fisheries. These researches made remarkable achievements, especially in the identification of spawning season, spawning and nursery grounds, the impact of indiscriminate catching of hilsa juveniles (jatka) and gravid fish, establishment of sanctuaries, gear selectivity, stock assessment and stock discrimination.

I am very much delighted that BFRI is publishing a valuable book on "Hilsa Fisheries Research and Development in Bangladesh" mainly focusing on progress and contributions of hilsa research by BFRI. However, it also includes information on hilsa research by Universities and other organizations. Research information if missed here will be included in the next edition subject to the availability. I believe, the book will serve as an important source of information and knowledge for policy formulation and guiding future hilsa research by administrators, planners, academicians, students and development partners for hilsa fisheries development.

I wish to express my deep appreciation to Dr. M.A. Mazid, Former Director General of BFRI for his painstaking review and revision to enhance the standards of the book. I also extend my sincere thanks to Dr. G.C. Haldar and BFRI hilsa research team including Ms. Flura and Mr. Mehedi Hasan Pramanik for their cooperation in publishing the book. I acknowledge the support of the Hilsa Research Strengthening Project for the publication of this book.

Dr. Yahia Mahmud
Director General
Bangladesh Fisheries Research Institute

Acronyms and Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AIGA	Alternate Income Generating Activities
APHA	American Public Health Association
ARDMCS	Aquatic Resource Development Management and Conservation Studies
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Centre for Advanced Studies
BFDC	Bangladesh Fisheries Development Corporation
BFRI	Bangladesh Fisheries Research Institute
BOBP	Bay of Bengal Program
BoBLME	Bay of Bengal Large Marine Ecosystem
BWDB	Bangladesh Water Development Board
CBFM	Community Based Fisheries Management
CBO	Community based Organization
CNRS	Centre for Natural Resources Studies
CBD	Convention on Biological Diversity
CPUA	Catch per Unit Area
CPUE	Catch per Unit Effort
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAE	Department of Agricultural Extension
DFID	Department for International Development
DFO	District Fisheries Officer
DoF	Department of Fisheries
DPDT	Department of Patent, Design and Trademarks
ECOFISH^{BD}	Enhanced Coastal Fisheries of Bangladesh
ESBN	Estuarine Set Bag Net
ESCAP	United Nation Economic and Social Commission for Asia and the Pacific
FAO	Food and Agricultural Organization of the United Nations
FCD	Flood Control and Drainage
FCDI	Flood Control and Drainage with or without Irrigation
FFP	Fourth Fisheries Project
FRSS	Fisheries Resource Survey System
GEF	Global Environment Facility
GIS	Geographic Information System
GMB	The Ganges, Meghna and Brahmaputra
GoB	Government of Bangladesh
GDP	Gross Domestic Product
GPS	Global Positioning System
GSI	Gonado-Somatic Index
HFMAP	Hilsa Fisheries Management Action Plan
ICLARM	International Centre for Living Aquatic Resources Management
IDRC	International Development Research Centre
IMED	Implementation Monitoring and Evaluation Division

IMSF	Institute of Marine Science and Fisheries
IUCN	International Union for Conservation of Nature
IWA	International Water Association
IWTA	Inland Water Transport Authority
LF	Length Frequency
LGED	Local Government and Engineering Department
LWR	Length Weight Relationship
m	Million
MACH	Management of Aquatic Ecosystem through Community Husbandry
MoE	Ministry of Environment, Forest and Climate Change
MoFL	Ministry of Fisheries and Livestock
MoLGRDC	Ministry of Local Government, Rural Development and Cooperatives
MoU	Memorandum of Understanding
MoWR	Ministry of Water Resources
MPA	Marine Protected Area
MSBN	Marine Set Bag Net
MSY	Maximum Sustainable Yield
MT	Metric Ton
NARS	National Agricultural Research System
NFP	National Fisheries Policy
NGO	Non-Government Organization
NSTU	Noakhali Science and Technology University
NTU	Nephelometric Turbidity Unit
OEL	Optimum Exploitation Level
PL	Post-larvae
RAB	Rapid Action Battalion
SD	Standard Deviation
SDG	Sustainable Development Goals
SGR	Specific Growth Rate
SRO	Statutory Regulatory Order
SSB	Steady State Biomass
UFO	Upazila Fisheries Officer
UNO	Upazila Nirbahi Officer
UNDP	United Nations Development Program
UP	Union Parishad
USAID	Unites States Agency for International Development
USDA	United States Department of Agriculture
VGD	Vulnerable Group Development
VGF	Vulnerable Group Feeding
VMC	Village Management Committee
VPA	Virtual Population Analysis
WARPO	Water Resources Planning Organization
WB	World Bank
WCS	Wildlife Conservation Society
WPCL	Water Pollution Control Laboratory

Contents

Chapter I

Importance of Hilsa Fisheries in Bangladesh

Hilsa shad, *Tenualosa ilisha* is popularly known as 'ilish' in Bangladesh. The fish comprises the most important and largest single species open water fishery of the country. It currently contributes to about 12% of the total fish production, 27.50% of capture fisheries production (inland and marine capture combined), and 1.0% of national GDP. Of the current total fish production of 4.27 million tonnes (2017-18), hilsa alone contributes 0.52 million tonnes. It is the National Fish and declared as the Geographical Indication (GI) product of Bangladesh by the Department of Patent, Design and Trademarks (DPDT) in 2017 after completing due process by the Department of Fisheries, Ministry of Fisheries and Livestock, Government of the People's Republic of Bangladesh.

Trend in Production

The production of hilsa remained almost stable between 144,000 and 229,714 tonnes during 1983-84 to 2000-01 with little ups and downs. However, in 2001-02 and 2002-03, a sharp decline in production of about 4.0% and 10.0%, respectively was recorded compared to the previous year production. This decline in production caused a huge concern to the government and the government felt it necessary to bring the resources under a well-designed management plan for sustainable increase in production by offsetting the production that was declined. In this context, hilsa fisheries management plan with a set of actions was prepared based on research findings and started implementing from 2003-04. Since then, production started increasing and continuing consistently. The trend in production of hilsa from 2000-01 to 2017-18 is given in Fig. 1. It is noted that in the last 11 years from 2007-08 to 2017-18, hilsa production has increased by 78.34% with an average annual growth rate of 7.1%. In 2007-08, the production was 0.29 million tonnes which increased to 0.52 million tonnes in 2017-18. This was possible due to strict implementation of the Hilsa Fisheries Management Action Plan by the government. This is undoubtedly a remarkable achievement for any capture fishery like hilsa.

Contribution to GDP and Export Earnings

The total production of hilsa in 2017-18 was 517,198 tonnes, of which inland water bodies contributed 232,698 tonnes accounting 45% and marine waters 284,500 tonnes accounting 55% of the total hilsa production. Hilsa represents about 68.63% of the riverine and estuarine fisheries (0.33 million tonnes) and 43.42% of the marine fisheries production (0.65 million tonnes). It is noted that before implementation of Hilsa Fisheries Management Action Plan (HFMAP), the total production of hilsa in Bangladesh was only 199,032 tonnes in 2002-03. Due to implementation of HFMAP, hilsa production has increased by 78% from 0.29 million tonnes in 2007-08 to 0.52 million tonnes in 2017-18. The present market price of the total hilsa produced in the country is about Tk. 206,800 million (US$ 2,462 million) (@ Tk. 400/kg, US$ 4.76/kg), contributing about 1.0% to the GDP of Bangladesh.

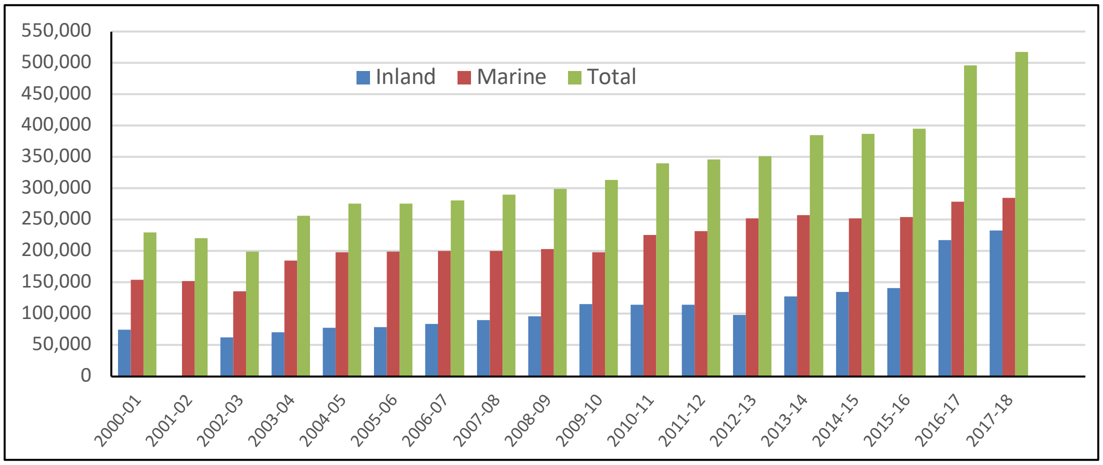

Fig. 1. Trend in production of hilsa in Bangladesh.

Before the ban of hilsa export in 2012, about Tk. 2,500-3,000 million was earned yearly by exporting hilsa mainly to India and to a few Middle East countries. A considerable amount was also exported to other countries such as UK, USA, Australia and Malaysia. Both the species of hilsa and Chandana ilish, (*T. ilisha* and *T. toli*) are very popular food fish in Malaysia and Indonesia. The egg-bearing females and the brine-salted roe (eggs) also have good demand, and command very high price in the markets of Malaysia and Indonesia. Further increase in production of hilsa will help to significantly increase the export and foreign exchange earnings of the country.

Contribution in Employment and Poverty Reduction

About 0.50 million hilsa fishers belonging 145 upazilas under 40 districts of Bangladesh were found directly employed in hilsa and jatka (hilsa juveniles) fishing activities. Over the last 11 years (2007-08 to 2017-18), hilsa production has increased by 0.23 million tonnes with an annual growth rate of 7.1%. It indicates that more fishers have been employed in hilsa fishing as the number of fishers is directly related with the production and abundance of fish. Thus, at present the total number of fishers in inland waters would be about 500,000 (@ 8 fishers/boat). In the marine sector, the number of mechanized and non-mechanized boats has increased from 25,369 in 2001-02 to 37,216 (mechanized - 20,385, non-mechanized - 16,831) in 2017-18 and the fishing nets from 106,316 to 118.353 (FRSS, 2017-18). In the above context, the number of total hilsa fishers in the marine sector would be 535,000, of which 366,462 fishers for mechanized (@18 fishers/boat) and 168,310 for the non-mechanized boats (@10 fishers/boat). In addition, during 2017-18, an amount of 11,060 tonnes of hilsa was caught by industrial trawling. In these trawl boats, another 10,000-15,000 fishers are also employed. Based on above, about 1.0 m fishers are presently employed in hilsa fishing.

Indirect Employment

A huge number of people are also employed in net making factories, making boats, nets, ropes, floats, baskets, and work in ice factories and trading of these materials. It is anticipated that about 5-6 million people are employed in these sectors related to hilsa fisheries. Besides, in and adjacent to the hilsa landing centers, considerable number of people are employed in other small trades. Thus, it is assumed that all together about 10 million people are employed in the wider hilsa sector, and the fish is providing employment to about 6.0% of the population of the country.

Source of High-Quality Protein, Fat and Minerals

Hilsa is the most popular and tasty fish in Bangladesh. The fish is highly rich in nutritional values. Fresh fish contains 19.40% protein, 21.80% fat, 1.35% minerals, 1.00% carbohydrate and the rest amount is water. The fish contribute 5.25% to the national animal protein intake of the people of Bangladesh. Hilsa protein contains nine different types of essential amino acids which are not synthesized in human body. The fat is also rich in poly unsaturated fatty acids (about 50%). Of the unsaturated fatty acid, about 2.0% is omega-3, which reduces blood cholesterol of human body. Among the minerals, it is highly rich in calcium, potassium and phosphorus. Besides, minor amount of vitamin A, B, C, D and E are also available in hilsa fish. The hilsa possess some medicinal values such as, its flesh is demulcent/stomachic, soothing, phlegmatic and carminative (Chopra, 1933). About 60% of hilsa is edible. Therefore, hilsa is an important source of protein, nutrition and maintaining good health.

Administrative and Social Structure of Hilsa Management

Different stakeholders involved in hilsa fisheries play different role in managing and exploiting the hilsa fisheries. The roles and responsibilities of different stakeholders of the fisheries are briefly discussed below:

Administrative Authorities

Hilsa is a natural resource and public property and thus, the responsibility of management and development of the resource is lying with the Ministry of Fisheries and Livestock (MoFL), Government of the People's Republic of Bangladesh. The MoFL is managing the fishery through the Department of Fisheries (DoF) and other government organizations such as BFRI and BFDC by implementing various development programs and plans following the approved policies, acts and regulations of the government. The Ministry also works in consultation and cooperation with the Ministry of Law, Ministry of Home, Ministry of Food and Disaster Management, Ministry of Water Resources, Ministry of Land etc. In addition, international agencies, research and development organizations, NGOs and social organizations are also involved in hilsa management and development programs.

In each district and upazila, there are fisheries management committee consists of members from different administrative services, public and fishers' representatives and fish traders. The different committees involved in hilsa fisheries management are described below:

National Advisory Committee

A multidisciplinary National Advisory Committee is constituted with 36 members with the Honorable Minister of Fisheries and Livestock as chair for planning, advice, policy decision and coordination at the national level in matters related to hilsa fisheries management.

District Task Force

At the district level, there is a District Task Force with 16 members from different disciplines with Deputy Commissioner as the chair and District Fishery Officer as the member-secretary, where Honorable Parliament Member remains as the advisor. The main responsibilities of the committee are implementation of rules and regulations related to conservation of jatka and gravid hilsa and awareness building among the different stakeholders about the importance and needs for conservation of the fishery.

Upazila Task Force

A 14-member multidisciplinary Upazila Task Force is constituted with Upazila Nirbahi Officer as the chair and Upazila Fisheries Officer as the member-secretary where Honorable Parliament Member is the advisor. The main tasks of the committee are monitoring, awareness building, implementation of hilsa conservation rules, selection of fishers for alternate income generating activities and food or financial assistance, alternate job creation, proceedings for legal action etc.

Social Authorities

The government initially formed Fishermen Cooperative Societies for management and development of different fisheries called Jalmohals (a section of river). These societies used to look after the Jalmohals, carry out fishing and collect revenues for the government. Later, the government changed the policy and declared "Open access to all for fishing in the Jalmohals" and thus, except a few, all the cooperative societies became nonfunctional. As a result, social power became ineffective for management of the hilsa fishery.

Fishing and Sharing of Benefits

Due to open access of all for fishing in the inland waters, anybody those have fishing boat and nets can fish there. In the meantime, fishing pattern have changed, and mostly mechanized boats and nets are used that require higher capital. The small scale-fishers could not afford the cost. Usually, one person called Head Mazi, organize the boat and net from his own source or lending money from the dadondar (money lender/aratdar owner) and hire the fishers either on daily payment or sharing the harvest by 50 to 60% for operating the boats and nets. The Head Mazi by deducting daily incremental cost of fuel, oil and food; the rest amount of is shared among the crew fishers. As a result, the benefit of increased harvest not actually goes to the crew fishers. Thus, for fishing in inland waters, the absolute power is lying with the Head Mazi and with the Dadondar or money lenders.

Marine hilsa fishing is more capital intensive. Here the merchant boat owner organizes the boat and net and employ crew fishers for operation of the boat almost following the system as of the inland waters and they hold absolute power for fishing. In the marine sector as well, the crew fishers are being deprived from the benefit of any increase of hilsa production.

Chapter II

Hilsa Fisheries Development and Management

Introduction

Hilsa Shad, *Tenualosa ilisha* is the most important and largest single species capture fisheries of Bangladesh both in inland and marine waters. Hilsa is inseparable from the culture and heritage of the people of Bangladesh. It is also the national fish of Bangladesh. This is a very popular fish in the whole Indo-Bangladesh sub-continent for its taste, flavor and culinary properties. During 1980s, hilsa was contributing about 30% of the total fish production and playing an important role in food, nutrition, employment, and foreign exchange earnings. However, its production was declining, particularly in the freshwater habitat due to over exploitation, environmental degradation and other anthropogenic activities.

Before the establishment of the Bangladesh Fisheries Research Institute (BFRI) in 1984-85, no systematic hilsa research was done in Bangladesh. The Universities carried out some research, which were mostly basic and academic in nature. Department of Fisheries (DoF) through its Freshwater Research Station located at Chandpur, which was subsequently transferred to the newly created BFRI also conducted some studies on catch monitoring, catch efficiency of chandi jal, food and feeding habits of hilsa etc. However, the results of those research were not comprehensive enough to formulate hilsa fisheries management plan.

In 1985, a one-year research program was undertaken under BOBP, which was funded by FAO and UNDP. Following this, the newly established BFRI felt it necessary to undertake a comprehensive research program to know the actual state of the hilsa fisheries in riverine, estuarine and marine waters in respect of the trend in changes of its life cycle, spawning season, identification of spawning and nursery grounds, migration, age, stock discrimination, population dynamics and socio-economic aspects with a view to formulate an appropriate hilsa fisheries management plan for development and sustainable production of hilsa in Bangladesh. In this background, BFRI undertook a research project entitled "Hilsa Fisheries Development and Management" with the financial and technical assistance from International Development Research Center (IDRC), Canada and Government of Bangladesh (GoB) as the first formal Technical Assistance project for systematic research on hilsa fisheries development in Bangladesh. BFRI started research under this project in 1986 and completed in 1992. Since then, BFRI has been continuing uninterrupted hilsa fisheries research for the last 35 years and gathered a huge information on all aspects of hilsa fisheries ranging from biology to stock assessment and population dynamics including socio-economics and formulated Hilsa Fisheries Management Action Plan based on research findings for sustainable development and management of the fishery in Bangladesh.

Objectives

The overall objective of the Hilsa Fisheries Development and Management project was to gain better understanding of the life history and population dynamics for development of a sound management policy for the fishery. The specific objectives of the project were as follows:

- To establish hilsa research facilities and develop trained human resources to carry out needed hilsa research in the future.
- To monitor catch and catch per unit of effort of various types of fishing gear, and to determine the effects of these efforts on different races/stocks of hilsa.
- To undertake regular sampling through experimental fishing to provide information on size frequency, age, gonadal development stage, morphometric data, and seasonal abundance of hilsa.
- To locate the hilsa spawning and nursery grounds.
- To develop techniques for age validation of hilsa.
- To investigate the seasonal migration of hilsa through tagging.
- To identify the different fish stocks which are being harvested.
- To collect information pertaining to regional catch trends and determines, if possible, the effects of various environmental and other factors on hilsa catches.

The Major Research Topics Covered under the Project

1. Studies on biological aspects of hilsa.
2. Identification of spawning grounds, nursery grounds and spawning season.
3. Migration, seasonal abundance and indiscriminate catching of gravid hilsa and jatka (hilsa juveniles).
4. Stock assessment, stock discrimination, population dynamics and management of the hilsa fishery.
5. Gear selectivity.
6. Catch and landings of hilsa in Bangladesh.
7. Estimation of production.
8. Pond culture of hilsa.
9. Canning of hilsa.

Research Approach

This research describes investigations carried out on hilsa *Tenualosa ilisha* in Bangladesh waters during the period 1986 to 1992. The investigations covered all environments-riverine, estuarine and marine with six sampling stations: Chandpur (Meghna river), Goalanda (Padma river), Barisal (Tetulia, Payra, Kirtankhola, Bishkhali), Khulna (Estuarine), and Chattogram, Cox's Bazar (Marine). These six sampling stations were selected based on catch, landings and availability of hilsa. Each of the sampling stations was monitored fortnightly on specific date and time for information about crafts and gears, catch monitoring, length frequency, biological studies, availability of hilsa juveniles (jatka) etc. Chandpur landing station was monitored every alternate day in order to determine the validity of collection of information following the methods stated above. At least 25 samples from each station were examined fortnightly for 2 years (1987-88) for different biological information such as: maturity, spawning, sex-ratio, fecundity, aging and racial information.

Monthly 15 days voyage by a mechanized boat in the Gangetic river system was also conducted for two years (September 1989 to October 1991) for experimental fishing, limnological study, and study of food and feeding habit, gillnet selectivity and for identification of nursery grounds and spawning grounds.

Catch and Landing Statistics

For assessment of the catch and landing statistics of hilsa in the country, the number of fishing boats and carrier boats were counted from each of the six selected stations fortnightly during 1986 to 1988. The information that were collected from at least 10 fishing boats and 10 carrier boats includes: the size of hilsa captured, fishing methods, types of fishing crafts and gear used, length, depth and mesh size of fishing gear, capacity of engine, size of fishing boats, actual fishing time per day per boat, time absent from port per trip, number of fishers engaged in fishing in each boat, location of fishing grounds and duration of fishing trip, total quantity of hilsa catch, etc. Data on total hilsa landings at each landing station were collected fortnightly. The efficiency of each fishing gear *i.e.* the catch per unit effort was assessed through analysis of this information.

Catch Monitoring

In order to assess the catch monitoring, 50 fish from each boat from each landing station were measured for length frequency related measurements during fortnightly data collection. The variation in size frequencies of hilsa in different seasons was determined by this method.

Major Findings

Extensive research carried out under the project for five years during 1986 to 1992 has made the following significant findings which are very important for the management of hilsa fishery in Bangladesh. This research for the first time in Bangladesh identified the spawning and nursery grounds and spawning season of hilsa and quantified the jatka (hilsa juveniles) that were indiscriminately caught by hilsa fishers from the Meghna River was a major threat to the sustainability of the fishery.

Biological Aspects

Sex ratio, spawning and fecundity of *Tenualosa ilisha* of the river Meghna near Chandpur were studied for biological information. Out of 544 specimens examined, 325 were found males, and 219 were females and the ratio were 1:0.67. According to size-wise sex-ratio distribution, the number of males were dominant in 33.0 to 45.0 cm and the females were dominant in 41.0 to 50.0 cm length groups.

The month-wise gonadosomatic index (GSI) values showed three peaks, *viz*. February-March, July and September-November with the highest being in October. Fecundity ranged from 226 thousand (total length 28.7 cm and body weight 275 g) to 1931 thousand (total length 52.3 cm and body weight 1715 g). The mean fecundity was 904±422.677 thousand for a fish having mean total length of 41.63±6.499 cm and a mean body weight of 961.3±422.485 g. The fecundity of per g body weight of fish was 978. A linear relationship of fecundity was observed with total length, fork length, body depth, total weight and gonad weight. Station-wise findings from sampling on biological aspects are as follows:

1. Landings: Hilsa is harvested and landed throughout the year but September and October are the peak landing season. The estimated annual landings in the five major stations such as Chandpur, Goalanda, Chattogram, Barisal and Khulna were 15,381, 2,008, 12,704, 8,725 and 7,188 tons, respectively during the study period.
2. Crafts and gears and their relative efficiencies: The crafts and gears used for hilsa fishing are mostly gillnet and chandi jal.
3. Trends in catch and landings: Historically, the location of major fishing grounds was restricted to the upper reaches of the main rivers. During the project period (1986-1992), the major fishing activities were confined to the lower reaches, estuaries and coastal waters.
4. Sex-ratio: The male and female sex-ratio in the natural population of hilsa for Chandpur, Chattogram, Khulna and Goalanda was found as 1:0.57, 1:1.14, 1:0.98, and 1:0.24, respectively. The average sex ratio in the population of all the sampling stations was found as 1:0.70.
5. The male hilsa was predominating from 31 to 43 cm length group and the female from 38 to 50 cm length groups in the population. Most hilsa over 40 cm were females. This is due to differential growth rate and survival. The females grow faster than males. The excess of males in the smaller fish is due to differences in habitat selection by each sex when they are young.
6. Spawning: From the gonado-somatic index (GSI) value, it was observed that hilsa spawns throughout the year, but the peak spawning season was found in September and October.
7. Fecundity: The fecundity of hilsa varied from 0.20 to 2.00 million depending on size and physical condition of the fish. Sampling station-wise mean fecundity at Goalanda, Chandpur, and Chattogram were found as 0.60 (range 0.179-1.392), 0.704 (range 0.226 - 1.931), and 0.802 (0.375-1.423) million, respectively.
8. Food and feeding habits of hilsa: Hilsa is plankton feeder. The gut analysis showed that the food composition of hilsa was found as algae (41.65%), sand and debris (36.28%), diatoms (15.36%), rotifers (3.19%), crustaceans (1.89%), protozoans (1.22%), and miscellaneous (0.41%). A total of 27 phytoplankton genera and 12 zooplankton genera were identified.

Identification of Spawning Grounds and Spawning Season

A large spawning ground of hilsa has been identified in the lower stretches of the river Meghna in the region of Hatia, Sandwip and Monpura. The important spots are Moulavir char (Hatia), Kalir char (Sandwip) and Monpura, Dhal char, Basunbhanger char of Bhola (Fig. 1).

Spawning grounds of hilsa were identified by the occurrence of ripe (egg diameter, 0.8-0.9 mm) and running (oozing) males and females and spent fish in the experimental and commercial catches. Mature hilsa were found available in the estuaries and the major rivers of Bangladesh almost round the year and also release eggs to some extent throughout the year. However, two clear spawning seasons were identified as follows:

1. September and October - the highest spawning season.
2. January to March - the second highest spawning season.

Fig. 1. Major spawning and nursery grounds of hilsa in the Meghna river and estuary identified during 1986-89.

In September and October, plenty of fully ripe and oozing male and female hilsa come up in large shoals to the Meghna estuary and adjacent Kalir char (Sandwip) areas every year during high tides of full moon and new moon for spawning. During this time, huge amount of oozing hilsa are caught by the fishermen. In the experimental catch, about 90 to 100% females were found in egg releasing condition. Some were half spent when caught and eggs were still releasing normally, and some began to shedding eggs just after catching without any pressure in the abdomen. Milts were observed from large number of males without any touch or slight pressure on abdomen.

Water in the large lower stretches of the Meghna river during monsoon period (July to October) becomes entirely fresh, turbid and no salinity observed at those spawning areas. The combined action of strong current and tidal force triggers migration of hilsa from the sea to the rivers. Due to high flood pressure and active tidal action, water current creates turbulence, upwelling and repeated circular rings due to irregular bottom topography. Water becomes highly oxygenated which helps to meet high oxygen demand during spawning activity of hilsa.

The spawning cycle of hilsa was found to be closely synchronized with the lunar cycle and it was observed that hilsa spawn mainly during full moon and new moon. It was also observed that the proper time of breeding for hilsa is afternoon to evening. However, maturity and abundance of ripe hilsa differs with areas, water current, and availability of food and with other environmental parameters (Mazid and Shiraj, 1990).

Identification of Nursery Grounds

Two major nursery grounds were identified by the occurrence of juvenile hilsa locally called jatka. These are the riverine nursery grounds and the coastal nursery grounds.

Riverine Nursery Grounds

The largest riverine nursery ground of hilsa juveniles (jatka) was identified in the Meghna river in and around Chandpur extending from Shatnol to Nilkomol (Mazid and Shiraj, 1990). The second nursery ground of jatka was identified in the Padma river from Goalanda-Aricha of Rajbari and Manikganj to Mawa of Munshiganj area.

Jatka catching (2-12 cm size) starts in November and continues up to June. The major catching takes place from 15 February to 15 May with the peak in March-April. During this period, about 3,456 tons of jatka which equals to about 442.37 million individuals were harvested each year by 'Jagatber jal' (beach seine net), and 'Current jal' (synthetic monofilament net) during the project implementation period. This reflects the extent of damage causing to hilsa fishery every year. It is noted that, the length of these nets is about 2-3 km and mesh size is 1.5 to 2 cm.

Coastal Nursery Grounds

Another large coastal nursery ground was identified in the coastal area from Kuakata of Patuakhali district to Dubla Island of Khulna district. Within this area, considerable amount of comparatively large size (11-15 cm) jatka are caught by Savar jal, Ber jal and Behundi jal during the period of December to January. The harvested jatka are dried in plenty in the temporarily prepared dry yard near their respective harvesting areas.

Artificial Breeding

First successful artificial breeding of hilsa was done at the lower most part of the Meghna river areas near Hatia and Sandwip for two consecutive years (September 1990 and October 1991). Fully running (oozing) males and females were collected by experimental fishing at the spawning grounds and simultaneously, the gonadal contents of the male and female were collected in enamel trays/plastic bowls containing fresh river water. The diameter of the freshly laid eggs ranged from 0.8 to 0.9 mm. After fertilization, the diameter of the eggs became 2 mm. The eggs began to hatch after 16 hours of fertilization and completed in 18 hours. The rate of fertilization was 90%. The hatchlings were released in the river at the breeding ground.

Fishing Season

Commercial hilsa fishing in Bangladesh occurs in the marine and riverine areas throughout the year. However, the peak fishing season is September-October. The lean fishing season appears to be during December to February both in the marine and riverine areas. Harvesting of hilsa was found to be closely related to the full and new-moon periods when bulk catching takes place.

Stock Discrimination

- Investigation on biometric aspects of hilsa indicated that hilsa from the four environments (rivers, estuaries, coastal and marine ecosystem) are morphologically different. Hence, there is a possibility of having four stocks/races of hilsa.
- However, electrophoretic studies indicated the availability of at least two stocks/races of hilsa in Bangladesh.
- More research on this aspect through electrophoresis, otolith microchemistry and genetic analysis is needed to establish whether Bangladesh has a single or more than one hilsa population.

Stock Assessment

Stock assessment of hilsa from length-based methodology using ELEFAN software revealed following information:

- The exploitation level of hilsa was near the optimum but the relative production was found low due to catch of small fish.
- The growth parameters L_∞ and K were found as 61.1 cm and 0.74/yr, respectively.
- The natural mortality (M), fishing mortality (F) and total mortality (Z) were found as 1.16, 1.25 and 2.41/yr, respectively.
- The exploitation rate (E=F/Z) was found as 0.518 which indicates no evidence of over-exploitation of the fishery during the study period in 1986-1992.
- The size of first capture should be maintained at 35 cm of total length.

- The annual recruitment patterns were found continuous with two major peaks in September-October and March-April.

Gillnet Selectivity

- Gillnet selectivity study of hilsa showed that minimum mesh size of 10.2 cm should be used to catch hilsa at the desirable size (total length 40 cm or larger) which have high market value.
- Minimum mesh size to catch fish at the size of first capture (total length 35 cm) as estimated by the relative yield per recruit analysis was found to be 9.0 cm. So, any gillnet having mesh size smaller than 9.0 cm should not be allowed in the fishery to catch hilsa.

Pond Culture of Hilsa

First experimental culture of hilsa in freshwater ponds was conducted in Riverine Station of BFRI at Chandpur with a view to develop its breeding and culture technology in confined waters. Hilsa juveniles (jatka) collected from the Meghna River were stocked at the density of 2,500/ha in two ponds of the Riverine Station. A total of 600 and 300 jatka were stocked in two different ponds. The average length and weight during stocking were 5.31 cm and 1.25 g, respectively. After 12-month rearing, the average total length and total weight were 22.56, 28.91 cm and 119.28 and 267.33 g for pond 1 and pond 2, respectively. No supplemental feeds were applied, and only periodic manuring was done by cow-dung (3,000 kg/ha/10 days) in pond no. 1 and TSP (30/kg/ha/10 days) in pond 2. Higher growth rate was obtained with fertilization by TSP than that by cow-dung. The growth rate slowed down in the second year. Hilsa were reared for subsequent years, however, its rate of growth and taste were less than the river and marine hilsa. After long time rearing, the maturity and gonadal development of hilsa were not satisfactory. So, neither natural nor artificial breeding was possible to develop culture technology of hilsa in freshwater ponds. Collection of juveniles from the nature and make them survive was also very difficult to continue culture practice in confined waters.

The preliminary study showed the possibility of pond culture of hilsa. However, this would depend on the availability of seed.

Canning of Hilsa

During the peak hilsa fishing season, fishes are caught in plenty. However, due to poor transportation and marketing system, a large quantity of fish gets spoiled in the hilsa landing centers. Efforts on product development and value addition could save this bulk seasonal catch from losses. In view of this, the riverine station of BFRI initiated canning of hilsa during 1987-89 and successfully produced canned hilsa. Canning of fish offers advantages as it can be stored at room temperature for long period. Additionally, bones remain in the flesh become softened. For canning, the fish was first scaled and thoroughly cleaned and washed. Then the fish was cut into steaks and soaked for 15 minutes in light brine. Brine treated steaks were then placed in the cans and added salt and soybean oil and sealed the can keeping about one-inch headspace. Then heat was applied to the can placing them at the canner at 121°C for 55 minutes under 15 lb pressure. The taste of the canned hilsa steaks so produced was good and its shelf life was 14 months.

Catch and Landings

Landings: The estimated annual landings of hilsa for different sampling stations have been given under the Subtitle discussed in the previous section 'Biological Aspects'. Hilsa landing at Chandpur attains peak during June to October with highest in September. November to May is the poor landing period. The landings also reach peak in September in Chattogram, Goalanda and Barisal. But at Khulna, the peak is in October. In Chattogram, the poor landings are observed from December to February and again in July. In Goalanda and Barisal, comparatively lean period was observed from November to May.

Crafts and gears: The crafts and gears used for hilsa fishing are mostly gillnet and chandi boat. In the Padma river section, mainly gillnet and kosha boat are operated. In the Meghna section, pocketed gillnet (gulti jal), kona jal, and chandi jal are operated by chandi boat. During February to May, beach seine net is used for hilsa as well as jatka catching. In the lower Meghna surface, mid and bottom water gillnets are mainly operated. The fishermen of that area use chandi, kosha, dingi and also mechanized boats. Current jal (monofilament net) is being used mainly in the Padma and Meghna (Chandpur, Haimchar, Doulatkhan and Tazumuddin areas) to catch jatka as well as adult hilsa. Among the different types of gear, maximum number of fishermen (about 30 to 40) is required for operation of jagatber jal.

At Chandpur, both non-mechanized and mechanized small local carrier boats contributed to the major landings. The carrier boats collect fish from non-mechanized fishing boats operated mainly down of Chandpur in the river Meghna. The landing period was observed from May to November. In Chattogram, the catch and the number of landing boats were poor in February, May and July. In Khulna, the landings were mainly contributed by mechanized carrier boats. The catch of local hilsa was very poor in Goalanda.

Trends in catch and landings: Historically, the major fishing grounds were located in the upper reaches of the main rivers. At present, the major fishing activities have been confined to the lower reaches, estuaries and coastal waters. This may be due to siltation in the upper reaches because of Farakka Barrage in India and for different obstacles to the migratory routes and indiscriminate catching of jatka.

Estimation of Production

Hilsa represented about 30% of total fish production in 1980s. Once the abundance of hilsa was highest in the Meghna river near Chandpur. Among other rivers, the availability of hilsa was quite significant in Tetulia and Payra river near Barisal, the Padma near Goalanda and Shibsha near Khulna. About 95% of hilsa then used come from the Padma, the Meghna and other rivers of the country and only 5% from the sea. In the mid-1980s, the marine hilsa landings increased to about 60% and less than 40% from the freshwater rivers. It is alarming that presently its contribution has declined to about 12% but maintaining a stable or slightly increasing condition due to implementation of some management interventions including banning of jatka (hilsa juveniles) capture and protection of mother hilsa in peak spawning season in October (Bengali month of Ashwin).

As per information gathered by BFRI, the annual production of hilsa ranged from 0.10-0.15 million tonnes during 1950s. Its production started declining from the beginning of 60s and continued up to 70s. No information on landings was available during those periods due to lack of continuous research and catch monitoring system. However, analyzing the relevant information, the production of hilsa was calculated at about 0.10 million tonnes in 1980-81, and since then hilsa production started showing an increasing trend. In 1982-83, its production increased to a previous level of about 0.15 million tonnes. BFRI in analyzing the results of research conducted under the Bay of Bengal Program (BOBP) implemented in cooperation with FAO, estimated hilsa production at about 0.23 million tonnes in 1985-86. Out of this, marine landing was about 0.14 million tonnes and riverine, 90,000 tonnes. Based on information collected by BFRI, hilsa production stood at 0.242 m tons in 1986-87, up by 0.142 million tonnes from 1980-81, which mostly came from the marine sector. This indicates that hilsa is gradually migrating from the rivers towards the sea due to fishing pressure and environmental degradation in riverine ecosystem.

Stock Assessment and Management of Hilsa Fishery in Bangladesh

Introduction

Hilsa, *Tenualosa ilisha* is the most important single species fishery in Bangladesh, which contributed about 30 % of the total catch. However, no measures were taken before 1980s for correct assessment and effective management of the fishery. In the above background, "Hilsa Fisheries Development and Management" Project was undertaken by the government with the financial and technical assistance from International Development Research Center (IDRC), Canada to conduct research to generate adequate information on the status of the hilsa stock, exploitation level and maximum sustainable yield for better understanding of the fishery for development of a sound management policy.

Hilsa is widely distributed in the Gangetic river system including estuaries and the sea. Though hilsa is generally considered an anadromous species, it is found in all the principal rivers more or less round the year. For a migratory fish like hilsa, a homogeneous stock thus is not normally expected. The external appearance of hilsa from the Padma and the Meghna rivers, estuary and sea are somewhat different from each other which an experienced worker can separate only by eye observation. Such difference is also observed for the juveniles (jatka) from different nursery grounds. This apparent complexity of the bionomics of this fish leads to think about the possibility of existence of different stocks/races at different environment. Therefore, it is of basic importance to know whether hilsa of various localities are drawing on a single or several different populations and to ascertain the nature of their migrations. Keeping the above in view, stock assessment study was conducted with the following objectives:

- To examine the possibility of having several races or stocks of hilsa in Bangladesh waters based on morphometric and meristic data.
- To assess the exploitation levels of hilsa.
- To suggest a management action plan for hilsa fishery for sustainable production.

Materials and Methods

Stock Discrimination

For stock discrimination study, at least 25 hilsa were collected monthly during November 1986 to October 1987 from each of 6 different sampling locations *viz*. Chandpur, Goalanda, Barisal, Khulna, Chattogram and Cox's Bazar which represents fish of the major rivers the Meghna, Padma, Shibsa, Tetulia, Payra, Kirtankhola and the estuary and the sea. From each specimen, 19 morphometric and 5 meristic characters were measured for comparisons. For computational purpose, Advanced Statistical Module of the SPSS/PC$^+$ version 4.0 computer software was used.

Stock Assessment

Length-based stock assessment method was applied for this study. Length frequency data measured from 18,915 hilsa were analyzed using the "Complete ELEFAN version 1.11'' software package (Gayanilo *et al*., 1989). Asymptotic total length (L_∞) and growth constant (K) were estimated by means of ELEFAN I. Total mortality (Z) was estimated by length converted catch curve method as implemented in ELEFAN II. Natural mortality rate (M) was estimated using Pauly's empirical relationship (Pauly, 1980) between M, L_∞, K and mean annual temperature (26°C). Fishing mortality (F) was obtained by subtracting M from Z and exploitation rate ($E=F/Z$) was also determined, probability of capture, size of first capture (L_c) and recruitment pattern were also obtained by means of ELEFAN II. Relative yield per recruit (Y/R) values as a function of E were estimated for different levels of L_c incorporating probabilities of capture at different size classes (Pauly and Soriano, 1986).

Gillnet Selectivity

The Baranov-Holt method (Baranov, 1914; Holt, 1957; Gulland 1969 and 1983; Hamley, 1975 and Jones, 1984) was applied to study the gillnet selectivity of hilsa. At first the ratios of the catches of two adjacent mesh sizes were calculated. The natural logarithms of the ratios of the catch were taken. The least square regression line was established by using the following formulas:

In (c_2/c_1) = a+b, L, where

In (c_2/c_1) = natural logarithms of the ratios of catches (c_2 and c_1) of two adjacent mesh size;

L = total length of fish of corresponding catch;

A = constant, the intercept of the regression line; and

b = regression coefficient, the slope of the line.

After establishing regression line, selection factor (SF) was calculated using the following formula:

$SF = 2a.b^{-1}(m_1 + m_2)^{-1}$, where m1 and m2 are the mesh sizes of two adjacent gillnets.

Then optimum length (L_{opt}) was calculated using the equation, $L_{opt} = SF._m$, where m is the size in cm.

The standard deviation of the selection curve was computed using the equation:

$SD = ((L_2 - L_1), b^{-1})^{0.5}$, where L_1 and L_2 are optimum lengths calculated by the aforesaid formula for two adjacent mesh size m_1 and m_2, respectively.

A regression relationship between the two mesh size of the gill net and the optimum length of hilsa caught in each mesh size was also established by using least square method.

Results and Discussion

Stock Discrimination

Discriminant function analysis of the results showed significant difference in both morphometric and meristic characters of hilsa for each of the four environments (Tables 1 and 2). Out of 19 morphometric characters, about 12 characters were found highly significant for distinguishing the groups (Table 3) and among the meristic characters mostly three were found highly significant (Table 4).

Table 1. Results of the discriminant function analysis of the 19 morphometric characters of four environments of *Tenualosa ilisha*.

Group comparison	Canonical correlation	Wilk's λ	Chi-square	DF	Significance level
Chandpur-Goalanda	0.430	0.615	263.7	10	0.000
Chandpur-Khulna	0.380	0.855	160.1	10	0.000
Chandpur-Chattogram	0.448	0.798	221.2	15	0.000
Goalanda-Chattogram	0.570	0.674	463.0	12	0.000
Goalanda- Khulna	0.385	0.851	184.0	9	0.000
Khulna-Chattogram	0.501	0.748	245.2	14	0.000

Table 2. Results of the discriminant function analysis of the 5 meristic characters of four environments of *Tenualosa ilisha*.

Group comparison	Canonical correlation	Wilk's λ	Chi-square	DF	Significance level
Chandpur-Goalanda	0.174	0.969	41.2	4	0.000
Chandpur-Khulna	0.193	0.962	37.0	3	0.000
Chandpur-Chattogram	0.075	0.994	6.5	4	0.000
Goalanda-Chattogram	0.128	0.983	22.5	5	0.000
Goalanda- Khulna	0.211	0.955	54.0	3	0.000
Khulna-Chattogram	0.228	0.948	52.9	3	0.000

Table 3. Highly significant morphometric characters of *Tenualosa ilisha* as found in the discriminant function analysis.

Group comparison	TL	FL	BD	BT	HL	SL	ED	IO	JL	DFB	AFB	STD	STA	PTP	PTA	CPD	CPW	CPL	CFTL	Total
Chandpur-Goalanda	6			10		4	5	8	7			6		9			1	2		10
Chandpur-Khulna			5	7	8		3	4	10			9			6		1	2		10
Chandpur-Chattogram	15	5	4		3	11		7	6		12	14		2	13	10	1	8	9	15
Goalanda-Chattogram	11	3			2	9	10	7	4			6	12			1	8		5	12
Goalanda-Khulna			8		1	6	5	3	7							2	9	4		9
Khulna-Chattogram		10	13	6	11	8	5		12	14		3		2		9	1	4	7	14

The number indicates relative position in discriminant function *i.e.* 1 for first distinct character, 2 for second distinct character and so on.

Table 4. Highly significant meristic characters of *Tenualosa ilisha* as found in the discriminant function analysis.

Group comparison	DFR	AFR	LLS	AS	PS	Total
Chandpur-Goalanda	3	4	2	1		4
Chandpur-Khulna		1	2	3		3
Chandpur-Chattogram			1			1
Goalanda-Chattogram	5	3	2	1	4	5
Goalanda- Khulna		2	1	3		3
Khulna-Chattogram		1	2	3		3

The number indicates relative position in discriminant function *i.e.* 1 for first distinct character, 2 for second distinct character and so on.

From the aforesaid results, it may be concluded that hilsa from the four environments are morphologically different and hence, there is possibility of having at least four stocks of hilsa in Bangladesh waters. However, for final conclusion, serological study (by electrophoresis) is necessary.

Stock Assessment

The estimated von Bertalanffy growth parameters, mortality rates and size of first capture of hilsa, *T. ilisha* are given in Table 5.

Table 5. Growth parameters, mortality rate and exploitation rate of *T. ilisha* in Bangladesh waters.

Sl. No.	Parameters	Values
1	Asymptotic total length (L_∞)	61.1 cm
2	Growth constant (K)	0.74yr^{-1}
3	Rn value (Gayanilo *et al*, 1989)	0.18
4	Total mortality (Z)	2.41
5	Natural mortality (M)	1.16
6	Fishing mortality (F)	1.25
7	Exploitation rate ($E=F/Z$)	0.52
8	Length at first capture (L_c)	35.0 cm

In Bangladesh, hilsa is exploited by multi-mesh gillnet with mesh size ranging from 7.6 to 12.7 cm. The studies on gillnet selectivity (Rahman *et al*., 1992) indicates that the effect of gillnet selection on the catch sample over a wide size range is small. As such length-based stock assessment procedures could be employed to the hilsa fishery for stock assessment.

It appears from the results that the populations of *T. ilisha* in Bangladesh may be comprised of more than one stock. To confirm it, it is essential to assess each stock separately. However, the present data do not permit for stock discrimination and therefore, fish landed from all areas of the country are considered to come from a single stock.

The growth performance index ($Ø' = 2 \log L_\infty + \text{Log } K_1$, Pauly and Munro, 1984; Moreau *et. al*, 1986) estimated for hilsa using the growth parameters (L_∞ = 61.1 cm and K = 0.74 yr^{-1}) is 3.44 and is well within the clupeid fishes. The estimated growth parameters are appreciably different from those (L_∞ = 58.8 cm and K = 1.1 yr^{-1}) estimated by Vender Knap *et al*., (1987) who used data only from Chattogram station. Annual recruitment pattern was found continuous with two major peaks in April to June and October. This is supported by the phenomenon of the occurrence of juvenile fish throughout the year with two major peak seasons. Since a considerable range of fish in the fully recruited phase in the catch sample from the multi mesh gillnet hilsa fishery is considered to have the probability of capture near unity, first few points of the descending part of the length converted catch curve could be considered for obtaining a reasonable estimate of *Z*. The estimated *Z* values using length converted catch curve method was found as 2.41 yr^{-1}. The Y'/R analysis at different levels of L_c indicate that at the present level of E, high yield could be obtained by reducing the size at first capture of hilsa. However, the exploitation rate should not be increased further at the lower levels of L_c. The effective management strategy in a fishery is to maintain the E around $E_{0.1}$ (*i.e. E* corresponding to Y'/R of 10% of the maximum rate of increase of Y'/R with increasing E). In view of the possibility of increasing E in the hilsa fishery, as in any artisanal fishery, maintaining the size of first capture at the present level (35.0 cm) which is biologically a sub-optimal level seems to be the most appropriate management strategy.

This study evaluated the present status of the hilsa fishery in Bangladesh and generated useful information for formulating for the first time a Management Policy and Action Plan for the fishery which has not been managed so far for sustainable production. However, continuous research is needed on stock assessment, population dynamics of this migratory fish and influence of the fishery of one locality on the yield of another locality to arrive at a more precise conclusion with regard to the management of the fishery.

Gillnet Selectivity

The selection factor, optimum lengths and selection range ($L_{opt} \pm SD$) are shown in Table 6. The relationship of the estimated mean optimum length and mesh size was found to be linear and is described by the equation:

$L_{opt} = -6.055 + 4.51$ m ($r = 0.972$, $p<0.05$), where

L_{opt} = optimum length in cm; and

M = stretches mesh size in cm.

Table 6. Mesh size-wise optimum length (L_{opt}), standard deviation (SD), selection factor (SF) and selection range (SR) for gillnet catch of *Tenualosa ilisha.*

Mesh size (cm)	L_{opt} (cm)	SD (cm)	SF	SR (cm)
7.6	29.05	5.578	3.822	29.05 q 5.578
10.2	39.92	6.045	3.914	39.92 q 6.045
11.4	42.16	4.486	3.696	42.16 q 4.486
12.7	53.62	7.333	4.225	53.62 q 7.333

Using the established regression equation, the minimum mesh size to catch the fish at the desirable size which has the high market value (total length 40 cm or higher) was found as 10.2 cm and the mesh size needed to catch the fish at the size at first capture (total length 35 cm) as estimated by the relative yield per recruit was found about 9.0 cm. So, any gillnet having mesh size smaller than 9.0 cm should not be allowed in the fishery to catch hilsa.

Hilsa Fisheries Management Action Plan

The achievement of research under this project in identification of spawning and nursery grounds, spawning season, distribution and quantification of jatka catches and its negative impact on hilsa production, harmful effect of current jal (monofilament net) were the milestones in the annals of hilsa fisheries management and development research in Bangladesh leading to formulation of a well thought management plan.

Purpose

Hilsa Fishery Management Action Plan was formulated with the aim of conservation of gravid (mother) and juvenile hilsa (jatka) through imposing fishing bans and establishment of sanctuaries, regulating mesh size and gear restriction, awareness building of relevant stakeholders, human resources development and strengthening of research.

Action Plan

Based on the research findings stated above, following HFMAP was formulated in early 1990s and suggested for implementation by the government for management, development and sustainable production of hilsa fish in Bangladesh:

Conservation of Gravid Hilsa during Major Spawning Season for Breeding

Catching of hilsa should be completely banned in the major spawning grounds of the lower stretches of the Meghna river near Moulavir char (Hatia), Kalir char (Sandwip), and Monpura, Dhal char, Basunbhanger char of Bhola during the peak spawning season in September-October or at least mid-September to mid-October. If not possible, at least 8 days (3 days before full moon, 3 days after new moon and the day of full moon and new moon) during first Ashwini Purnima (Full moon of Bengali month Ashwin) to allow mother hilsa to spawn in the spawning season for recruitment of new population to the fishery.

Conservation of Hilsa Juveniles (Jatka)

Protect hilsa juveniles (jatka) in the largest riverine nursery grounds as identified in and around Chandpur extending from Shatnol to Nilkomol of the river Meghna and around Munshiganj extending from Aricha, Vaigyakul and Mawa of the Padma river during the peak nursery season in March to April or at least from mid-March to mid-April by banning Jagatber jal (beach seine net), Moshari jal and Current jal (synthetic monofilament net) having mesh size smaller than 10 cm.

Protection of Coastal Nursery Grounds during December to January by Banning Jagatber Jal and Behundi Jal

Coastal nursery grounds as discovered in the coastal area from Kuakata (Patuakhali) to Dubla Island (Khulna) should be protected also during the period of December to January or at least in the month of January by banning Jagatber jal and Behundi jal.

Banning of Jatka Catching below 23 cm for the Whole Year throughout Bangladesh

Jatka (juvenile hilsa) is found and caught more or less throughout the year in the country. So, for its conservation and recruitment, catching of jatka below 9 inches or 23 cm should be banned in the riverine nursery grounds and the coastal nursery grounds for the whole year instead of currently enforced ban from November to June. In the meantime, government has gradually increased the size and banned catching of jatka below 25 cm (2018).

Banning Erection of Garajal (bamboo fencing) and Bandh Jal in the Rivers

Ban should be imposed on erection of all 'Garajal' (bamboo fencing) and 'Bandh jal' across the river especially in the Padma river from Mawa, Vaigyakul of Munsiganj through C & B Ghat to Aricha of Manikganj district and in the Meghna river and its all tributaries flowing through Mehendiganj to Hizla to Muladi region of Barisal district during the winter season which are made for catching and obstructing free movement of fish.

Banning Use of all Kinds of Synthetic Monofilament Nets

The use, import, manufacturing, marketing, carrying, transporting of all kinds of monofilament net (popularly known as current jal) should be permanently banned.

Regulation of Mesh Size of Gill Nets to Control Over Exploitation

All gillnets of below 9 cm mesh size should be banned to protect hilsa below 35 cm size so that maximum hilsa can attain maturity and get chance to participate in spawning at least once in life. In case of current jal, the smallest acceptable mesh size must be 10 cm.

Creation of Alternate Income Generating Activities for Hilsa Fishers

Alternate income generating opportunities should be created for hilsa fishers for such period when they will be barred for catching hilsa during hilsa spawning and jatka conservation seasons.

Human Resource Development for Hilsa R&D Activities

Both research scientists and hilsa resource management officials should be adequately trained in relevant areas through short and long-term study/training programs at home and abroad. There should be a core research group developed in BFRI with advanced degrees (MS and PhD) in hilsa biology, population dynamics and stock assessment, processing and preservation, socio-economics etc.

Awareness Creation among the Hilsa Fishers and other Relevant Stakeholders

Awareness should be created among the hilsa fishers and other relevant stakeholders to make them aware about the importance of conservation measures and the need for regulating the resources and cooperation of the stakeholders. Both BFRI and DoF should conduct large scale training programs for all kinds of stakeholders, organize rallies and demonstration and publish and distribute information and extension materials like posters, booklets, leaflets, training manuals for enhancement of knowledge and make the stakeholders responsible for management of the hilsa resources.

Continuation of Hilsa Research

Hilsa is an important resource which immensely contributes to nutrition, livelihood and economic development of Bangladesh. It's a migratory fish which inhabits in all the three ecosystems as the rivers, estuaries and the seas. Its life cycle is complex; it lives in the sea and migrates to freshwaters in the rivers for spawning although recently it has been reported to spawn also in the coastal waters. Due to intense fishing pressure, ecological and human activities, both recruitment and production of hilsa particularly in the upstream rivers have been declined. So, there is a need to conduct continuous research on the spatial and seasonal distribution, the magnitude and dynamics of the population, growth, mortality, recruitment, maximum sustainable yield, impact of climate change on biological aspects, water quality, carrying capacity, pollution etc. to generate adequate information and update them on regular basis for better management of the resources for sustainable production.

Revision/Amendment of Fish Acts and Rules

The existing Fish Acts and Rules should be revised in light of the above action plan and necessary steps should be taken for their strict implementation.

Suggestion for Implementation

A Joint Task Force should be established under the Ministry of Fisheries and Livestock including representatives from Ministry of Home Affairs, Government of the People's Republic of Bangladesh, DoF, BFRI, Bangladesh Police, Coast Guard and other relevant agencies to oversee, monitor and coordinate implementation of the conservation measures and formulation/amendment of necessary rules and regulations incorporating the provisions as suggested in the Action Plan for management of the hilsa fishery in Bangladesh.

In addition, mass awareness should be created through extensive publicity in Radio, Television, Newspapers, and organizing press conference, rallies, public meetings, training and demonstration.

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Chapter III

Hilsa Fisheries Research in Bangladesh

Introduction

Hilsa is an anadromous fish that migrates from the sea to the freshwater rivers for spawning. It is the most important and largest single species open water fishery in Bangladesh which is greatly contributing to nutrition, employment and economic development of the country. This is a national fish and is inseparable from culture and heritage of the people of Bangladesh. When BFRI undertook this research under a BFRI/ACIAR/CSIRO supported project 'Hilsa Fisheries Research in Bangladesh' in 1996, production of hilsa was about 2,00,000 tonnes having a share of about 20% of total fish production worth about BDT 1,000 crore. About 2.0 million people are directly or indirectly employed in the fishery which represents 2% of the country's total population. Earlier, the fishery was mostly concentrated in the upper reaches of the main rivers. However, this upstream fishery has been destroyed partly or fully in some areas due to decrease in water flow, environmental degradation and increase in fishing pressure. Now the fishery is mainly concentrated in the downstream of the rivers, estuaries and the sea. Due to low discharge from the river Ganga and consequent heavy siltation in most of the rivers, the feeding, spawning, nursing and migration areas of hilsa has been reduced in the upstream. This is a great threat to the sustainability of this important fishery and if proper management measures are not developed and strictly implemented, the fishery will be affected very seriously. So, there is a need to conduct research to continuously generate and update data and information for the development of sound management policy and plan for sustaining hilsa production.

After the end of IDRC supported Hilsa Fisheries Research Project in 1992, BFRI was continuing hilsa research and was looking for foreign assistance to further strengthen its hilsa research activities. At this time in 1993, Dr. G. Rothschild, Director, Australian Center for International Agricultural Research (ACAIR) visited BFRI and held discussion with its Director Dr. M.A. Mazid. During the discussion, Dr. Mazid briefed Dr. Rothschild about the importance of hilsa fishery in Bangladesh and the government priority for its research and development. The project is an outcome of this discussion. The research under the project was started in 1996 after signing an MoU between the Ministry of Fisheries and Livestock, Government of the Peoples' Republic of Bangladesh and the Australian Center for International Agricultural Research. An extensive research covering identification of different hilsa stocks/races, stock assessment and population dynamics, genetic structure of hilsa population, biology, migration and distribution, ecology and biodiversity, identification of spawning and nursery grounds, jatka (hilsa juveniles) dynamics, gillnet selectivity, length frequency, socio-economics etc. were conducted till the project ended in 2001.

Objectives of the Project

The primary objective of the project 'Hilsa Fisheries Research in Bangladesh' was to develop a suitable management plan together with the policy recommendations that would lead to the conservation and sustainability of the hilsa resource in Bangladesh.

Specific Objectives

- Development of catch monitoring system of hilsa.
- Assessment of the impact of environmental parameters and water quality on the catch, abundance and distribution of hilsa.
- Assessment and confirmation of races/sub-populations that may exist in Bangladesh.
- Identification of spawning and nursery grounds, estimation and enumeration of juvenile hilsa (jatka) that are caught by different gears at different habitats of Bangladesh.
- Development of aging techniques and determination of the age structure of hilsa population.
- Study the reproductive biology and defining the age at sexual maturity and spawning frequencies of hilsa in different habitats.
- Assessment of the socio-economic status of hilsa fishers and determine the impact of different management options on them.
- Training of BFRI scientists in stock assessment, electrophoretic technique, and biochemical genetics at home and abroad to develop a capable hilsa research team both in the riverine and marine stations of BFRI.

List of Research Programs

- Identification of different hilsa stocks/races, assessment of stock and population dynamics of hilsa *Tanualosa ilisha*
- Identification of spawning and nursery grounds
  - Study of gonadal developments
  - Eggs and larval development
  - Juvenile distribution pattern and habitats
- Studies of juvenile hilsa (jatka)
  - Seasonal migration and abundance
  - Analysis of existing records and further field sampling
  - Catch per unit effort data
  - Chemical analysis of otoliths for tracing movements between sea and freshwater
- Differences in diets between river systems and influence on biology, distribution, growth etc.
- Determination of genetic structure of hilsa shad population
- Socio-economic studies of hilsa fishery and hilsa fishers of Bangladesh

Significant Findings

Extensive research has been carried out under the project for long six years commencing 1996. The project has made the following significant findings that are very relevant to managing hilsa resources in Bangladesh.

Biology

- Hilsa in Bangladesh are a single population that is probably shared with India and Myanmar.
- There is no evidence of sex change in hilsa *T. ilisha*, but there is a bias in the sex ratio and males are more abundant among the smaller fish.
- Most hilsa spawn in freshwater, but there is spawning in coastal waters of low salinity.
- Fish in the Meghna river move freely between riverine and coastal habitats, but some population in the upper reaches may be resident.
- Bay of Bengal comprised a single population of *T. ilisha*.
- Hilsa are gonochoristic unlike other *Tenualosa* species but females live longer and grow larger than males.
- Hilsa live for at least 3 years but majority of the population are 1+ year old fish.
- There is differential survival of males and females and females live for at least one year more than males.
- Hilsa first spawn at 1 year age and most fish older than 2 years are female.
- Mesh sizes over 10 cm are catching predominantly females and this is having a selective impact on spawning and egg production as fecundity is related to fish size.
- Mean hilsa fecundity has declined throughout the study period.
- Most fishers are tied to traders to finance their trips and buy the catch. This makes the traders the strongest groups in the marketing chain for hilsa. Future management needs to involve the traders in developing common management objectives.

Hilsa Fishery

- Gillnets of the most common size (8 cm mesh) caught the greatest number of fish but not the greatest biomass.
- Nets over 10 cm mesh size catch mainly female hilsa.
- Stock assessment based on length frequency data collected from market sampling will underestimate mortality and exploitation rates because of the effect of net selectivity.
- Length frequency analysis with the FiSAT software can produce realistic growth parameter estimates that are consistent with results from direct fish ageing by counting daily rings in otoliths.

Gillnet Selectivity

Gear selectivity study was conducted with experimental fishing in the lower reaches of the Meghna river by using BFRI research vessel for stock assessment. Fish were caught with BFRI gillnets of the range of mesh sizes used in the commercial fishery and by visiting fishers and measuring their catch. A total of 2,815 fish were caught during the study, with most being taken in the 8 cm mesh net. Fish between 30 and 35 cm were the most commonly caught size classes. When the selectivity of the eight mesh sizes was combined, fish over 40 cm are being fully selectively fished by the fishery. Any fish over this size that encounters a net has low probability to escape. Fish of the size of 40 cm and above are caught mostly by nets over 10 cm mesh size and are exclusively female. The results showed that the smaller size classes were under-represented in the data and that total mortality estimates are inaccurate and lower than the true values. So, selectivity of gillnet and representative sampling should be taken into account for length frequency study for stock assessment.

The results suggest that reducing the use of larger nets that are catching females (>10 cm mesh size) and represent < 20% of the nets used by the fishery may improve survival of females for spawning. The most common nets sizes used maximized the number of fish caught, not necessarily the maximum CPUE (by weight). Thus, it appears that the fishers do not fish to maximize the biomass of the catch but rather than the total number of fish. Based on findings of the gear selectivity study, it was recommended to reduce the maximum mesh size to 9.5 cm to enhance the egg production of the population and increase subsequent recruitment.

Hilsa of Critical Sizes and Sex Reversal

Hilsa of critical sizes (15–25 cm) were examined histologically to determine the sex. Results show that hilsa reach sexual maturity at 20 cm and one year of age and that both males and females can spawn at that size.

There is no evidence of sex change in hilsa *T. ilisha*, but there is a bias in the sex ratio and males are more abundant among the smaller fish.

Most fish over 30 cm are females and almost all fish over 40 cm are females. Males predominate between 10 and 25 cm and the sex ratio of the smaller fish or fish below 10 cm is almost 1:1.

The biases in the sex ratio suggest that males may not live as long as females. The predominance of females in larger fish is due to differential growth and survival whereas; the excess of males in the smaller fish must be due to differences in habitat selection by each sex when they are young.

After examining the large number of samples (N=240) from extensive range of sites, it was concluded that hilsa are gonochoristic, unlike the other *Tenualosa* species.

Contrary to the previous belief, hilsa is strictly anadromous, the data show clearly that the hilsa spawn in the rivers, estuaries and on the coast, although the proportion of fishes spawning on the coast is perhaps lower, but the pattern differ from year to year.

Otolith core microchemistry indicates that some fish (from Cox's Bazar) are born in the middle to high salinities. This suggests that salinity per se may not be relevant to the location of spawning areas.

The large-scale movements of hilsa show a marked correlation with water temperature. The upstream movements during the monsoon (July to September) take place when water temperatures are highest inland. Conversely, the movement towards the sea corresponds with a marked drop in upstream water temperature from around October. At this time, the sea temperatures are 3-4°C higher than the riverine temperatures. These large-scale movements may be more related to temperature and food availability than to salinity and the results strongly suggest that.

Hilsa Length Frequencies

Following gillnet selectivity analysis, it was found that routine market sampling analysis for hilsa stock assessment would not provide accurate representation of the length frequency of the population. It indicates that the smaller length classes are not fully selected. The consequence of not adjusting for selectivity will be that the mortality and other measures of population health will be underestimated. It suggests that the fishing mortality is higher than the current estimates and that the hilsa populations are more overexploited that current estimates predict.

Jatka (Juvenile hilsa) Dynamics and Survival Rates

Tendency of catching jatka by current jal is decreasing but catching of jatka by Jagatber jal is continuing in full swing. More than 60% of the total catches of jatka are caught by the Jagatber jal. About 50,000 fishermen are catching over 55% of the total catch of jatka in the Meghna river.

Maximum abundance of jatka in the nursery ground is found during the month of December to May with peak in March. The maximum catch occurs in March (59%), followed by April (17%), February (14%) and January (10%). If the above amount of jatka could be saved and got a minimum of survival of 20%, then these jatka would contribute an additional potential catch of 50,000-70,000 tonnes of adults hilsa with an average individual weight of 0.5-0.7 kg after 1 year. So, this jatka must be saved to grow to brood stock to be able to participate in spawning in the next year.

Jatka in the riverine area are mostly caught between sizes of 8-12 cm (average length 7.5+3.5 cm and average weight 8.0+0.75 g). The growth parameters of jatka population such as asymptotic length (L_∞), curvature character (K) and initial time (t_0) were found to be 30.9 cm, 1.2 yr^{-1} and 0.45 year, respectively. The natural, fishing and total mortality were 1.37 yr^{-1}, 1.41 yr^{-1} and 2.78 yr^{-1}, respectively. The survival rate was found to be S=6.2%. A small difference was found between age at first capture (Tc=0.5yr, 2 cm size) and recruitment age (Tr=0.7yr, 8 cm size). From the length-frequency data on jatka fishery, it was found that the hilsa fishery is affected by recruitment overfishing at their juvenile stage. The fishing pressure (E=5.1) is towards overfishing level. Indiscriminate killing of jatka should be stopped.

The survival of jatka is similar throughout the region with few regional differences. Coastal spawning is not a large contributor to total fish recruitment. Riverine spawning contributes much to recruitment. Jatka is being caught in huge amount. So, fishing pressure must be controlled to protect jatka and other fish species that are caught as by-catch which will improve biodiversity conservation as well. There is a need to continue monitoring of jatka recruitment in different areas of the river Meghna to assess its trend of survival and recruitment.

Tagging of Hilsa

Tagging of hilsa was done to know the migratory route of different races/stocks of hilsa and their growth and mortality. Anchor type tag was attached just below the dorsal fin of the fish using a punch machine while fishermen were catching fish in the river Meghna and Meghna estuary area. Some tags were attached by using rubber band in the caudal peduncle region of the fish. The tagged fish were quickly released in water after measuring the total length and weight. Each tag contained an individual code number and an announcement for reward if returned to Fisheries Research Institute, Chandpur. This was also announced among the fishermen in the region. Altogether 100 hilsa were tagged. It was really very difficult to g*et al*ive hilsa for tagging as they are very sensitive than other fishes. The recovery rate of tagged hilsa was very poor. At the end of 1994 only one tagged hilsa was recovered after 15 days of tagging. The migration route of that hilsa was towards downwards stream.

Results of Stock Assessment of Hilsa

The Riverine Station, Chandpur, Bangladesh Fisheries Research Institute has been doing stock assessment of hilsa since 1986. The results of stock assessment from 1992 to 2000 have been presented in the Table 1 as follows:

Table 1. Results of stock assessment studies over a period of 7 years from 1992 to 2000.

Parameters	**Results in different years**						
	1992	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Asymptotic (L_∞) length	61.1	58.3	59.97	61.50	66.00	60.00	62.50
Growth constant (K)	0.74	0.74	0.99	0.83	0.67	0.82	0.72
Total mortality (Z)	2.41	2.61	3.19	3.29	3.43	3.77	2.79
Natural mortality (M)	1.16	1.18	1.41	1.28	1.25	1.28	1.17
Fishing mortality (F)	1.25	1.43	1.78	2.01	2.18	2.49	1.62
Exploitation rate (E)	0.52	0.55	0.56	0.61	0.63	0.66	0.58
Maximum Exploitation level (E_{max})	-	-	-	-	0.60	0.59	0.46
Length at first capture (L_c)	35.0	30.0	30.34	30.25	27.06	22.80	13.12
Growth rate	-	3.40	3.55	3.50	3.46	3.47	3.45

It appears from the Table that during the nine year study period from 1992 to 2000, the asymptotic length (L_∞) and growth constant (K) exhibited considerable variations. The highest asymptotic length was found in the year 1998 (66.00 cm) and the lowest in1995 (58.3 cm). On the contrary, the highest growth constant was found in 1996 (0.99) and the lowest in 1998 (0.67). During this time, the exploitation rates of hilsa were higher than the optimum exploitation level of 0.50. The exploitation rate has successively increased every year (except 2000) from 0.52, 0.55, 0.56, 0.61, 0.63, 0.66, and 0.58 in 1992, 1995, 1996, 1997, 1998, 1999, and 2000, respectively. This means that during these years, the hilsa were exploited at 0.13 to 0.16 higher level than the optimum level (E) of 0.50, *i.e.* the fish was over exploited on an average by 26 to 32% in those years. The maximum exploitation levels (E_{max}) were 0.60, 0.59 and 0.46 in 1998, 1999 and 2000 which show, the exploitations of hilsa were more than the maximum exploitation level all through these years. Although, the natural mortality (M) was almost similar during this time, the fishing mortality (F) has increased from 1.25 in 1992 to 2.49 in 1999 indicating that the fishing effort for hilsa in Bangladesh has consistently increased. On the other hand, the size of hilsa at first capture decreased from 35.0 cm in 1992 to 13.12 cm in 2000. That is smaller fish was exploited at higher rates than the standard size of 31.0 cm for sustainable production which are alarming for existence of the fishery. If the exploitation of smaller fish including over exploitation of the fishery is not controlled, the overall hilsa stock will highly decline in future.

Socio-economics

- The economic and social structures of the hilsa fishery have been extensively studied and described in the relevant section.
- Average family size was small with the hilsa fishers and paikers (6.2) than the aratdars (7.62). The fishing crews (fishers) and paikers had the smallest household size.
- About 20-30% of the aratdar and paikers are illiterate while the rate of illiteracy was over 60% among fisher folks (fishing crew and head mazhi).
- Average farm sizes were 5.04 acre, 2.61 acre, 1.01 acre and 0.94 acre for aratdar, paiker, head mazhi and crew fishermen, respectively. The largest farm size belonged to aratdar whose income was always highest.
- Head mazhi from Chattogram earn on an average Tk. 47,858 per hilsa season which is the highest income compare to any other location and income from fishing for crews is about Tk. 18,910. However, the earning pattern is different for different places which depend on availability of fish and wage pattern of different categories of fishermen at different places.
- Most fishers are dependent on a fish trader (aratdar) for provisioning and income.
- Most fishers do not get real market price of the fish and they are seriously exploited by the middlemen.
- More than 90% of the hilsa fishers usually change their profession in the lean season. It is very important to find alternative sources of income such as providing short term loan, food for work etc.
- The fish traders are the economically most powerful sector in the hilsa fishing industry. Most fishers are tied to traders to finance their trips and buy the catch. They are the strongest groups in the marketing chain for hilsa.
- Effective management of the hilsa fishery must involve the fish traders in order to succeed.

Hilsa Fisheries Management Action Plan

Based on the research findings under the project, BFRI formulated a Hilsa Fisheries Management Action Plan (HFMAP). The plan was presented in the Final workshop held in IDB Bhaban, Dhaka on 16 January 2001 and obtained feedback from representatives from all stakeholders including Ministries and Planning Commission, Department of Fisheries (DoF), other government organizations, NGOs, private sector, fishermen and fish trader's organizations and industry stakeholders. The Minister and State Minister, Ministry of Fisheries and Livestock, Govt. of the Peoples' Republic of Bangladesh were present in the workshop as the chief guest and special guest, respectively. The Secretary of the Ministry presided over the inaugural and the concluding sessions.

The Action Plan was finalized by incorporating the recommendations of the workshop and the whole outcomes of the workshop were summarized into a document and submitted to the Department of Fisheries for implementation (Annexure 1).

Transfer of the Project Results to Fourth Fisheries Project of the Department of Fisheries

Dr. S.J.M. Blaber of CSIRO, Australia participated in the inception meeting of the DFID/WB funded Fourth Fisheries Project and had a meeting with the consultants of the project in June 2000. He passed a briefing document to the consultants detailing the aims and achievements of the BFRI/ACIAR Hilsa Research Project and discussed the most appropriate activities that could extend the outcomes and ensure maximum uptake by the Fourth Fisheries Project. Later in September 2000, Dr. D.A. Milton, another ACIAR/BFRI consultant had further meeting with Mr. Dirk Reyntjens from the Fourth Fisheries Project in this regard. DoF implemented the DFID/WB funded Fourth Fisheries project and the research findings of BFRI/ACIAR project were utilized in updating management plans for hilsa fisheries development. The research studies under the FFP were implemented in collaboration with BFRI, and BFRI provided all research results, logistics, laboratory, research vessels and other research facilities including resource persons for implementing the research studies under a MoU signed between DoF and BFRI on 16 September 2002.

Impact of the Research from the Project

The project made a number of significant scientific advances that impact the management of hilsa resources in Bangladesh and adjacent countries. The management plan that had been prepared by the project led to formulation of regulation for implementation of the plan.

The hilsa research project had some direct social and economic benefits. The fishery had been declining for several years and there was widespread concern as fisher's income declined. The implementation of the management plan has increased the production of hilsa and improved the economic and social wellbeing of the large fishing sector and sustainability of the fishery.

Major Impact and Future Direction of the Hilsa Research

Sl. No.	Findings	Impact
1	Single population in the Bay of Bengal.	Demonstrates that fish caught throughout Bangladesh are the same population and that fish caught in India and Myanmar are part of the same population and fishing in these countries is impacting on Bangladesh catches.
2	Location of spawning grounds and movements.	Shows that some spawning occurs in coastal waters unlike previous beliefs and that hilsa move long distances between marine and riverine areas in main river. Fish in upper reaches are probably resident.
3	Age of critical life stages.	Determined directly the age structure of the population and showed that fish are sexually mature within a year, but live for about 3-4 years. This information has direct use in population assessment.
4	Gillnet selectivity.	Shows that most common mesh sizes catch mainly male hilsa and that nets over 10 cm mesh size catch mainly females. Restricting mesh size can be useful as one method of managing fishing effort and enhancing recruitment.
5	Identification of the influence of traders in the hilsa economic chain.	Demonstrates that traders have the most influence on hilsa fishing and marketing. Must involve the traders in management for it to be effective.

The project identified major structural impediments to effective management of hilsa fish resources including measurement of fishing effort, lack of legal power of the fishery managers for enforcement of fish act and rules, and weak influence of the fisher over the powerful fish traders who control the finances and behavior of the fishing industry.

Life History of *Tenualosa ilisha* and its Implications on the Fishery

Summary

Tenualosa ilisha (known as hilsa) is the most widespread of the five species of tropical shads *Tenualosa* spp. It is found from north Sumatra in the east to Kuwait in the west. It is the basis of important fisheries in Bangladesh, India, Myanmar, Pakistan, and Kuwait and is probably forms the largest estuarine fishery in the world. In Bangladesh, *T. ilisha* represents 25% of total fish production amounting to 200,000 tonnes per year (2000). Despite a large body of literature, there had been no attempt to relate the marine, estuarine and freshwater components of the hilsa populations and describe the full life history. To address this, Bangladesh Fisheries Research Institute (BFRI) conducted studies with the assistance of Commonwealth Scientific and Industrial Research Organization, Australia during 1996 to 2001. Results show that male and female *Tenualosa ilisha* reach sexual maturity at 20 cm and one year of age and that both are able to spawn at this size. Unlike other *Tenualosa* species, there is no histological or macroscopic evidence for sex change in *T. ilisha*, but there is a bias in the sex ratio and males are more abundant among the smaller fish. Most fish over 30 cm and almost all fish over 40 cm are females. Males predominate between 10 and 25 cm, but the sex ratio below 10 cm is more even. The biases in the sex ratio suggest that males may not live as long as females. Spawning occurs throughout the year in all areas, from upstream at the Indian border to the coast at Chattogram and even in the sea off Cox's Bazar. Contrary to the previous belief that *T. ilisha* is strictly anadromous, the data show clearly that *T. ilisha* spawn in the rivers, in estuaries and on the coast. Otolith core microchemistry indicates that some fish (e.g. from Cox's Bazar) are born in middle to high salinities. This suggests that salinity per se may not be relevant to the location of spawning areas. The large-scale movements of hilsa show a marked correlation with water temperature. Upstream movements during the monsoon (July-September) take place when water temperatures are highest inland. Conversely, the movement towards the sea corresponds with a marked drop in upstream water temperature from about October, when sea temperatures are 3 to 4°C higher than riverine temperatures. These large-scale movements may be more related to temperature or food availability, than to salinity. Otolith Sr:Ca ratios and reproductive surveys indicate that the movement patterns of hilsa are both complex and variable. Individuals attain 20 cm standard length by the end of their first year and grow at similar rates to other tropical shads and clupeids. The population is now dominated by 1-year old fish, whereas in the 1960s; it was composed mainly of 3-year old fish. Hence the probability of recruitment failure has greatly increased because 1-year old fish now contribute most to egg production and have a relatively low fecundity. The absence of fish older than 3-year old from this study, probably a result of intense fishing pressure, mean that the asymptote of the growth curve could not be accurately estimated, but previous studies indicate that hilsa live at least 5 years. This, together with a decline in female fecundity, has far-reaching implications for the future of the fishery, which recorded large declines in catches in 2000 and 2001 in the inland waters.

Introduction

Hilsa, *Tenualosa ilisha* is the most widespread and well-studied of the five species of tropical shads (*Tenualosa*). It is found from north Sumatra in the east to Kuwait in the west, and is the basis of important fisheries in Bangladesh, India, Burma, Pakistan and Kuwait (Al-Baz and Grove, 1995; Whitehead, 1985; Blaber, 2000). In terms of tonnages landed (> 500,000 tons in 2017-18), it is probably the largest estuarine fishery in the world. The economic importance of hilsa in Bangladesh, India and Pakistan has resulted in many studies on this species in the region. Jafri and Melvin (1988) published an annotated bibliography of all publications relevant to hilsa and found 368 publications between 1803 and 1986. Most are concerned with hilsa in the Bay of Bengal and adjacent rivers in India and Bangladesh. However, despite this large body of research data, much of the previous work on hilsa has concentrated on the fishery in single areas, or on a single biological aspect. There has been no attempt to relate the marine, estuarine and freshwater components of the populations and sort out the full life history.

In Bangladesh hilsa is the basis of the most important fishery, contributed about 25% of total fish production amounting to about 200,000 tonnes year^{-1} in 2000. The fishing season extends from August to March, with a major peak in September-October and a minor one in February-March. There are two main components- coastal and inshore marine habitats and a riverine fishery in the major river systems (Meghna and Padma). The riverine fishery is artisanal and uses mainly drift/gillnets from traditional non-mechanized wooden boats. In contrast, the marine fishery has greatly expanded since the introduction of larger, mechanized vessels in the last thirty years. The marine fishery component has become the dominant source of hilsa at the expense of the riverine component of the fishery. However, how this is related to the biology and life cycle was largely unknown.

The present research was carried out by BFRI and CSIRO during 1996 to 2001. The main objectives of the project were thus to determine the genetic stock structure of *T. ilisha* in Bangladesh and to elucidate the life cycle by investigating reproduction and spawning habits, distribution and movement patterns, age and growth, and whether or what ways the species is anadromous. The research on the stock structure (Salini *et al*., 2001) shows that hilsa in Bangladesh and the Bay of Bengal as a whole, consist of a single genetic stock, but that this differs from stocks further east in north Sumatra and in the north western Indian Ocean. Further impetus was given to the need for detailed biological work on *T. ilisha*, when simultaneous research on the life cycles of congeners *T. toli* and *T. macrura* in Sarawak, Indonesia (Blaber *et al*., 1996; 2000) showed that these species were protandrous hermaphrodites with complex life histories.

Materials and Methods

Field Sampling

Monthly samples of up to 20 adult hilsa were collected from fishers from five sites between May 1996 and August 1997. Sites were chosen to cover the range of hilsa in Bangladesh and included marine and riverine upper reaches: Cox's Bazar, Chandpur, Ramgoti, Goalanda (Aricha Ghat) and Khulna (Goalanda) (Fig. 1). Fish were measured for standard and total length (mm) and weighed with a spring balance (±5g). They were dissected and the gonads removed, weighed (±0.1g) and a sample fixed in 10% formalin. These were sent to Australia for histological studies. In addition, a random sample of at least 100 fish was measured from each site each month to provide length frequency information for egg production estimates. A country-wide survey to check for spawning activity was undertaken at 10 sites within a two-week period in August 1997 (Fig. 1, Table 1).

Salinity, temperature and oxygen concentration were measured at 13 sites, and on at least a monthly basis at Chandpur, Cox's Bazar, Khulna and Ramgoti, with a TPS meter. Turbidity was measured with a Hach Nephelometer.

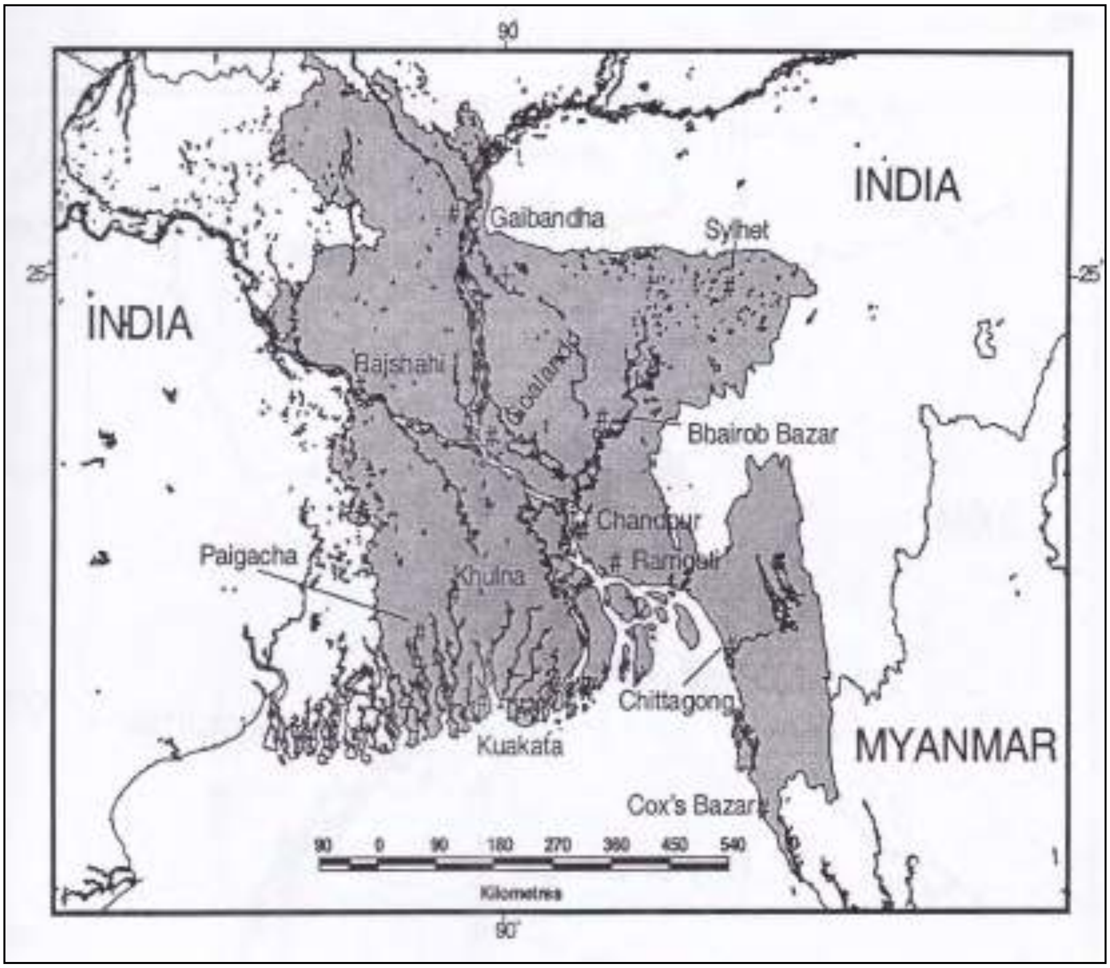

Fig 1. Map of sites in Bangladesh where fish or physical data were collected during the study.

Reproduction

The gonads of both sexes were weighed in the laboratory (± 0.001 g) and sub-samples from each gonad from all fish placed in cassettes for histological processing.

The Gonadosomatic Index (GSI) was calculated as follows:

$$GSI = \frac{\text{Gonad weight}}{\text{Fish weight (minus gonad weight)}} \times 100$$

The histological samples were dehydrated, infiltrated with wax and sectioned at 9 mm. The sections were stained with haematoxylin and eosin.

Oogenesis

Stage 1=oogonia; stage II=pre-vitellogenic oocytes; stage III to V=vitellogenesis; stage III=yolk precursor; stage IV=non-staining yolk; stage V=red-staining yolk; stage VI=completion of development, stage VII=atresion.

Spermatogenesis

Stage I = primary germ cells (stem spermatogonia); stage II=spermatogonia; stage III=primary spermatocytes; stage IV=secondary spermatocytes; stage V=spermatids; stage VI=spermatozoa.

Table 1. The sites where fish were collected during the countrywide survey of hilsa spawning during the 1997 monsoon season (August).

Site	Spawning Percentage	Number of females
Bhairab Bazar	80	20
Chandpur	34	29
Cox's Bazar	0	13
Gaibandha	100	5
Goalanda	75	8
Khulna	35	17
Naf River	33	9
Paikgacha	83	23
Rajshahi	100	10
Ramgoti	71	7

Fecundity

Gonads that were shown by histology to be from pre-spawning females were sub-sampled. The sub-samples (1.0g) were weighted (±0.001g) and their number of ripe eggs counted under a microscope. Annual fecundity was estimated by the formula:

F = ovary wet weight x sub-sample egg count/sub-sample wet weight.

As fecundity is usually related to fish size, comparisons of relative fecundity (fecundity/fish weight) among years and sites were made using an analysis of covariance (ANCOVA) including age as a covariate. Ratios were log transformed to adjust for heteroscedasticity.

Estimates of Egg Production

In addition to the 20 fish collected from each site each month for biological studies, random samples of at least 100 mature fish (>20 cm SL) obtained directly from fishers were measured from five sites throughout Bangladesh (Cox's Bazar, Ramgoti, Chandpur, Goalanda and Khulna) each month from January 1996 to June 2000. As estimates of overall egg production for the whole country was required, fish samples for each site were combined and then grouped into 20 cm length classes. Mean egg production (E) for the whole population during each month was calculated as:

$$E = \sum_{i-1}^{k} n \; x \; p \; x \; f \; x \; s,$$

Where n = the number of fish in ith length class, p = the production of females in the ith length class, f = mean fecundity of a fish of the class mean length and s = proportion of spawning females. The relative contribution of each of the j age classes (0+, 1+, 2+, 3+) to total monthly egg production (Ej) was calculated as:

$$E_j = \sum_{i=1}^{m} \frac{E_i}{E} \mathrm{x}100,$$

Where Ej is the sum of the mean monthly egg production of the m length classes in each age group. Ages were calculated from the inverse von Bertalanffy growth equation using the parameters estimated from counts of growth increments in otoliths.

Age and Growth

The sagittal otoliths were removed in the laboratory and cleaned of adhering tissue with thin glass rods, dried with tissue paper, weighed (±0.1 mg) and one otolith from each fish was stored in clean, labelled plastic bags until required for microchemical analysis. The other was used for ageing. Otoliths for ageing were weighed (±0.0001g), embedded onto microscope slides with thermoplastic cement, and then polished with wet and dry sandpaper (800 grit) until the mid-plane was reached. Otoliths from larvae were not polished. The otoliths were viewed under immersion oil at 400x to 1000x on a video screen attached to a microscope. Daily rings were counted along the longitudinal axis towards the posterior of the otolith, as this was the axis where rings were most easily distinguished. No annuli were visible in one or two-year-old fish either before or after polishing of the otoliths.

A von Bartalanffy growth curve was fitted separately to the data from each sex and for small fish of indeterminate sex. The curve was of the form defined by Francis (1998), which provides uncorrelated growth parameters that can be directly compared. Details were presented in Milton *et al*., (1991, 1993).

Movement Patterns Using Otolith Microchemistry

The concentration of strontium (Sr) in otoliths has been closely correlated with both salinity (Secor *et al*., 1995) and water Sr concentrations (Farrell and Campana, 1996; Bath *et al*., 2000). This property of otoliths, when combined with an up to 100-fold difference in Sr concentration between marine and freshwater (Durum and Haffty, 1963; Sharp, 1990), indicates that Sr concentration in these structures provides a proxy of fish movements between marine and freshwaters (Shen *et al*., 1998).

Prior to chemical analysis, each otolith was mounted in thermoplastic cement on a labelled microscope slide and ground along the transverse axis with heavy-duty silicon carbide paper until the core region of the otolith was exposed. The otolith was then polished to the core with 1200-grade wet and dry sandpaper moistened with double-distilled water. To remove any contamination, the surface was wiped vigorously after polishing with a piece of tissue paper moistened with 0.5 M aristar nitric acid. The slides were then placed in plastic bags until analyzed by Laser-ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS).

Transects of 10 to 18 ablations, approximately 20 μm in diameter, were made across otoliths of 31 fish from four sites (Chandpur (n=5), Cox's Bazar (n=5), Goalanda (n=4), and Sylhet (n=17). Craters were ablated at regular intervals (0.10-0.15 mm apart) across the otolith from the core to the edge. Data were acquired for 13 elements, but data only on Sr were presented as this provides the most sensitive indicator of fish movement through waters of changing salinity (Kimura *et al*., 2000).

Results

Hydrological parameters

A summary of salinity, temperature, turbidity, and dissolved oxygen values are shown in Table 2.

Temperature

Water temperature varied seasonally from a low of about 20°C to a high of about 33°C. Monthly temperatures from May 1997 until May 1999 from four sites are plotted in Fig. 2a and show a clear seasonal pattern with highest temperatures during the monsoon period. Dry season (winter) temperatures were consistently lower at inland sites (Chandpur, Khulna) than at marine sites (Ramgoti, Cox's Bazar).

Table 2. Salinity (‰), temperature (T°C), turbidity (NTU) and dissolved oxygen (O_2) values measured at 13 sites in Bangladesh between 1996 and 1999 (N=number of samples).

Site	N	mean ‰	min ‰	max ‰	mean NTU	Min NTU	max NTU	mean T°C	min T°C	max T°C	mean O_2	min O_2
10 km N Chattogram	1	19.5	19.5	19.5	627	627	627	32.1	32.1	32.1	-	-
Chandpur	54	0	0	1.8	199	22	781	28.3	19.6	31.4	6.7	1.9
Chattogram	5	6.8	0.9	18.9	516	475	560	30.6	24.6	33.6	-	-
Cox's Bazar	16	5.0	0	32.0	21	21	21	28.2	22.5	31.5	7.3	5.0
Gaibandha	1	0	0	0	-	-	-	29.6	29.6	29.6	7.4	7.4
Goalanda	21	0	0	0.2	34	34	34	26.8	20.3	31.8	7.9	5.8
Khepupara	12	6.6	0	15.8	-	-	-	29.9	26.0	32.5	6.6	3.5
Khulna	32	0.8	0	6.3	-	-	-	28.8	19.6	32.7	6.9	4.0
Mongla	4	13.2	13.2	13.2	521	437	650	31.9	31.8	32.1	-	-
Monpura	2	0	0	0	-	-	-	28.6	28.6	28.6	7.3	7.0
Paikgacha	2	0.4	0.4	0.4	-	-	-	31.0	30.8	31.2	6.3	6.3
Rajshahi	2	0	0	0	-	-	-	30.8	30.8	30.8	6.6	6.6
Ramgoti	25	1.2	0	9.8	541	427	606	28.8	24.0	32.5	6.4	3.7

Salinity

Most of the riverine areas were fresh year-round (Fig. 2b), and in the Meghna, measurable salinities were only recorded downstream from about Chandpur (Figs. 1, 2b). Even in the marine coastal region of Chattogram and Cox's Bazar, salinities were 0 in the monsoon period, only reaching moderate salinities during the dry season (Fig. 2b).

Turbidity

Turbidities were generally very high throughout the study area (up to 781 nephelometric turbidity units, NTU). Moderate turbidities (21-34 NTU) were recorded only at Cox's Bazar and at Goalanda and Chandpur in the dry season.

Reproduction and Ageing

Size and Sex Ratios

The sex ratio of all fish (n=2216) that could be sexed, either macroscopically or from histology, is shown by 5 cm size-classes in Fig. 3. There is a bias in the sex ratio and males are more abundant among the smaller fish. Most fish over 30 cm are females and almost all fish over 40 cm are females. Males predominate between 10 and 25 cm, but the sex ratio below 10 cm is apparently more even (1:1). Histology showed no evidence of the sex change seen in other *Tenualosa* species (Blaber *et al*., 1996; Blaber, 2000). The histology of the gonads of 1,390 fish (827 females and 563 males) were analyzed, including 356 fish (141 females and 215 males) between 15 and 25 cm size range over which sex change could be expected. These numbers are far greater than those that were necessary to show sex change in *T. toli* and *T. macrura*. The biases in the sex ratio in *T. ilisha* suggest that males may not live as long as females.

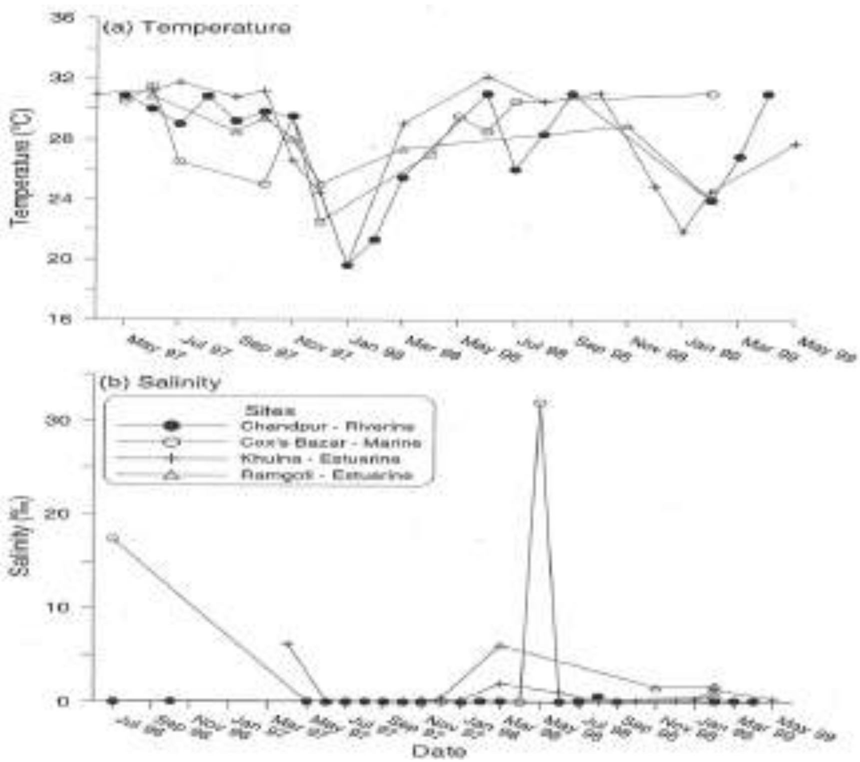

Fig. 2(a). Monthly water temperatures and (b) salinities at two inland (Chanpur and Khulna) and two coastal (Cox's Bazar and Ramgoti) sites in Bangladesh.

Maturity and Spawning

Gonadosomatic indices of females studied in relation to standard length are plotted for 5 years from 1996 to 2000 (Fig. 4) show that hilsa, *T. ilisha* reach sexual maturity at 20 cm and one year of age. Both males and females are able to spawn at this size. However, it is noteworthy that during 2000, large numbers of smaller females of 16-18 cm SL were found in spawning condition at Chandpur during June.

The proportion of females spawning each month from July 1996 to January 2000 using histological staging is shown in Fig. 5. These data are based on 1,382 fish that were in spent condition or where more than 70% of the eggs were at stage V. Spawning evidently occurs throughout the year and the patterns differed from year to year. The reproductive data from the five sampling sites from both coastal and riverine areas also showed that fish spawn throughout the year with peak periods that varied between areas. However, there are two seasons of increased spawning activity, one during the monsoon (July-October) and a second in January-March (Fig. 5). The country wide survey during the monsoon (August 1997) showed that hilsa spawn in all areas, from upstream at the Indian border to the coast at Chattogram and even off Cox's Bazar Table 1; Fig. 6). Hilsa spawn in the rivers, estuaries and on the coast, although the proportion of fishes spawning on the coast is perhaps lower.

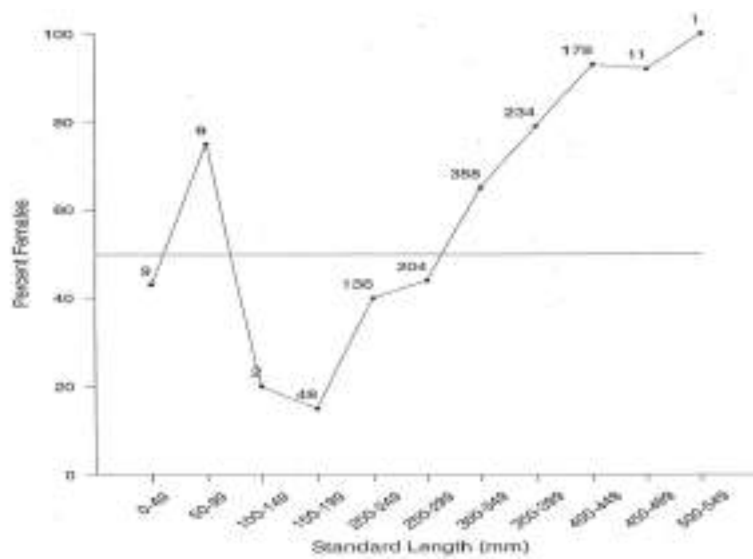

Fig. 3. Proportion of females in each 50-mm length class of *T. ilisha*. The number of females in each sample is shown on the graph.

Fecundity

Fish fecundity was examined at four sites in each of the four years of the study. Fecundity is linearly related to fish length (F = 4912.3 ± 289 length – 898332 ± 98225, r^2 = 0.53). It ranged from 108,500 eggs for a 171 mm fish to 1,993,846 eggs for a 415 mm fish. Ripe running female gonads contained only hydrated eggs. They appear to spawn a single batch of eggs, but it is not clear whether an individual spawn more than once a year. It was found that there was a fairly consistent decline in female fecundity at all sites across Bangladesh over the four years

(Fig. 7), from a mean of about 1000 eggs/g body weight in 1996 to about 600 eggs/g body weights in 1999. Relative fecundity of *T. ilisha* varied both among sites and among years ($P < 0.0001$). Analysis of covariance showed that year had the most significant effect on fecundity ($F_{3, 177} = 16.2$, $P < 0.0001$) compared with site ($F_{3, 177} = 5.7$, $P < 0.001$). Site x year interaction was also significant ($F_{7, 177} = 2.4$, $P < 0.05$), but the covariate, age, was not ($P > 0.68$). The fecundity of *T. ilisha* declined each year of the study at all four sites (Fig. 7), with the fecundity in 1999 almost half that in 1996.

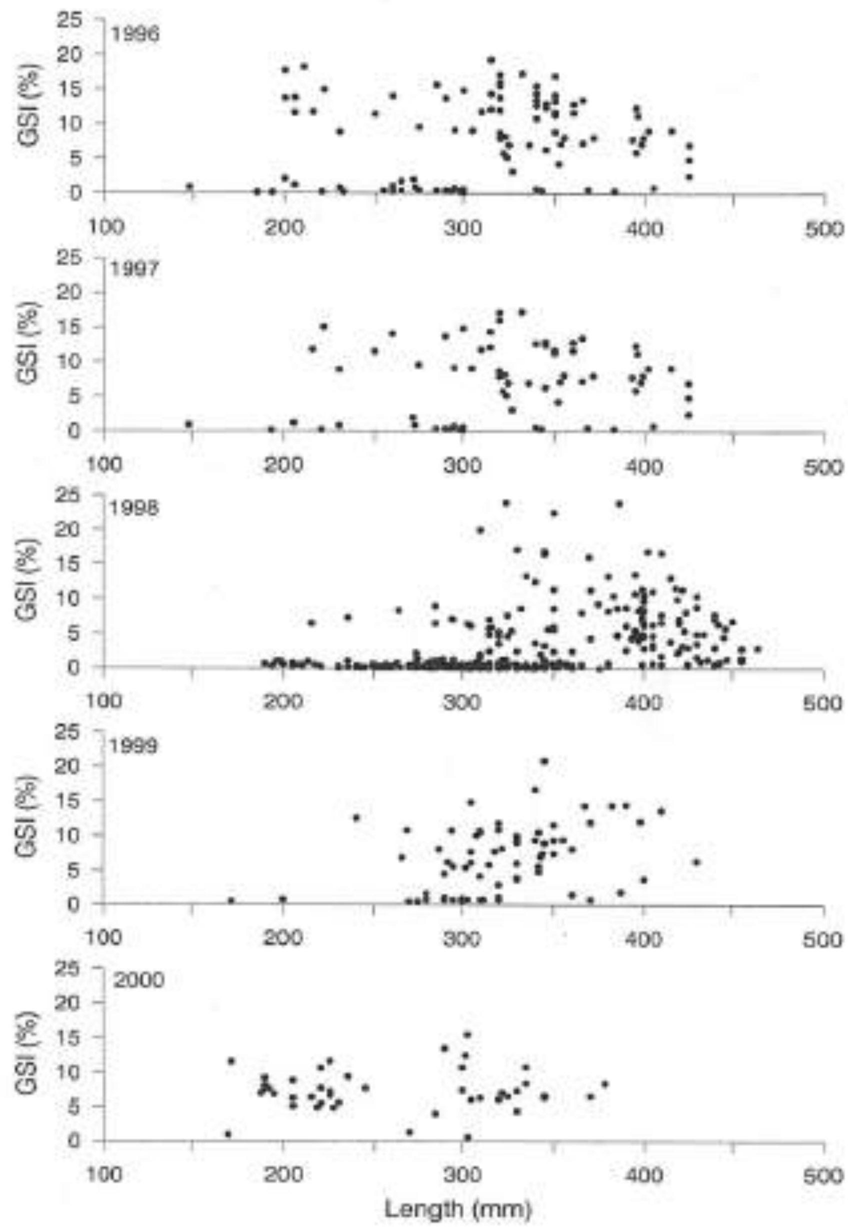

Fig. 4. Gonadosomatic indices (GSI) by standard length for female *T. ilisha* from 1996 to 2000.

Age and Growth

Von Bertalanffy growth curves for 158 fish from Chandpur (92) and Cox's Bazar (66) are shown in Fig. 8. There is no significant difference in growth rates from the two sites. Based on the converted length-frequency data from 29,790 fish, the population in Bangladesh comprises mainly fish that are 1 to 2 years old (Fig. 9). *T. ilisha* population caught by the commercial fishery in Bangladesh was dominated by young adults (1-year age-class) in all years of the study. There was also a similar proportion of immature fish (0-year age-class) in the catch in most years with a higher proportion in 1999. Old fish greater than 3 years were absent in all years except 1998 when they comprised 0.5% of the samples. The 2-year age-class did not form a large percentage of the population in most years except in 1998, perhaps a result of a slightly stronger 1-year age-class in 1997.

In summary, fish more than 3 years old are now rear (compared with Pillay and Rao, 1963) and represent less than 1% of the total population. No fish older than 4 years was found in this study, and the majority of fish are in the 1-year age class. Most 2-year old fish and all 3-year old fish were females.

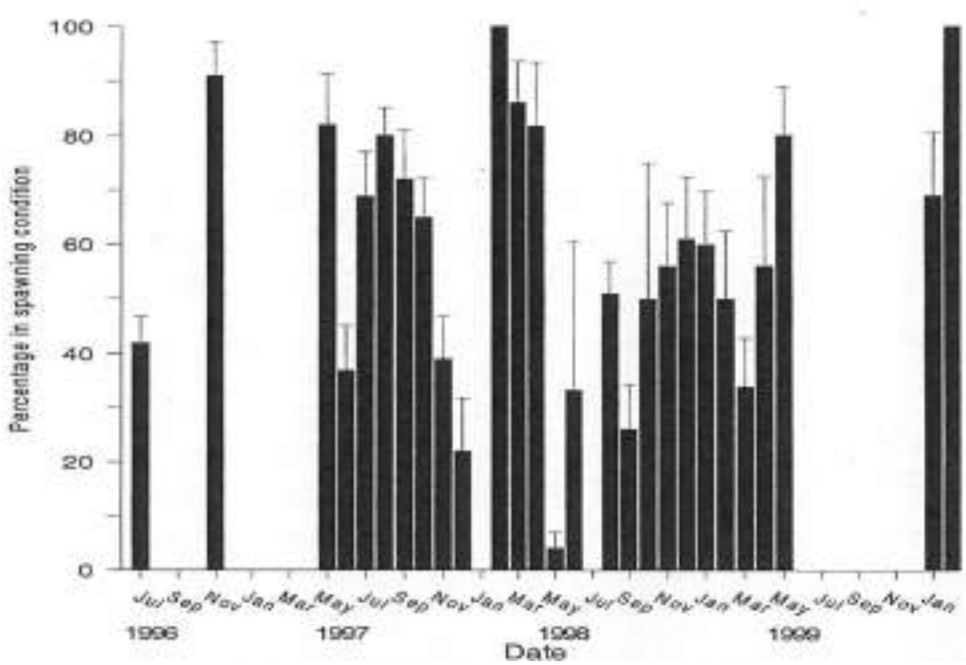

Fig. 5. Proportion of female *T. ilisha* in spawning condition for all sites combined from July 1996 to January 2000.

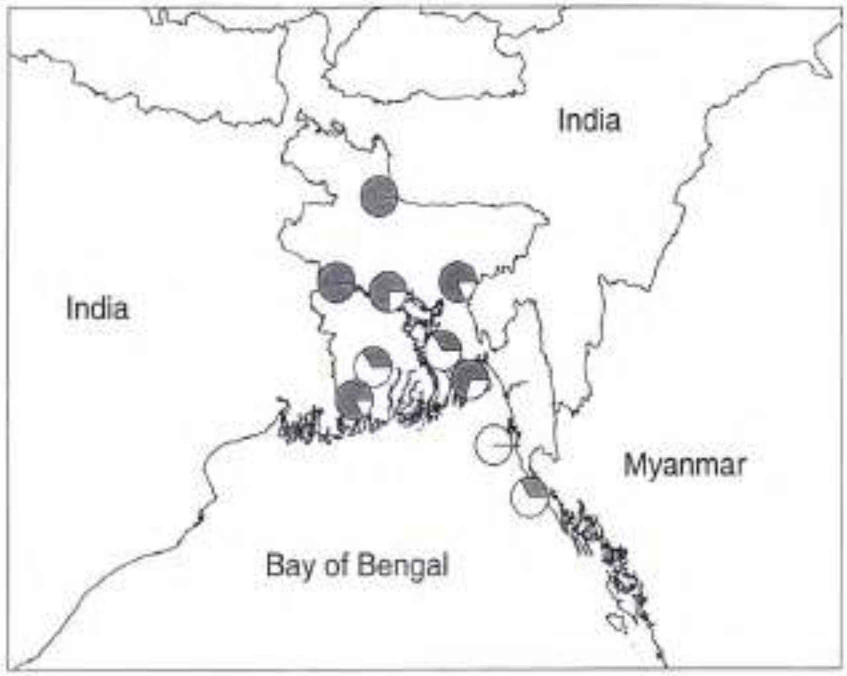

Fig. 6. The proportion of spawning females (dark) caught at each site during a country wide survey in August 1997.

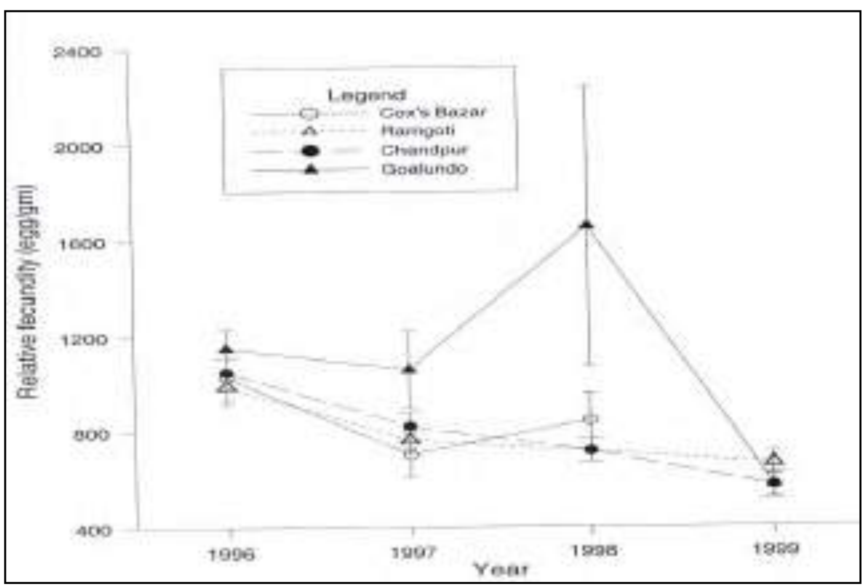

Fig. 7. Changes in the relative fecundity (±SE) of hilsa at four sites in Bangladesh between 1996 and 1999.

Recruitment

Data from reproduction (proportion spawning and fecundity), ageing, and length frequency were used to provide estimates of monthly recruitment based on egg production from each age-class (0-3) from January 1996 until December 1999 (Fig. 10). Larger 2-year-old females and 3-year- old females (> 40 cm) have a higher relative fecundity, spawn more eggs, and contribute proportionally more to the egg production for potential recruitment than 1-year old-fish (20-30 cm). During 1996, the older 2-year fish contributed most to recruitment, but from 1997, the proportion of 2-year-old fish in the population declined and the bulk of egg production is now coming from 1-year-fish that have a relatively low fecundity. Hence, it is likely that the age structure of the population may have played a role through lower recruitment, in the decline of the hilsa population between 1996 and 2000.

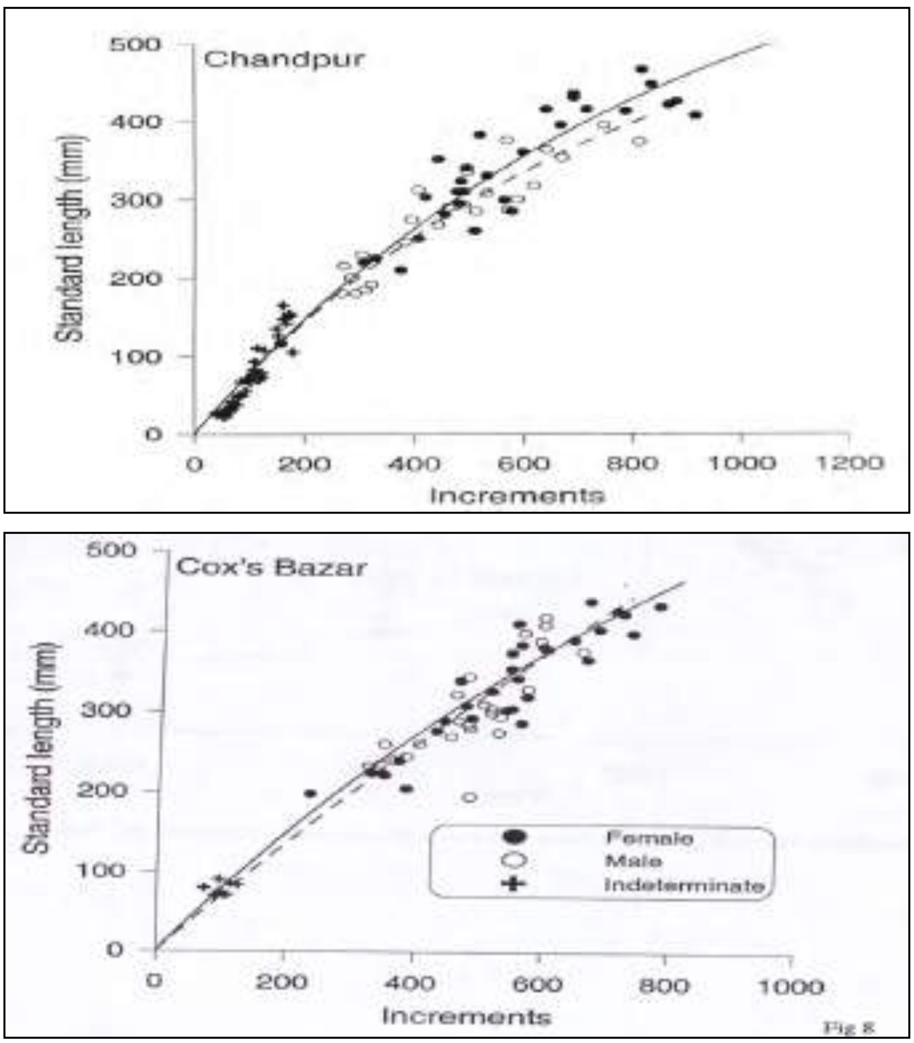

Fig. 8. Growth increment of male and female hilsa in Chandpur and Cox's Bazar.

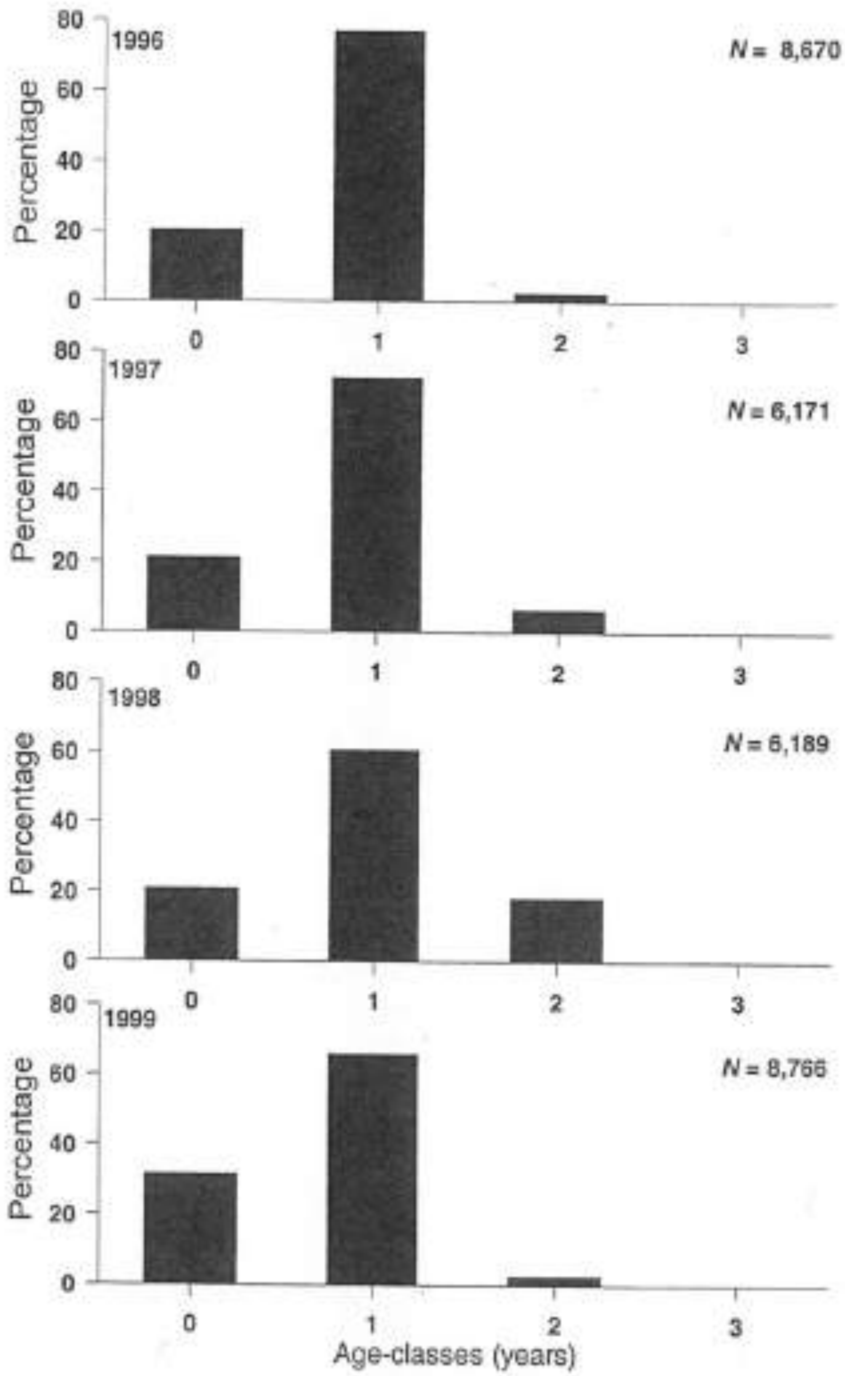

Fig. 9. Mean age structure of the *T. ilisha* population of Bangladesh from 1996 to 1999.

Movement Patterns

Plots of mean Sr concentrations across the otolith of fish from Chandpur, Cox's Bazar, Goalanda and Sylhet are shown in Fig. 11. The Sr concentrations from the otolith cores of fish from Chandpur, Goalanda and Sylhet suggest that they were spawned in freshwater. However, the values from Cox's Bazar fish indicate spawning at higher salinity marine or lower estuary sites. The mean Sr data from those spawned in freshwater show a tendency for fish to move to higher salinities in their first year and thereafter a movement back toward estuaries or freshwater. For Chandpur fish there is also another movement back towards marine salinities in the second year. Fish from Cox's Bazar that were spawned in the sea show a movement toward freshwater in their first year followed by a return to the sea.

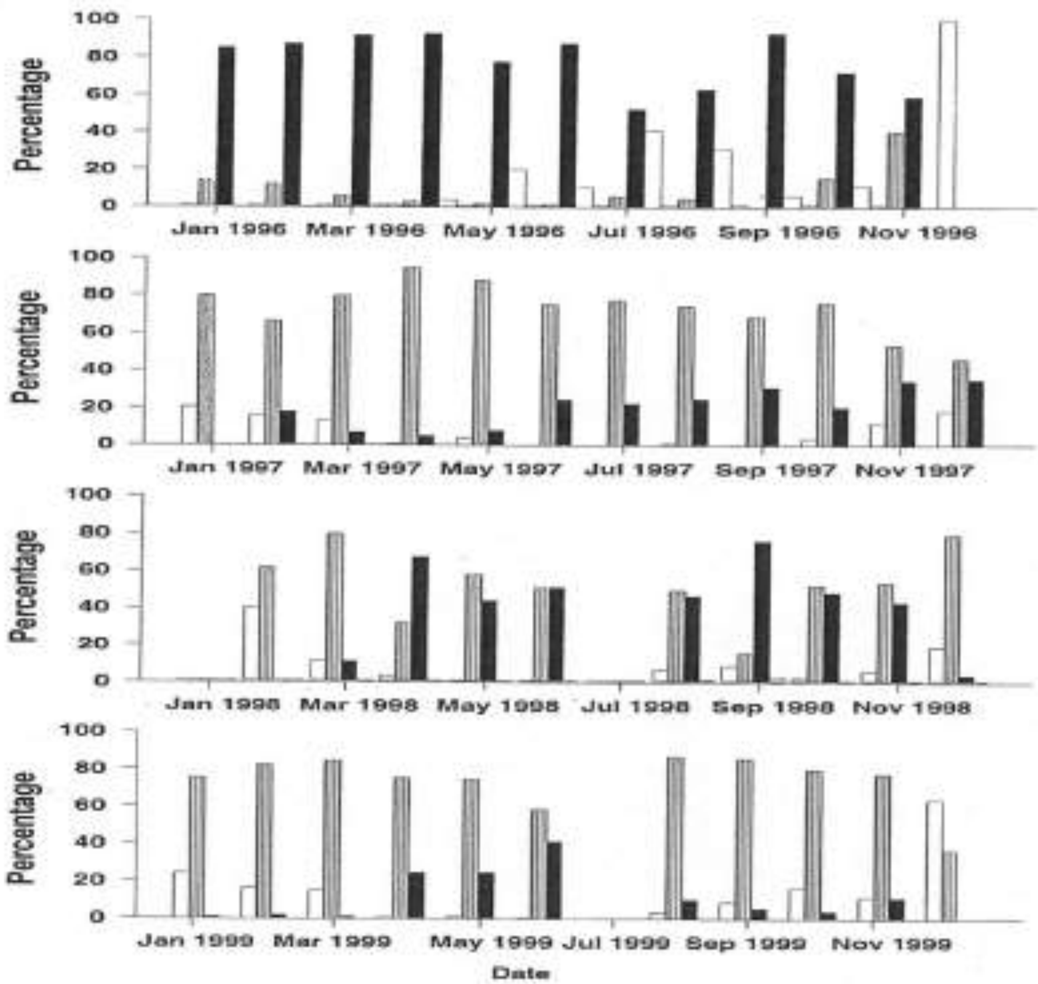

Fig. 10. Percentage contribution of different age-classes of *T. ilisha* to recruitment from 19996 to 1999 (white = age 0+, dotted = age 1+, black = age 2+, stippled = age 3+).

The above data are based on mean values. However, the situation becomes more complex when Sr values across the otoliths of individual fish from Cox's Bazar and Chandpur are examined.

Plots of single fish captured at Chandpur (riverine) and Cox's Bazar (marine) are shown in Fig. 12. These suggest that there is little consistency in movement patterns, with some fish moving in one direction and others in another. It does appear, however, that most fish visit both marine and estuarine or freshwater areas during their first 2 years of life.

Discussion

A large number of studies have investigated reproductive aspects of hilsa give conflicting results which showed that the size and age at sexual maturity varied between, for example, 16 cm and 1 year of age in the Hooghly River, India, to 40 cm and 4 years age in the Meghna River in Bangladesh, as summarized by Raja, 1985 (Pillay, 1958; Dunn, 1982). BFRI studies show that hilsa reaches maturity at 20 cm SL or less (1 year old) and can spawn at this size. Until the present study, histology had not been used to verify the sexual status of fish, and so these differences in results may simply be related to interpretation of gonad stages. The fecundity values from this study are similar to those from India (Raja, 1985) and vary between 0.1 and 2 million eggs per fish per spawning.

Present study cannot confirm whether hilsa *T. ilisha* in Bangladesh spawn more than once a year. In India, Pillay (1958) and Swarup (1959) suggested that fish spawn several batches of eggs during a spawning season, but De (1980) and Ramakrishnaiah (1972) found that *T. ilisha* only spawn once per season. In Bangladesh, three earlier conflicting studies have found that (a) each hilsa spawns intermittently throughout the year (Shafi *et al*., 1978) or (b) that spawning in the Meghna River takes place in only October and November (Moula *et al*., 1991) or (c) two morphs spawn at different times of the year (September and February) (Quddus *et al*., 1984a). No study has unequivocally determined whether fish spawn more than once a year, although earlier workers believed that separate stocks are involved in the monsoon and winter spawning events (Ghosh and Nangpal, 1970; Quddus, 1982). However, evidence from present genetic and otolith chemistry studies (Milton and Chenery, 2001; Salini *et al*., 2001) shows that hilsa in Bangladesh belong to a single well-mixed stock, lending support to the hypothesis that they may spawn more than once a year.

The otolith microchemistry and reproductive data from the present study indicate that hilsa spawn throughout the freshwater, estuarine and marine areas of Bangladesh (Fig. 6). Previously it was generally believed that spawning was confined to freshwater mainly in the rivers, and that fish ascend the rivers to spawn during the monsoon (July-September) (Pillay, 1958; Raja, 1985). Many fish certainly do this (de Graaf *et al*., 1999), and hydrological data (Table 2) show that most areas, even coastal sites, have freshwater of very low salinities during the monsoon. However, otolith core microchemistry indicates that some fish (e.g. from Cox's Bazar) are born in middle to high salinities (Figs. 11, 12). This suggests that salinity per se may not be relevant to the location of spawning areas. Most of the documented large-scale movements of hilsa (Raja, 1985) showed a marked correlation with water temperature. The upstream movements during the monsoon (July-September) take place when water temperatures are highest inland (Fig. 2). Conversely, the movement towards the sea corresponds with a marked drop in upstream water temperature from about October; at this time sea temperatures are 3-4°C higher than riverine temperatures (Fig. 2). Previous authors indicated that spent fish and juveniles migrate back down the rivers in October to November and move into the lower reaches of the rivers and adjacent coastal waters as salinity increases (Jones, 1957; Pandit and Hora, 1951; Pillay *et al*., 1963). Given our findings, the possibility now exists that these large-scale movements may be more related to temperature or food availability, than to salinity. Whether temperature is a stimulus to spawning activity in *T. ilisha*, as it is for many other tropical species (Blaber, 2000), is unknown, but the results here certainly suggest that this may be the case.

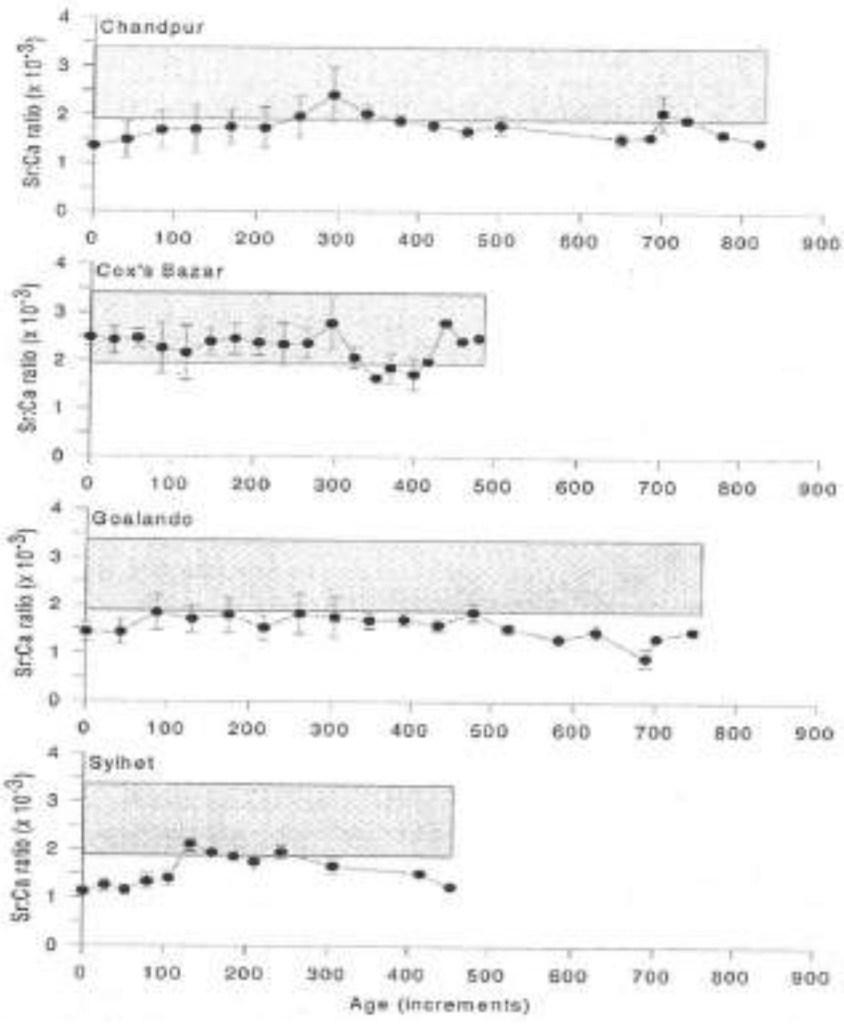

Fig. 11. Mean (±SE) Sr:Ca ratios across the otoliths of *T. ilisha* from Chandpur, Cox's Bazar, Goalanda and Sylhet. The shaded zone represents the mean minus the lower 45th percentile of the Sr:Ca ratio of marine fishes from the literature (Secor and Rooker, 2000).

Sr:Ca ratios of most ablations in the otoliths of *T. ilisha* were higher than those found in the closely related American shad Alosa sapidissima (same sub-family: Alosinae) that were spawned in freshwater (Limburg, 1995). Hilsh from both Chandpur (freshwater) and Cox's Bazar (marine) sites showed Sr:ca ratios higher than those of American shad from estuarine areas (5-18‰) in some ablations. The otolith Sr:Ca ratios and reproductive surveys indicate that the movement patterns of hilsa are both complex and variable. There is little consistency among individual fish, although there is tendency for marine fish to move towards freshwater or estuarine conditions once a year and for riverine fish to move towards the sea.

Earlier studies using tags showed that individual fish can move long distances, such as from the Hoogly River to the Meghna River (Pillay, *et al.*, 1963). There is no doubt that the species is very euryhaline and inhabits freshwater, estuarine, and coastal waters in the Bay of Bengal. Whether the species is anadromous in the true sense, as previously accepted, with all adult estuarine and marine fish migrating into the upper reaches of the rivers to spawn during the south-west monsoon (July-September) is now certainly open to question. Some fish do move in this direction, but others, both in freshwater and the sea, appear to remain in the same area throughout the year.

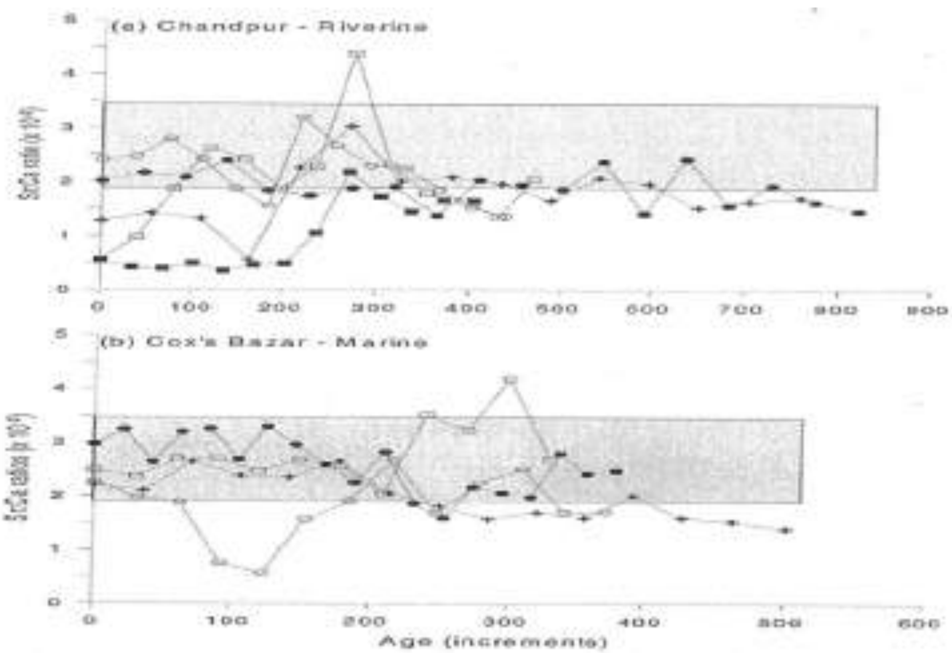

Fig. 12. Sr:Ca ratios across the otoliths of individual *T. ilisha* from (a) Chandpur (riverine) and (b) Cox's Bazar (marine). The shaded zone represents the mean minus the lower 45th percentile of the Sr:Ca ratio of marine fishes from the literature (Secor and Rooker, 2000).

The reproduction and spawning of *T. ilisha* are similar to that of the other two *Tenualosa* species that have been studied in detail (*T. toli* and *T. macrura*, Blaber *et al*., 1996; 2000) with one important difference – *T. ilisha* does not change sex. No evidence of sex change could find in *T. ilisha* in this study. It has been postulated (Blaber, 1997; 2000) that the protandrous habits of *T. toli* and *T. macrura* have rendered these species vulnerable to overfishing and led to their drastic population and geographic declines. However, *Tenualosa ilisha* is gonochoristic, much more widespread, and is the basis of very large fisheries in Myanmar, Bangladesh and India. Until very recently, its populations appear to have withstood sustained and intense fishing pressure over most of their range.

The results of age and growth studies of hilsa using annuli in scales published by many Indian and Bangladeshi authors are very inconsistent. Our study was the first to use daily ageing of otoliths and sample fish from throughout Bangladesh. Our data show quite clearly that fish attain 20 cm SL by the end of their first year and grow at similar rates to other tropical shads and clupeids (Blaber *et al*., 1996; 1998; 1999). This result accords with those of Hora and Nair (1940a,b) who stated that larval and juvenile growth is rapid with fish reaching 14 cm within 7 months and sexual maturity within 18 months. However, Quddus (1982) and Pillay and Rao (1963) indicated that fish can reach up to 35.5 cm at 1 year of age, and Dunn (1982) suggested that fish reach 15 cm in 6 months but take 5 years to reach 35 cm in Bangladesh. The only other study of age of *T. ilisha* by counting presumed annuli found that hilsa lived for up to 5 years and reached about 14 cm in 1 year and 20 cm SL by 2 years of age (Quddus *et al*., 1984b).

The absence of fish older than 4 years and a marked scarcity of 3-year-old fish in this study is probably a result of intense fishing pressure. This means that the asymptote of the growth curve could not be accurately estimated, but all previous studies seem to agree that hilsa, *Tenualosa ilisha* live at least 5 years (Raja, 1985). Most fish in their second year of life are females and almost all 2-year-old fish and 3-year-old fish are females. There is some suggestion from our study of a slightly slower growth rate for males (Fig. 8), but the absence of relatively small and old males from catches indicates that they may only live to about three years.

The overall conclusion from this study is that the population is now dominated by 1-year-old fish, whereas in the 1960s, it comprised mainly age 3 and older fish (Pillay and Rosa, 1963). This means that the probability of recruitment failure has greatly increased because 1-year-old fish now contribute most to egg production but have a relatively low fecundity (Fig. 10). This, together with the unexplained decline in female fecundity (Fig. 7) has far-reaching implications for the future of the fishery, which recorded large declines in catches in 2000 and 2001 in the freshwater. Fishing pressure needs to be reduced on the larger, more fecund fish that will increase the number of juveniles more rapidly than reducing catches of smaller 1-year-old fish. In addition, recent analysis of length-frequency data (Rahman *et al*., 2000) estimates the exploitation rate to be over 60% further indicating that current catches are unsustainable.

Acknowledgements

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Allozyme and Morphological Variation among Populations of the Hilsa Shad, *Tenualosa ilisha* throughout the geographical range

Summary

The population structure of the hilsa shad *Tenualosa ilisha* was studied with both allozymes and morphometric analysis. Fish samples were collected from nine sites within Bangladesh and compared with samples from four other countries that covered the entire range. Starch gel electrophoresis of different enzymes from liver and muscle tissues were used to investigate allozyme variation. Five polymorphic loci, Idh-I, Idh-m, Mdh-I, Mdh-m and Pgm, were interpretable in liver and muscle, although levels of variation were low. No significant differences in allele frequencies were detected within Bangladesh or within the Bay of Bengal (SE India and Myanmar) samples. Significant differences in allele frequencies occurred between Kuwait, Bangladesh and Indonesia.

Nine morphological measurements and two meristic counts were compared among the same hilsa fish for genetic analysis. Discriminant function analysis (DFA) of transformed measurement ratios varied widely between sites, even those separated by short distances (< 100 km). The results showed that hilsa vary greatly in shape and this showed little geographic cohesion. Indonesian and Indian hilsa were more distinctive than the most distant sample from Kuwait. Samples from sites in the middle and upper reaches of the Meghna River were more similar, but a single sample from north-eastern Bangladesh was distinct. Cross-validation of the classification revealed that sites in the middle reaches of the Meghna River (Chandpur, Goalanda, Bhairab Bazar) and Cox's Bazar had less than half the fish correctly classified to their origin. Fish from other countries were much more distinctive. So, morphological results reflect local environmental conditions rather than any population level differences. The allozyme results indicate that there is substantial gene flow between groups of hilsa within the Bay of Bengal. This means that there is a need for Bangladesh to take into account actions and management decisions in India and Myanmar in order to sustainably manage the fishery.

Introduction

Hilsa, *Tenualosa ilisha*, is a large, anadromous fish occurs in the large river systems of southern Asia from the Arabian Gulf to Myanmar and northern Sumatra. It supports a large fishery that is very important to Bangladesh comprising 75% of the total world catches of this species (Raja, 1985). However, little is known about the population structure of the species across its range although extensive biological studies have been carried out in India and Bangladesh (Pillay and Rosa, 1963; Dunn, 1982; Melvin, 1984; Raja, 1985).

Early studies of population structure of hilsa in Bangladesh using morphometric and meristic traits, identified between two and four populations that overlap in at least part of their range (Pillay *et al*., 1963; Quddus *et al*., 1984; Rahman and Moula, 1992; Rahman *et al*., 1997). More recently, studies with allozymes (Rahman *et al*., 1997; Rahman and Naevdal, 1998) and RAPD DNA methods (Dahle *et al*., 1997) have compared samples from three or four sites, respectively. These studies also found some population structuring and suggested that the marine and riverine fish are genetically distinct.

Hilsa is a migratory fish, mainly spawn in freshwater during both the monsoon (June-October) and dry season (January-April) (Jenkins, 1938; Hora, 1941; de Graaf *et al*., 1999). They are fished throughout most of the lower and middle Meghna River (up to 400 km inland), coastal and offshore marine waters during the year. In a new study of BFRI, Milton and Chenery (2001) examined hilsa population structure in Bangladesh from the variation in the trace metal composition in the cores of their otoliths. Their data confirmed that a large proportion of hilsa collected in freshwater and in the sea had been born in the other habitat, confirming that the populations within Bangladesh move widely between these areas. This suggests that identifiable, discrete populations within Bangladesh are unlikely, despite the genetic differences detected among the few sites sampled in previous studies. The aims of this study were to examine the population genetic structure of hilsa from throughout its range, focusing on Bangladesh, and compare the population structure from the genetic studies and the complementary otolith microchemistry study.

Materials and Methods

Sample collection and preparation

Random samples of hilsa were collected directly from local markets throughout Bangladesh (Fig. 1). Fish from markets were only taken where the site of capture was known. For the Allozyme study, Chandpur was sampled three times. Morphometric samples were usually a subset of up to 30 fish from the allozyme samples. Once purchased, Bangladeshi fish were iced, transported to the laboratory and stored at -20°C until processed. Samples from India, Indonesia, Kuwait and Myanmar were obtained as whole frozen fish and processed in Australia. Sample sizes, collection dates and locations are listed in Table 1.

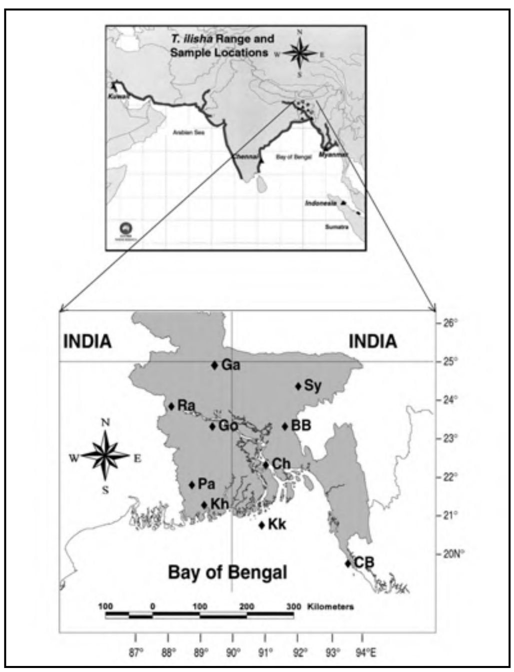

Fig. 1. Location of sample sites from Kuwait, Chennai (Parangapettai, India), within Bangladesh (expanded area), Myanmar (Yangon) and Indonesia (north east Sumatra = Labaun Bilik), Ga: Gaibandha; Ra = Rajshahi; Sy: Sylhet; Go: Goalanda; Bhairab Bazar; Ch: Chandpur; Pa: Paikgacha; Kh: Khulna; Kk: Kuakata; CB: Cox's Bazar.

Table 1. Details of the collection sites within Bangladesh and other countries, dates and sample sizes for both the morphological and genetic analyses (Labuan Bilik is in north-east Sumatra).

Country	Sites	Date	Morphology	Genetics
Bangladesh	Bhairab Bazar	August 1997	30	80
Bangladesh	Chandpur	July 1996	36	20
Bangladesh	Chandpur	October 1996	30	39
Bangladesh	Chandpur	August 1997	-	70
Bangladesh	Cox's Bazar	July 1996	43	82
Bangladesh	Cox's Bazar	August 1997	30	49 (no activity)
Bangladesh	Cox's Bazar	August 1998	53	No tissues
Bangladesh	Gaibandha	August 1997	32	58
Bangladesh	Goalanda	July 1996	32	33 (poor activity)
Bangladesh	Goalanda	October 1996	51	69
Bangladesh	Khulna	October 1996	28	67
Bangladesh	Kuakata	October 1996	22	No tissues
Bangladesh	Paikgacha	August 1997	30	80
Bangladesh	Rajshahi	August 1997	30	80
Bangladesh	Sylhet	May 1999	30	101
India	Parangapettai	August 1998	28	52
Indonesia	Labuan Bilik	November 1996	21	33 (no activity)
Indonesia	Labuan Bilik	April 1997	33	33
Kuwait	Kuwait City	May 1996	45	47
Myanmar	Yangon	August 1998	30	36

In the laboratory, morphometric and meristic traits were measured or counted prior to dissection of about one gram of white muscle, heart, liver and eye (whole) tissues. Only liver and muscle were collected for most samples after initial screening of tissues revealed variable loci could be scored without eye and heart muscle. About one gram of dissected tissue was placed into small, 1.5 ml plastic tubes and 3-5 drops of homogenizing buffer (0.1M Tris, 0.1M EDTA, 50µ M NADP+, pH 7.0) were added to the samples. The vials were transferred to liquid nitrogen until the electrophoretic laboratory was reached, where the samples were then kept at -196°C.

Electrophoresis

Gels were made with 10% potato starch (StarchArt, USA) in a specific buffer solution. Before each gel run, tissues were partially thawed, then centrifuged at 10,000 g for a few minutes at

4°C. Supernatant was soaked onto paper wicks of about 2-3 mm width, allowing 45 samples per gel. The rest of the electrophoretic protocol and histochemical staining used in this study followed Shaklee and Keenan (1986), Aebersold *et al.,* (1987) and Whitmore (1990).

Thirty-five specific enzymes were examined during the initial survey to identify allelic variation. Five buffer systems were used to obtain optimum resolution of enzyme stains. Ten enzymes had insufficient activity to be scored reliably. The remaining 25 enzymes yielded information on 42 loci. Locus designations follow Shaklee *et al.* (1990). Of these 25 enzymes, G6PDH, PGDH, AH, AAT, FH and Haemoglobin, proved either unscoreable or inconsistent in their activity. Five variable loci were successfully screened using both TC-1 (0.135M Tris, 0.043M citric acid monohydrate pH 7) and TM (0.10M Tris, 0.1M Maleic acid, 0.01M Disodium EDTA, 0.01M MgCl, NaOH adjusted to pH 7.4 with NaOH) buffers to optimize allele resolution. The most common allele at each locus was assigned a relative mobility of 100 and the mobility of all other alleles was calculated relative to this allele.

Statistical analysis

All genetic analyses were undertaken with the "Genes in populations" version 2 programs (May and Krueger, 1995) and allele pooling followed the procedures included in the software. During early screening of the Goalanda, Cox's Bazar, Khulna and Kuwait samples, the medium fast Idh-I allele (relative mobility 108 on TC-1) and the medium slow Pgm allele (relative mobility 64 on TC-1) were not distinguished and so they were pooled into the nearest allele for analyses. Observed and expected genotypic proportions were tested for agreement with Hardy-Weinberg equilibrium using a log-likelihood ratio G-test (Sokal and Rohlf, 1981). Coefficients of inbreeding values, F_{st} (Wright, 1965) and G statistics (Sokal and Rohlf, 1981) calculated by "genes in populations" (May *et al.,* 1995) were tested for significant deviations from zero and from expected values. Initially, data from all sites were compared to see if there was significant genetic heterogeneity among sites. Then a series of adjacent pair wise comparisons were conducted, where appropriate, with Sidak's multiplicative inequality correction for P (0.05).

Morphometric and meristic measurements

Eleven morphological and two meristic characters were measured (± 0.1 mm) on at least 30 fish from each sample. These were standard length (SL), head length (HL), snout length (SnL), horizontal eye diameter (ED), inter-orbit cross-section (IOS), maxilla length (ML), body cross-section (BXS), body depth (BD) (both at dorsal fin origin), pelvic fin-anus distance (PA), caudal peduncle height (CPH), caudal peduncle length post-anal fin to tail length (CPL), pectoral fin rays (PFR), post-pelvic scutes (PPS) (Fig. 2).

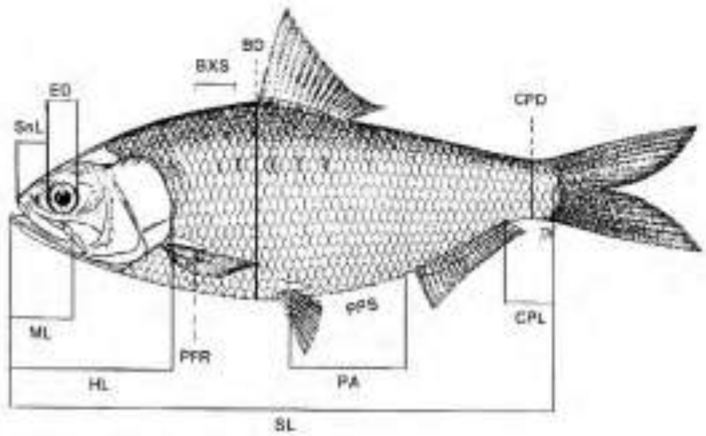

Fig. 2. Morphological characters measured. (SL= Standard length, HL= Head length, SnL = Snout length, ED = Eye diameter horizontal, ML= Maxilla length, BXS = Body cross-section, BD = Body depth, PA = Pelvic fin-anus distance, CPD = Caudal peduncle height, CPL= Post anal fin-tail length).

These measurements were chosen to facilitate comparisons with previous studies of hilsa morphometrics in Bangladesh (Quddus *et al*., 1984; Rahman *et al*., 1997). Most of these measurements were significantly correlated with size, so each measure was adjusted by the following allometric equation $\hat{Y} = aX^b$ such that the standardized value of this variable in the case of an individual of size Xi would be $Yi^* = Yi\ [X_0/X_i]^b$ where, Yi is the true value of the variable Y, Yi* is the standard value and Xo is an arbitrary reference size (300 mm SL). This method normalizes the individuals in a sample to a single, arbitrary size, common to all samples, but maintains the individual variation (Tudela, 1999). Finally, the data were analyzed with the principal component analysis (PCA) and the correlation between the first three factors of the PCA and the length (SL) were also examined but found to be insignificant (all $P > 0.78$).

The degree of similarity among samples in the overall analysis and the relative importance of each measurement for group separation were assessed by stepwise discriminant function analysis with cross-validation. The standardized morphometric measurements of fish from Bangladesh were also plotted to see if there was any evidence of hilsa showing the 'fat' and 'thin' shapes identified by Quddus *et al.,* (1984).

Results

Allozymes

Genetic variation was detected in 5 loci, Idh-m (muscle), Idh-1 (liver), Mdh-m (muscle), Mdh-1 (liver), and Pgm (liver/muscle), although Idh-m could not always be scored from all samples. Only one locus, Pgm, was polymorphic within Bangladesh at the 0.95 level, but all five loci were polymorphic at the 0.99 level (Table 2). The samples from Kuwait, India, Indonesia, and Myanmar, were polymorphic at the 0.95 level for all loci except Mdh-1, which was monomorphic (Table 3).

Table 2. Allele frequencies for all Bangladesh sites, the Chandpur replicate samples that were pooled[a].

Locus	Allele	Pop 1	Pop 2	Pop 3	Pop 4	Pop 5	Pop 6	Pop 7	Pop 8	Pop 9
IDH-m	1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.987	1.000
	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000
	Ho	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000
	Hs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000
	Fis	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.013	0.000
	N	95	81	19	64	75	43	80	76	99
IDH-1	1	0.984	0.986	0.990	0.965	0.994	0.991	0.994	1.000	1.000
	2	0.004	0.014	0.000	0.009	0.000	0.000	0.000	0.000	0.000
	3	0.012	0.000	0.010	0.026	0.006	0.009	0.006	0.000	0.000
	Ho	0.033	0.000	0.020	0.070	0.013	0.019	0.013	0.000	0.000
	Hs	0.032	0.027	0.020	0.068	0.012	0.019	0.013	0.000	0.000
	Fis	-0.013	1.000	-0.010	-0.029	-0.006	-0.010	-0.006	0.000	0.000
	N	123	74	49	57	80	53	79	71	58
MDH-m	1	0.994	1.000	1.000	1.000	0.979	1.000	1.000	0.994	0.995
	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.005
	4	0.006	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000
	Ho	0.013	0.000	0.000	0.000	0.043	0.000	0.000	0.013	0.010
	Hs	0.013	0.000	0.000	0.000	0.042	0.000	0.000	0.012	0.010
	Fis	-0.007	0.000	0.000	0.000	-0.022	0.000	0.000	-0.006	-0.005
	N	77	75	64	70	70	39	80	80	99
MDH-1	1	1.000	0.994	1.000	1.000	0.988	0.991	1.000	0.994	1.000
	2	0.000	0.006	0.000	0.000	0.006	0.009	0.000	0.006	0.000
	3	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000
	Ho	0.000	0.012	0.000	0.000	0.025	0.018	0.000	0.013	0.000
	Hs	0.000	0.012	0.000	0.000	0.025	0.017	0.000	0.013	0.000
	Fis	0.000	-0.006	0.000	0.000	-0.009	-0.009	0.000	-0.006	0.000
	N	128	81	65	70	80	57	80	78	59
PGM	1	0.938	0.963	0.954	0.955	0.949	0.930	0.969	0.925	0.955
	2	0.031	0.031	0.046	0.045	0.051	0.035	0.000	0.038	0.020
	3	0.000	0.006	0.000	0.000	0.000	0.000	0.006	0.000	0.000
	5	0.031	0.000	0.000	0.000	0.000	0.035	0.025	0.038	0.025
	Ho	0.094	0.062	0.092	0.091	0.101	0.140	0.063	0.150	0.089
	Hs	0.119	0.072	0.088	0.087	0.096	0.133	0.061	0.142	0.086
	Fis	0.213	0.139	-0.048	-0.048	-0.053	-0.056	-0.027	-0.060	-0.035
	N	128	81	65	66	79	57	80	80	101
	Avg Hs	0.033	0.022	0.022	0.031	0.035	0.034	0.015	0.039	0.019
	S.E.	0.022	0.013	0.017	0.019	0.017	0.025	0.012	0.026	0.017
	Avg Ho	0.028	0.015	0.023	0.032	0.036	0.035	0.015	0.040	0.020
	S.E.	0.018	0.012	0.018	0.020	0.018	0.027	0.012	0.028	0.017

[a] Pop 1= Chandpur, Pop 2= Cox's Bazar, Pop 3= Khulna, Pop 4= Goalanda, Pop 5= Rajshahi, Pop 6= Gaibandha, Pop 7= Paikgacha, Pop 8= Bhairab Bazar, Pop 9= Sylhet.

Table 3. Allele frequencies for the four collections across the species range and the pooled Bangladesh collections[a].

Locus	Allele	Bangladesh	Kuwait	Indonesia	India	Myanmar
IDH-m	1	0.998	0.943	-	1.000	1.000
	2	0.002	0.057	-	0.000	0.000
	Ho	0.003	0.068	-	0.000	0.000
	Hs	0.003	0.107	-	0.000	0.000
	Fis	-0.002	0.364	-	0.000	0.000
	N	632	44	0	47	35
IDH-1	1	0.989	1.000	0.803	0.989	1.000
	2	0.003	0.000	0.182	0.011	0.000
	3	0.008	0.000	0.015	0.000	0.000
	Ho	0.018	0.000	0.394	0.022	0.000
	Hs	0.021	0.000	0.322	0.022	0.000
	Fis	0.135	0.000	-0.224	-0.011	0.000
	N	649	27	33	45	36
MDH-m	1	0.995	0.872	0.894	1.000	1.000
	2	0.002	0.117	0.106	0.000	0.000
	4	0.003	0.011	0.000	0.000	0.000
	Ho	0.009	0.255	0.212	0.000	0.000
	Hs	0.009	0.225	0.190	0.000	0.000
	Fis	-0.004	-0.134	-0.119	0.000	0.000
	N	654	47	33	50	36
MDH-1	1	0.996	1.000	1.000	1.000	1.000
	2	0.003	0.000	0.000	0.000	0.000
	3	0.001	0.000	0.000	0.000	0.000
	Ho	0.007	0.000	0.000	0.000	0.000
	Hs	0.007	0.000	0.000	0.000	0.000
	Fis	-0.003	0.000	0.000	0.000	0.000
	N	698	47	33	49	36
PGM	1	0.984	0.745	0.848	0.943	0.944
	2	0.032	0.255	0.152	0.023	0.028
	3	0.001	0.000	0.000	0.000	0.000
	5	0.018	0.000	0.000	0.034	0.028
	Ho	0.096	0.426	0.303	0.114	0.111
	Hs	0.099	0.380	0.257	0.109	0.106
	Fis	0.028	-0.119	-0.179	-0.045	-0.043
	N	737	47	33	44	36
	Avg Hs	0.028	0.143	0.154	0.026	0.021
	Std err	0.018	0.073	0.066	0.021	0.021
	Avg Ho	0.027	0.150	0.182	0.027	0.022
	S.E.	0.018	0.083	0.080	0.022	0.022

[a] To compare the Kuwait sample with the other collections, alleles 1 and 4 at Idh-1 and alleles 2 and 4 at Pgm were pooled. Idh-m was not scored from the Indonesian sample.

[b] Ho: average heterozygosity observed; Hs: average heterozygosity expected; Fis: deviation from random mating.

Comparisons of allele frequencies among the replicate Chandpur samples and among all Bangladesh samples showed no significant differences for any loci. The Chandpur samples were collected in July and October 1996 and August 1997 showed no evidence for temporal differences over 1 year. The Pgm locus showed weak evidence of heterogeneity between populations at $P<0.05$ but was not significant after applying Sidak's multiplicative inequality (Genes in populations) and Bonferroni corrections (GENEPOP). The pooled Bangladesh sample was then compared with the samples from other countries and showed strongly significant heterogeneity at four of the five loci (Table 4). Samples from Indonesia and Kuwait were significantly different from Bangladesh, India and Myanmar ($P<0.001$). Bangladesh, India and Myanmar were not significantly different from each other and suggesting that the Bay of Bengal comprised a single population (Table 4).

Within Bangladesh, average heterozygosity, H_o, was 0.05±0.03, was not significantly different across countries H_o, 0.10±0.04, but the differences reflect the relatively low levels of variation within Bangladesh compared to other countries (Table 2). The same pattern occurred for indices of fixation within Bangladesh, average $F_{st} = 0.002$, and across countries, $F_{st} = 0.07$, which indicates the reduced flow of alleles outside Bangladesh. High gene flow within Bangladesh probably reflects the geographically close proximity of sites and high mobility of hilsa.

Table 4. Table of F_{st} values for country comparisons (Bangladesh vs Bay of Bengal samples, stock boundary F_{st} comparisons Kuwait vs Chennai, Indonesia vs Myanmar or Bangladesh, Chennai vs Bangladesh vs Myanmar homogeneity test results).

Comparisons	*F*st	P (overall)	Significant Locia
Within Bangladesh	0.007	ns	ns
Bangladesh vs Myanmar	0.001	ns	ns
Bangladesh vs India	0.005	ns	Pgm
Myanmar vs India	0.014	ns	ns
Bangladesh vs Indonesia	0.05	0.001	Idh-1, Mdh-m, Pgm
Kuwait vs India vs Bangladesh vs Indonesia	0.085	0.001	Idh-1, Mdh-m, Pgm
Kuwait vs Indonesia	0.033	0.001	Idh-1
Kuwait vs Bangladesh	0.069	0.001	Idh-1, Mdh-m, Pgm
Kuwait vs Myanmar	0.078	0.001	Idh-m, Idh-1, Mdh-m, Pgm
Kuwait vs India	0.072	0.001	Idh-m, Mdh-m, Pgm

The relationships between homogenous samples were tested with F_{st} tests across all loci. These samples included pooled Bangladesh samples and Kuwait, Chennai (south-eastern India), Myanmar and Indonesia (north-eastern Sumatra). Kuwait and Indonesia were significantly different from each other and from Bangladesh, Chennai and Myanmar. Chennai and Myanmar were not significantly different from Bangladesh or from each other for all loci. However, Idh-l was significantly different for the Myanmar and Bangladesh per locus comparison. Despite this, the data suggest that the Bay of Bengal, including Chennai, Bangladesh and Myanmar was genetically homogenous.

With genetic homogeneity within the Bay of Bengal, a measure of isolation by distance was calculated. Values of F_{st} for all combinations of nine sites, Kuwait, Chennai (India), Paikgacha, Aricha Ghat, Rajshahi, Gaibandha, Chandpur, Bhairab Bazar, Cox's Bazar (Bangladesh), Myanmar and north-eastern Sumatra (Indonesia), were plotted against the closest geographic distance between sites. This test of 'isolation by distance' uses the Mentel test as described in GENEPOP (Raymond and Rousset, 1995). For all sites, these distances ranged from 100 (Chandpur to Bhairab Bazar) to 3,800 km (Kuwait to Chennai, India). Distances to Kuwait from Cox's Bazar, Myanmar and Sumatra were taken as direct paths over the Bay of Bengal. The correlation was highly significant: $r^2 = 0.46$, $P < 0.001$, N = 36 comparisons (Fig. 3).

Morphometrics and Meristics Analysis

The nine morphological measurements showed wide variation between samples even after standardization. Mean head length varied from 81 mm at Khulna to 96 mm at Sylhet (Table 5). The two meristic counts showed little variation between sites and the ranges overlapped across the entire range (Table 3). Given this result, the meristic counts were not included in subsequent analyses. Fish from Myanmar had lower counts of both pelvic fin rays and pre-pelvic scutes than other samples. The median value and the means of the two counts varied among sites but all sites had counts within the same range.

The first two principal components explained 56% of the variation between sites in Bangladesh (Table 6). The caudal peduncle height (CPH) had the highest loading on PC 1 and body cross- section (BXS) had the highest loading on PC 2 (Table 6). There were highly significant differences between sites on both components ($P<0.0001$) and sex was significant on PC 1 ($F_{1,446} = 4.3$; $P<0.05$). Plots of the 95% CI of each site on each component showed that the fish from many sites separated (Fig. 4). There was separation between repeated samples from three sites where multiple samples were taken (Cox's Bazar, Chandpur and Goalanda). These samples tended to group with samples from other sites sampled at the same time. From morphometric and meristic analysis, six site groups were identified in Bangladesh (Fig. 5).

The two sites in north-eastern Bangladesh (Bhairab Bazar and Sylhet) separated strongly from other sites (Cox's Bazar, Chandpur and Goalanda) on both components.

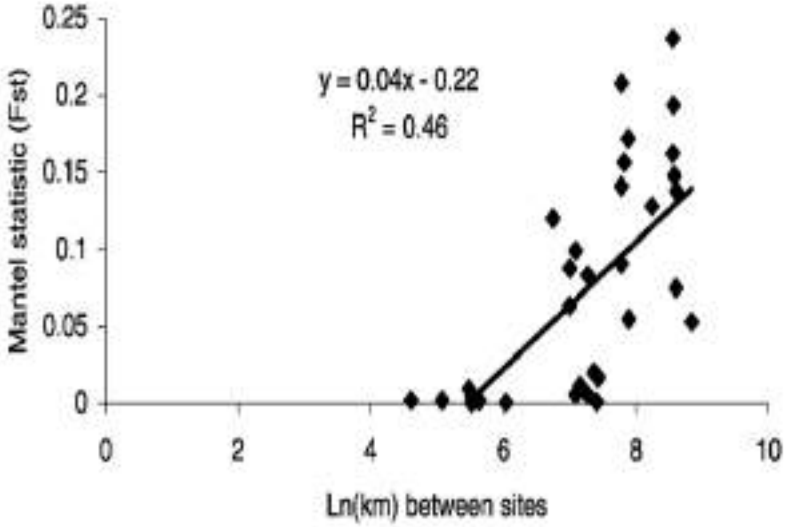

Fig. 3. Relationship between estimates of F_{st} and the relative distance between sites using the Mantel test for isolation by distance (Raymond and Rousset, 1995), P <0.001. Nine sites were compared in all possible ways (35 estimates): Kuwait, India, Paikgachha (Paikgachha and Khulna), Goalanda (Goalanda, Rajshahi and Gaibhanda), Chandpur, Bhairab Bazar, Cox's Bazar, Myanmar, Indonesia (Sumatra). Calculated in GENEPOP using F_{st} option 2, then option 5 to calculate Mantel values, used 200 permutations.

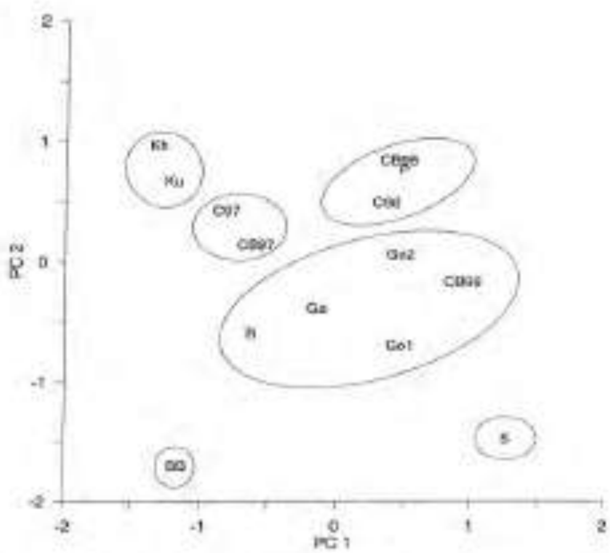

Fig. 4. Plot of the 95% confidence ellipse of the first two principal components of hilsa samples from Bangladesh based on nine standardized morphometric measurements. Site groups within each ellipse are not statistically significantly different (P <0.10) (BB: Bhairab Bazar, August 1997; C96: Chandpur, October 1996; C97: Chandpur, August 1997; CB96: Cox's Bazar, October 1996, CB97: Cox's Bazar, August 1997, CB98: Cox's Bazar, August 1998; Go1: Goalanda, July 1996; Go2: Goalanda, October 1996; Ga: Gaibandha, August 1997; Kh: Khulna, July 1996; Ku: Kuakata, July 1996; P: Paikgachha, August 1997; R: Rajshahi, August 1997; S: Sylhet, May 1999).

Table 5. The mean ± SE of the standardized morphometric measurements (in mm) of hilsa from throughout the species' range[a].

Country	Site	Date	SL	HL	SnL	IOX	ML	BXS	BD	PA	CPH	CPL	n
BD	Bhairab Bazar	Aug 97	213±3	87.0±0.4	21.1±0.2	22.9±0.2	34.5±0.3	36.0±0.4	82.5±0.9	63.9±0.4	25.3±0.1	24.8±0.3	30
	Chandpur	Oct 96	300±10	86.8±0.4	20.0±0.2	27.9±0.2	35.4±0.3	45.4±0.5	99.8±1.0	71.9±0.7	26.2±0.2	25.3±0.3	36
		Aug 97	349±11	83.5±0.5	19.4±0.2	25.9±0.2	33.3±0.2	44.5±0.5	96.1±1.1	66.9±0.7	24.3±0.3	25.3±0.4	30
	Cox's Bazar	Jul 96	249±6	88.7±0.4	21.7±0.2	25.8±0.3	36.6±0.2	44.4±0.4	101.2±0.8	73.7±0.6	26.5±0.2	28.2±0.3	43
		Aug 97	265±8	84.5±0.5	19.4±0.2	24.8±0.4	34.7±0.3	43.3±0.6	95.7±0.6	71.0±0.5	24.2±0.2	25.5±0.3	30
		Aug 98	387±8	84.8±0.4	21.7±0.3	25.0±0.2	34.2±0.3	45.4±0.5	106.0±0.9	74.1±0.6	26.5±0.2	25.9±0.5	53
	Gaibandha	Aug 97	228±9	85.7±0.3	20.9±0.2	28.3±0.2	35.3±0.2	43.5±0.4	90.3±0.6	67.4±0.6	25.1±0.2	26.9±0.3	32
	Goalanda	Jul 96	327±9	89.3±0.7	21.3±0.3	27.9±0.4	35.9±0.3	43.2±0.4	91.9±0.8	68.6±0.7	26.4±0.2	28.2±0.6	32
		Oct 96	246±8	87.7±0.3	21.4±0.3	28.4±0.2	35.3±0.3	44.9±0.4	95.6±0.7	70.9±0.7	26.4±0.2	26.0±0.3	51
	Khulna	Oct 96	308±5	81.2±0.5	18.0±0.2	24.2±0.3	32.8±0.3	45.1±0.5	95.1±0.9	67.0±0.8	25.1±0.2	22.1±0.4	28
	Kuakata	Oct 96	335±12	83.2±0.5	18.7±0.2	24.2±0.4	34.0±0.3	45.3±0.7	95.4±0.8	66.7±0.8	24.4±0.2	20.6±0.4	22
	Piakgacha	Aug 97	322±6	85.2±0.4	21.3±0.2	27.5±0.2	34.9±0.2	47.6±0.4	100.6±0.7	72.2±0.5	26.2±0.2	26.1±0.3	30
	Rajshahi	Aug 97	274±12	85.0±0.5	20.4±0.2	26.1±0.2	34.9±0.2	40.8±0.4	88.5±0.8	68.4±0.6	24.8±0.2	26.0±0.4	30
	Sylhet	May 99	168±5	95.7±0.5	22.0±0.2	23.9±0.3	37.5±0.3	43.0±0.5	101.0±0.8	69.6±0.9	26.1±0.3	31.9±0.4	30
IN	Parangapettai	Aug 98	327±5	88.8±0.3	21.6±0.2	27.0±0.2	37.6±0.2	48.1±0.4	103.2±1.0	75.6±0.9	26.9±0.2	27.9±0.3	28
ID	Labuan Bilik	Nov 96	258±3	85.7±0.4	19.6±0.2	24.6±0.3	34.3±0.3	44.6±0.4	101.9±0.8	66.3±0.8	28.5±0.2	26.6±0.3	21
		Apr 97	316±6	84.0±0.4	18.5±0.2	25.7±0.3	34.0±0.2	45.5±0.4	102.1±0.9	70.7±0.7	27.6±0.1	25.7±0.3	33
KUW	Kuwait City	May 96	305±5	87.0±0.3	20.8±0.2	23.5±0.2	36.7±0.2	43.3±0.3	98.7±0.5	67.6±0.5	26.5±0.2	27.7±0.3	45
MYR	Yangon	Aug 98	414±5	86.0±0.5	20.2±0.2	33.7±0.3	36.3±0.2	51.1±0.3	120.1±0.9	68.8±0.6	27.5±0.2	28.7±0.2	30

[a] (BD = Bangladesh; IN = India; ID = Indonesia; KUW = Kuwait; MYR = Myanmar; Chand = Chandpur; Cox's Bazar; Goal = Goalanda; Labuan B = Labuan Bilik).

Table 6. The standardized principal component coefficients of each morphometric measurement on the first two components, their eigen values and the variance explained by each.

Character	Bangladesh sites		All sites	
	PC 1	PC 2	PC 1	PC 2
Head length (HL)	0.21	-0.30	0.19	0.33
Snout-length (SnL)	0.20	-0.16	0.16	0.25
Distance between eyes (IOX)	0.14	0.10	0.15	-0.17
Snout-jaw length (ML)	0.21	-0.25	0.21	0.26
Body width (BXS)	0.14	0.37	0.19	-0.34
Body depth (BD)	0.20	0.30	0.23	-0.27
Pelvic-anus length (PA)	0.18	0.21	0.17	-0.10
Caudal peduncle height (CPH)	0.22	0.10	0.21	-0.11
Caudal peduncle length (CPL)	0.20	-0.19	0.20	0.17
Eigen value	3.04	1.97	2.99	1.98
Variance explained (%)	34	22	33	22

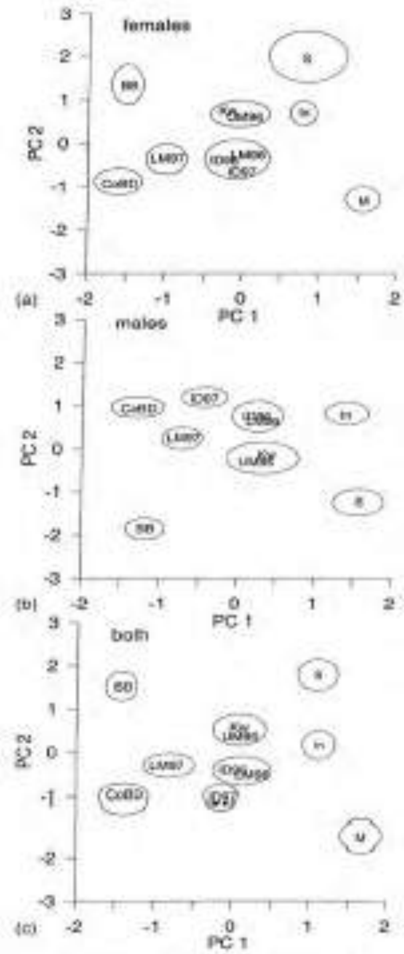

Fig. 5. Plot of the 95% confidence ellipse of the first two principal components of (a) females, (b) males and (c) both in hilsa site groups from Bangladesh and samples from elsewhere within the species' range based on nine standardised morphometric measurements. Site groups within each ellipse are not statistically significantly different ($P > 0.10$); site abbreviations as in Fig. 4 legend.

These six site groups were included in a second analysis that covered all sites examined. The first two components explained 55% of the variation between the site-groups. Both site-group and sex were significant on PC 1 (site group: $F_{10,610} = 67.7$; $P < 0.0001$, sex: $F_{1,610} = 7.3$; $P < 0.01$), but their interaction was not ($P > 0.28$). Only site group was significant on PC 2 ($F_{10,610} = 84.7$; $P < 0.0001$). Body depth (BD) and body cross-section (BXS) had the highest loadings on PC 1 and 2 (Table 6).

Most site-groups could be separated with discriminant analysis of the morphometric measurements. The overall percentage re-classification by cross-validation was high (83% correctly classified) but three of the ten site groups has less than 70% of the fish correctly classified. These site-groups all contained fish from the Meghna River and adjacent marine populations in Bangladesh (Table 7). Fish from these site groups tended to be misclassified among themselves. By comparison, fish from the sites in different countries, India, Indonesia, Kuwait and Myanmar were more morphologically distinct. Within Bangladesh, Sylhet, in north-eastern Bangladesh on the Meghna River had the highest proportion of correctly classified hilsa, 100% (Table 7).

Table 7. Cross-validation classification results of discriminant function analysis of the nine standardized morphometric measurements at six groups in Bangladesh and five sites in other countries throughout the species' range (% assigned to collection site in brackets)[a].

Collection sites	Cross-validation classification											
	BB	**LM96**	**LM97**	**UM96**	**CoBD**	**Sy**		**ID96**	**ID97**	**Kw**	**M**	**n**
Bhairab Bazar (BB)	29 (97)	0	0	0	0	0	0	0	0	1	0	30
Lower Meghna R (LM96)	1	65 (55)	12	16	4	0	8	2	10	2	1	119
Lower Meghna R (LM97)	0	7	39 (65)	3	5	0	1	0	2	3	0	60
Upper Meghna R (UM96)	6	21	10	119 (63)	1	3	8	4	4	12	1	188
Coastal Bangladesh (CoBD)	0	0	7	0	40 (80)	0	0	0	2	1	0	50
Sylhet (**Sy**)	0	0	0	0	0	27 (100)	0	0	0	0	0	27
India (**In**)	0	0	0	0	0	1	25 (89)	0	0	3	0	28
Indonesia Nov 96 (**ID96**)	0	0	0	0	0	0	0	16 (76)	5	0	0	21
Indonesia Apr 97 (**ID97**)	1	0	0	0	0	0	0	2	30 (91)	0	0	33
Kuwait (**Kw**)	0	2	1	0	0	1	3	1	1	32(71)	0	45
Myanmar (**M**)	0	0	0	0	0	0	0	0	0	0	30 (100)	30
TOTAL	37	95	69	138	50	32	45	25	54	54	32	631

[a] Codes of sites outside Bangladesh are shown in bold capitals and samples included in each site group are given in the caption to Fig.

Discussion

In this study, little evidence was found of having more than one genetic population of hilsa in Bangladesh or within the Bay of Bengal region. This supports the results of a parallel study of BFRI on the otolith core chemistry of the same fish (Milton and Chenery, 2001b). The levels of genetic isolation in hilsa within Bangladesh were low (F_{st} = 0.002) compared to that for more geographically distant sites outside Bangladesh (F_{st} = 0.07). However, they are similar to values of F_{st} for most marine fish (Gyllensten, 1985; Ward *et al*., 1994). Ward *et al.*, calculated an average F_{st} for 57 marine species of 0.062 and for seven anadromous species was 0.108, compared to an overall F_{st} of 0.07 in this study. Hilsa is anadromous and shows less genetic isolation than these published values. When compared to catadromous species *Lates calcarifer* in northern Australia (F_{st} = 0.08), the F_{st} of 0.07 for hilsa is about the same (Salini and Shaklee, 1988). For *L. calcarifer*, isolation by distance has been invoked as the mechanism contributing to observed gene flow (Keenan, 1994; Chenoweth *et al*., 1998).

The significant relationship between relative distance between sites and F_{st} (Fig. 3) suggests that in the case of hilsa, isolation by distance may be the explanation for the observed genetic structure. The within Bangladesh F_{st} was much lower (0.007), demonstrating high gene flow among fish from different parts of the country. These F_{st} values are consistent with those found in other studies of well-mixed marine fish populations (Grant 1985; Milton and Shaklee, 1987). Local fishers at the upstream sites on the main river (Rajshahi and Gaibandha) only catch hilsa during the monsoon season (June-September), which suggests hilsa movements between coastal or marine habitats and inland freshwater habitats are extensive. The biological evidence for large-scale movements of hilsa between marine and freshwater (Pillay *et al*., 1963) together with the seasonal inundation of Bangladesh linking most major waterways across the entire floodplain, the genetic isolating mechanism (if there is any) could only be inter-annual cohorts separated by time rather than location or habitat.

However, otolith microchemistry methods used in the current research have provided evidence of movement of the same hilsa between marine and freshwater environments from birth to time of capture and showed a similar pattern to the genetic data (Milton and Chenery, 2001a). The otolith chemistry was similar among samples from Bangladesh, India and Myanmar. This implied that fish spawned from different areas were moving and mixing sufficiently to provide a uniform otolith chemistry signature. Given the evidence from otolith microchemistry, there must be extensive gene flow between all sites within Bangladesh and to a lesser extent, within the Bay of Bengal. The morphological variation among hilsa from different sites within Bangladesh is more likely a consequence of environmental variation than strong genetic selection pressure (Campana *et al*., 2000).

In contrast to these results, Rahman (1997) and Rahman and Naevdal (2000) were able to detect significant allozyme heterogeneity at the Pgm locus between a coastal site, Barguna and two other sites (Chandpur and Cox's Bazar). This may be due to differences in the laboratory methods, or they may be related to the sampling strategy. They did not report variation at the Idh-1, Idh-m, Mdh-1 or Mdh-m loci, but was able to detect variation (Polymorphism) at AAT and EST loci using iso-electric focusing (IEF) on acrylamide gels. They also found low levels of genetic variation and were able to use DNA technology to find higher levels of genetic variation which support the IEF results of Rahman (1997).

The results of morphometric analysis in the present study are consistent with those of other studies of hilsa in Bangladesh (Rahman *et al*., 1997) and studies of other clupeids (Ryman *et al.,* 1984; Smith and Jamieson, 1986; Hedgecock *et al*., 1989; Kinsey *et al*., 1989; 1994; Tudela, 1999). All these studies have found wide morphological variation among genetically homogeneous samples. All these studies have suggested that the observed morphological variation reflect environmentally induced differences (Swain and Foote, 1999) and lack a genetic basis. Despite the wide variation between sites in hilsa morphology, no evidence for the 'fat' and 'thin' morphs of hilsa described by Quddus *et al.,* (1984) was found.

The pattern of association among the morphological samples from Bangladesh is similar to the patterns found by Milton and Chenery (2001a) for the otolith microchemistry of the same fish. It suggests that fish caught in the middle and lower Meghna River and the nearby coastal waters are a mixture of fish from throughout the region. The distinctive morphology of the hilsa from upper Meghna River (Bhairab Bazar and Sylhet) is also reflected in their distinctive parasite fauna (Alam, 2001) and matches the otolith chemistry of these fish and supports Milton and Chenery's (2001b) suggestion that at least part of the hilsa population may be resident or return migrants in this area (Milton and Chenery, 2003). This separation is insufficiently complete by allozyme studies (Ward and Grewe, 1994).

The implications of these results for the management of hilsa stocks in the countries where they occur are quite profound. There is considerable gene flow between hilsa in the Bay of Bengal and this means that Bangladesh, Myanmar and Indian fisheries authorities need to cooperate in developing joint management strategies for hilsa. Each country should be aware that changes in the available biomass within their waters may be due to fishing pressure in neighboring countries. In Indonesia, the data indicate that the population is genetically isolated and will be vulnerable to extinction if severely overexploited. Hilsa in the Persian Gulf are probably a single population, indicating that Kuwait and Iran should be managing that population cooperatively. Other populations in the Indus River, Pakistan and adjacent north western India are also like to be a single population and require cooperation between the two countries if it is to be sustainably managed.

Acknowledgements

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Otolith Microchemistry Study for Detection of Hilsa Population Structure and Comparison with the Results of Genetic and Morphological Studies

Summary

The stock structure of the valuable tropical hilsa shad *Tenualosa ilisha* has been studied in Bangladesh and India by analyzing morphometric and genetic data. However, these studies had a narrow geographic scope and their results conflict. BFRI in collaboration with CSIRO made a comprehensive study of the stock structure of hilsa with otolith microchemistry in conjunction with complementary genetic and morphometric studies of hilsa fish. We examined the trace-element composition of the otolith cores of hilsa with laser-ablation inductively coupled plasma mass spectrometry. The otoliths of fish from 19 collections at 13 sites in Bangladesh and six collections at four sites from elsewhere within the species' range (Kuwait, SE India, Myanmar and Sumatra) were analyzed for 8 trace elements. Samples were collected from Bangladesh mainly during two comprehensive surveys (1996 and 1997). When these data were analyzed separately, there were significant differences in otolith composition among sites. However, when both years' data were analyzed together there were few significant differences among sites, and some sites separated by hundreds of kilometers that were sampled in different seasons and years had very similar compositions. This was in spite of both large seasonal intra-site and between-site differences in water chemistry. Repeat samples from five sites (4 in Bangladesh) showed that differences in otolith composition at a single site were significant and of similar magnitude to that found among sites. Our results support the conclusion from allozyme studies that there is extensive movement and mixing of hilsa throughout Bangladesh, and therefore the population should be managed as a single stock. Genetic and otolith data both showed that hilsa from SE India and Myanmar were not significantly different from fish collected in coastal areas of Bangladesh and suggest that hilsa in the Bay of Bengal were a single stock. Both methods also separated fish from Sumatra and Kuwait from other sites, providing strong evidence of separate stocks in those regions. In contrast, morphometric studies separate fish from several nearby sites in Bangladesh, but these differences are likely to be largely due to phenotypic variability and are unlikely to be genetically based. Our results suggest that otolith microchemistry may be a good proxy for genetic structure at large scales where differences in water chemistry are obvious. However, for sedentary species and those without distinct spawning and non-breeding areas, it requires both comprehensive and repeated sampling at finer scales before any confidence should be placed in the results.

Introduction

Both by concept and definition, stock structure of a species has long been relevant to open-water fisheries management because the identification of discrete population within stocks is critical to rational resource exploitation (Smith *et al*., 1990). For proper fisheries resource management, stocks need to be easily and accurately defined (Kutkuhn, 1981), which is currently done with genotypic or phenotypic markers that are stable and repeatable (Booke, 1999). For most marine and estuarine species, stock structure is difficult or impossible to measure directly, as methods to measure the extent of larval homing have not been developed (Thresher, 1999). Stocks have thus usually been delineated by indirect methods, such as studies of larval advection, parasite loads, morphometric and genetic variation or locating and mapping discrete spawning areas. As all these methods have limitations in the scope and strength of inferences, alternative approaches continue to be evaluated.

One alternative approach is to analyze the chemical composition of calcified structures such as fish otoliths. Thresher's (1999) review of the potential of this approach identified several issues that cast doubt on its value for delineating stock structure. Nonetheless, he thought its potential should be further explored by research that compared the stock structures obtained from otolith microchemistry with those obtained from other sources such as tagging and genetic studies and assessed the stability and repeatability of delineating the structure of a stock from the otolith microchemistry. Hilsa is caught in coastal and marine waters from Kuwait in the west, to the Bay of Bengal as far east as Myanmar (Whitehead, 1985), and there is an isolated population in northern Sumatra (Fig. 1).This fish is also found in all the large rivers, and spawning fish have been caught as far as 1,200 km upstream. Most, however, live within 100 km of the coast.

Previous hilsa stock structure studies based on morphometric characters varied greatly in the stock structures, suggesting from no variation among several rivers (Pillay, 1957) to as many as four partly overlapping stocks in the lower Meghna river in Bangladesh (Rahman & Moula, 1992; Rahman *et al*., 1997). These apparently conflicting results may be expected given that phenotypic variation in morphological characters has both environmental and genetic components (Swain & Foote, 1999).

Previous genetic studies at three sites in Bangladesh about 150 km apart (riverine, coastal and marine) using RADP fingerprinting identified between one and three stocks (Dahle *et al*., 1997). Rahman *et al.,* (1997) sampled at two sites (riverine and coastal), using starch gel electrophoresis also found genetically distinct populations. Hussain *et al.,* (1998) made a more comprehensive electrophoretic and morphometric study, sampling nine riverine, coastal and marine sites throughout Bangladesh and others in adjacent Myanmar and south-eastern India (Fig. 1) found no evidence of genetic separation between the samples.

However, they found that fish from elsewhere in the species' range (Kuwait and Sumatra) were genetically distinct.

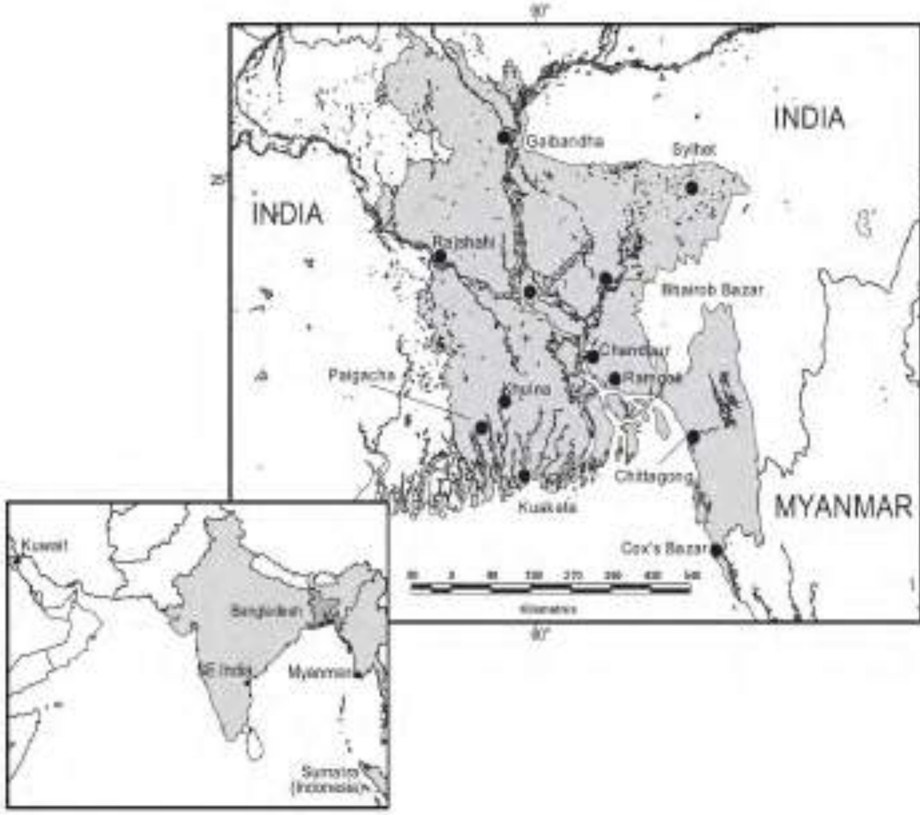

Fig. 1. Map of Bangladesh and southern Asia (inset) showing the sites of hilsa otoliths samples analyzed by LA-ICPMS.

Given the wide variation in the results of the morphometric and genetic studies, an alternative independent method is needed to clarify the stock structure of hilsa. The aims of this study were to examine the spatial variation in hilsa otolith chemistry focusing on Bangladesh, asses the reproducibility of patterns by examining multiple samples of fish from the same sites, and compare the results with those from complementary genetic and morphometric studies of the same fish (Hussain *et al*., 1998; Salini *et al*., unpubl. data) and morphometric studies of fish from the same region, thereby assessing the congruence of the otolith microchemistry results and those from other methods for identifying hilsa stock structure.

Materials and Methods

Sampling and Sample Preparation

Hilsa were collected by experimental gillnetting, buying them from commercial fishers or fresh from local markets at fifteen sites throughout Bangladesh and four sites elsewhere within the species' range (Fig.1). To minimize the effects of differences among sample collections of handling artefacts on measurements of trace metal concentrations, both saggittae were taken as soon as possible after collection (Proctor & Thresher, 1998; Milton &

Chenery, 1998). Fish were kept on ice when it was impractical to remove otoliths immediately after capture. As hilsa fishing is a daytime activity, most otoliths were removed within 10 h of the death of the fish. Successive collections were made at five sites (four in Bangladesh) to assess similarity in results over two years (1996-97).

On each sampling occasion in Bangladesh when otoliths were collected for elemental analysis, duplicate water samples were collected. All samples were taken from mid-water, at least 10 m from the riverbank at the site where the fish were caught, or 100 m offshore for the coastal samples. Water temperature and salinity were recorded at the same time with a TPS multimeter probe. Water samples were fixed to 1% Nitric acid and stored in the refrigerator until analyzed. Prior to analysis, samples were filtered through a 0.45 μm paper and analyzed with a Fisons/ARL 3580 Quantovac ICP-AES.

In the laboratory, fish were measured (SL in mm), weighed (g) and measured for the same suite of nine morphometric measurements and meristic counts of Quddus *et al.,* (1984a) and Rahman *et al.,* (1997). Fish were dissected, sexed and a sample of liver and muscle frozen for genetic analysis (Hussain *et al*., 1998). The otoliths were then removed and cleaned of adhering tissue with thin glass rods, dried with tissue paper and stored in clean, labelled plastic bags. Each otolith was weighed (±0.1 mg), and where possible, the left otolith of fish aged as 1+ from counts of daily increments (15-25 cm) (Blaber *et al*., 1998) in each sample were chosen for analysis. In some cases, such as in Myanmar, fish of this size were not available and older fish (2+) had to analyze.

The otoliths were mounted in thermoplastic cement on a labelled microscope slide and ground along the transverse axis with heavy-duty silicon carbide paper until the core region of the otolith was exposed. The otolith was then polished to the core with 1200 grade wet and dry sandpaper moistened with double-distilled water. To remove any contamination, the surface was wiped vigorously after polishing with a piece of tissue paper moistened with 0.5 M aristar nitric acid. The slides were then placed in plastic bags until analyzed by laser-ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS).

Laser Ablation

For laser ablation LA-ICPMS, the otolith being investigated was placed in a perspex ablation cell under a microscope objective and illuminated in transmitted light to identify the growth zones of the otoliths. After the core (region of the otolith just outside the hatch check) was placed under the crosswire, the laser was focused on the sample surface in reflected light and fired through the microscope objective lens. The ablated material was transported from the ablation cell to the ICPMS instrument in inert argon gas flow. The laser (pulsed Nd:YAG) was run in Q-switched mode at 266 nm. Three ablations were made at the core and rim of all otoliths analyzed. The core samples were made in the growth zone immediately outside the hatch check that corresponded to the first week of larval growth.

The isotopes in highest concentration in the otoliths were determined from solution ICPMS of an initial sample of six otoliths. These results were used to identify the best isotopes for analysis. For the main part of the study, the ICPMS was then operated by peak jumping mode rather than the scanning mode to maximize the signal from the isotopes of interest.

Calcium was used as an internal standard to compensate for the poor precision in the analytical signal, which is caused by variations in the mass of the material ablated (Campana *et al*., 1994). Calcium concentration was assumed from the stoichiometry of calcium carbonate to be 400 000 μg.g-1 and the concentrations of other elements were estimated against the Ca concentration. This enabled the ICPMS to be calibrated with aqueous solutions containing all isotopes of interest (Thompson *et al*., 1989; Chenery and Cook, 1993). Detection limits depend on the amount of material ablated.

ICPMS operating conditions and protocols used during otoliths ablations are described elsewhere (Million *et al*., 1997; Milton & Chenery, 1998). Before each group of ablations of an otolith, a blank was determined for subtraction from that group of ablations. These blanks are used to calculate the detection limit for each isotope during that analytical session. At the beginning and end of every day, a NIST glass reference material was analyzed to check the calibration and identify any inconsistencies. All samples were randomly assigned a sequential coded label in the laboratory before they were analyzed by LA-ICPMS, and the history of each otolith was unknown before analysis.

Data Analysis

The mean [metal:Ca] ratios of the eight elements at the core of each otolith was calculated from the replicate ablations. The ratios of most elements were not normally distributed. All data were natural logarithm transformed prior to analysis. Ratios were compared among replicate otolith collections (sites and dates) (Table 1, Fig.1) by MANCOVA covariance with otolith weight as a covariate and canonical discriminant analysis. The data from Bangladesh were separated by year of collection and the 1996 and 1997 samples analyzed separately. The canonical variate values of each sample were compared by MANCOVA with samples blocked for sex and otolith weight as the covariate. Samples that had similar means were grouped. This enabled the 19 otolith collections from Bangladesh to be reduced to ten samples groups (1996 and 1997 samples) or was collected in 1998 or 1999. These sample groups were compared to the samples from other countries in a similar way.

Results

In all, the cores of 338 hilsa otoliths from 19 collections in Bangladesh and 6 from other sites elsewhere within the species range were examined by LA-ICPMS (Table 1). Sampling spanned three years. Five sites were sampled more than once, four in Bangladesh and one from north-eastern Sumatra, Indonesia. The mean length and the sex ratio varied between collections, as larger fish were female. Eight elements were routinely detected by LA-ICPMS in concentrations above their detection limits in the majority of fish in all samples (Li, Na, Mg, Al, Mn, Zn, Sr, and Ba). One element, Li was found in concentrations that were often within its overall range of detection limits. However, as over 97% of all measurements were above the detection limit on the day that they were measured, Li was retained in the analysis.

Water concentrations of the 8 elements examined varied greatly, both between and within sites (Table 2). Most of the differences between sites appear to be related to the degree of mixing of fresh and marine waters. Coastal sites such as Chattogram, Cox's Bazar, Kuakata and Khulna had similar concentrations of these trace metals to those of marine waters. Seasonal and inter annual differences in concentration of some elements between samples at Chandpur and Goalanda were similar to those among sites sampled at the same time. Ca concentration also varied by over 20-fold among sites and by 5-7 folds among the freshwater sites.

Table 1. The mean length, weight and otolith weight of the sample collections of hilsa *Tenualosa ilisha* otoliths that were examined by LA-ICPMS (SL= standard length) and the water temperature and salinity at the time of collection. See Fig. 1 for the location of sampling sites. Collection sites in bold are from sites outside Bangladesh and all sites are ordered from west to east.

Site	n	Date	Water temperature (°C)	Salinity ‰	SL± SE (mm)	Weight ± SE (g)	Sex ratio (M:F)	Otolith weight (mg) ± SE
Kuwait	16	Jun 96	27	-	303±9	569±58	1:15	9.3±0.5
S.E. India	26	Aug 98	26	-	330±5	871±47	4:22	12.4±0.5
Paikgacha	19	Aug 97	22	2	330±8	931±61	11:8	11.4±0.3
Khulna	7	July 96	23	10	258±34	496±192	4:3	8.5±1.6
	14	May 97	23	12	300±5	498±34	12:2	10.0±0.4
Kuakata	9	July 96	24	14	321±15	799±130	6:3	11.1±1.2
Rajshahi	19	Aug 97	22	0	299±18	667±135	14:5	10.4±1.1
Gaibandha	20	Aug 97	22	0	222±11	262±42	18:2	6.1±0.7
Goalanda	9	July 96	23	0	362±14	1050±97	3:6	14.5±0.7
	9	Oct 96	25	0	263±23	517±130	5:4	8.7±1.1
	10	May 97	23	0	270±10	442±55	10:0	7.8±0.6
Bhairab Bazar	20	Aug 97	22	0	211±6	197±14	15:5	5.8±0.4
Sylhet	17	May 99	21	0	170±9	124±33	13:4	4.7±0.4
Chandpur	10	July 96	23	0	371±21	954±136	2:8	13.6±1.1
	9	Oct 96	25	0	302±12	674±101	4:5	10.0±0.7
	9	May 97	23	0	318±14	660±85	4:5	10.5±0.7
Ramgoti	7	Jul 96	23	4	377±11	1029±95	0:7	13.5±1.0
	12	Feb 99	26	2	322±7	795±47	1:11	11.7±0.5
Chattogram	14	May 97	24	14	259±4	289±13	11:3	8.2±0.3
Cox's Bazar	12	July 96	22	17	258±10	413±59	7:5	8.4±0.5
Myanmar	28	Aug 98	26	-	414±4	1812±50	0:28	17.8±0.4
Sumatra,	8	Nov 96	28	-	263±6	385±21	5:3	7.6±0.3
Indonesia	20	April 97	26	-	313±6	748±57	9:11	10.0±0.5
	8	Nov 97	28	-	283±8	604±60	0:8	8.6±0.5
	333				296±4	685±27	162:176	10.1±0.2

Table 2. The mean water [metal/Ca] ratios of the eight trace metals (in moles) in duplicate samples taken at the sites in Bangladesh when hilsa were collected (concentrations of Li below the detection limit of the ICP-AES are shown in bold).

Site	Date	Li (mmol mol^{-1})	Na (mol mol^{-1})	Mg (mol mol^{-1})	Al (mmol mol^{-1})	Ca (μg g-1)	Mn (mmol mol^{-1})	Zn (mmol mol^{-1})	Sr (mmol mol^{-1})	Ba (μmol mol^{-1})
Paikgacha	Aug 97	**3.6**	18.1	2.3	33.3	48.0	0.4	3.5	4.3	181.4
Khulna	July 96	2.7	31.9	3.8	158.6	205.8	3.1	0.5	6.0	482.1
	May 97	2.9	33.1	4.0	124.5	200.6	2.3	0.6	6.2	453.4
Kuakata	July 96	2.6	34.6	4.1	3.8	99.0	0.1	2.7	6.7	177.5
Rajshahi	Aug 97	**4.4**	0.3	0.4	305.0	40.0	5.7	7.7	1.3	664.6
Gaibandha	Aug 97	8.9	0.3	0.6	724.3	20.0	9.4	1.6	1.6	1047.6
Goalanda	July 96	**1.4**	1.5	1.0	166.2	12.7	4.8	2.0	3.1	480.9
	Oct 96	8.9	0.2	0.5	423.1	20.0	6.9	19.3	1.6	731.4
	May 97	5.0	1.5	0.7	117.2	34.6	2.3	19.8	2.4	590.4
Bhairab Bazar	Aug 97	8.8	1.3	0.7	278.4	5.2	5.9	1.4	2.2	780.1
Sylhet	May 99	5.0	1.7	1.1	638.8	6.1	10.4	1.2	2.9	964.6
Chandpur	July 96	8.6	3.3	0.7	63.2	20.2	1.1	52.7	2.0	433.4
	Oct 96	**5.6**	0.7	0.5	26.1	31.0	0.7	1.5	1.8	282.7
	May 97	9.5	0.7	0.4	62.0	18.3	0.8	17.7	1.8	318.9
Ramgoti	Jul 96	**3.5**	18.7	2.4	22.6	49.0	0.4	8.1	4.4	236.5
	Feb 99	**3.6**	18.8	2.4	16.0	49.0	0.3	0.6	4.3	180.0
Chattogram	May 97	3.8	44.1	5.3	165.5	250.3	2.9	1.1	7.9	132.4
Cox's Bazar	July 96	3.0	47.4	5.6	2.1	363.0	0.02	0.6	8.3	32.2

Table 3. The mean [metal:Ca] ratio ± SE of eight trace metals in the core of hilsa otoliths collected in 1996 from Bangladesh.

Site	Date	n	Li (μmol mol^{-1})	Na (mmol mol^{-1})	Mg (mmol mol^{-1})	Al (μmol mol^{-1})	Mn (μmol mol^{-1})	Zn (μmol mol^{-1})	Sr (mmol mol^{-1})	Ba (μmol mol^{-1})
Chandpur	July	10	24.1±5.1	10.9±0.6	0.20±0.06	30.4±7.5	18.8±2.9	15.7±4.3	1.37±0.28	49.7±23.5
	Oct	9	17.2±2.5	10.2±0.5	0.43±0.10	163.8±45.2	12.7±1.1	10.9±0.8	1.25±0.25	15.0±1.2
Cox's Bazar	July	12	26.8±7.1	11.3±0.8	0.15±0.02	22.4±2.5	22.5±6.3	12.6±1.9	2.20±0.20	21.5±5.4
Goalanda	July	9	24.1±4.6	12.3±0.8	0.16±0.02	33.0±8.6	13.0±1.9	16.1±3.7	1.21±0.26	19.2±2.3
	Oct	9	17.8±1.9	11.3±0.5	0.24±0.04	67.0±10.2	11.3±2.6	10.5±0.4	1.02±0.23	10.8±1.4
Khulna	July	7	11.3±0.8	11.5±0.3	0.19±0.04	58.5±40.2	8.8±1.6	6.2±1.4	1.06±0.22	8.6±1.5
Kuakata	July	9	18.8±1.5	11.3±0.4	0.34±0.07	71.5±15.1	12.0±1.2	10.2±1.4	0.86±0.11	11.2±1.8
Ramgoti	July	7	11.3±1.1	11.3±0.6	0.28±0.14	102.1±51.8	17.4±0.5	4.8±0.8	0.94±0.16	19.4±5.7

Repeat sampling

Of the five sites where sampling was repeated, there were only significant differences in the chemical composition of otolith cores at Chandpur (MANOVA Pillai's Trace = 0.67, $F_{8,16} = 4.3$, $P < 0.01$) and Khulna (MANOVA Pillai's Trace = 0.45, $F_{8,11} = 3.7$, $P < 0.05$). The differences at Chandpur were driven by changes in the concentration of Al and Mg between samples (Al: $F_{1,27} = 17.2$, $P < 0.001$, Mg: $F_{1,27} = 10.9$, $P < 0.01$) and Zn between years ($F_{1,27} = 50.8$, $P < 0.001$), whereas the differences between the two samples from Khulna were due to changes in the concentrations of Li ($F_{1,18} = 9.7$, $P < 0.01$), Mn ($F_{1,18} = 6.4$, $P < 0.05$) and Ba ($F_{1,18} = 8.8$, $P < 0.01$).

Comparison among the three sites sampled repeatedly in 1996-97 (Chandpur, Goalanda and Khulna) showed that the otolith elemental composition differed more between years (MANOVA Pillai's Trace = 0.58, $F_{8,63} = 10.8$, $P < 0.001$) than among sites (Pillai's Trace = 0.48, $F_{16,128} = 2.7$, $P<0.01$). Significant differences among sites were found for the mean concentration of Li, Mn, Zn, and Ba ($P < 0.05$). Li and Zn concentrations also varied highly significantly between years ($P < 0.001$) and the site x year interaction was significant for Mn and Zn ($P < 0.01$).

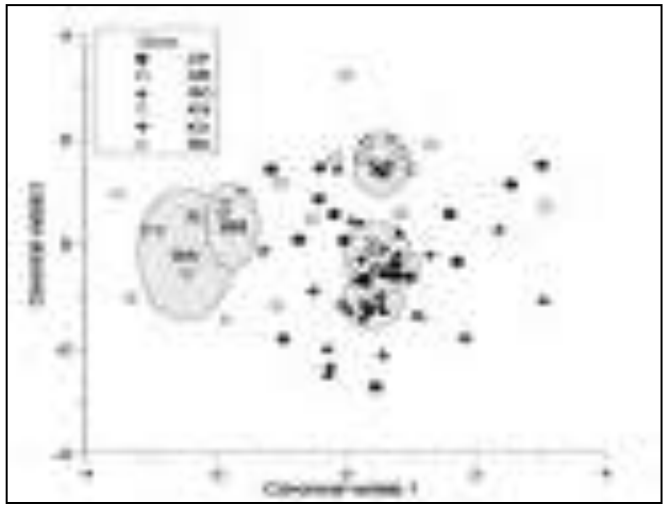

Fig. 2. Plot of the first 2 canonical variates (explaining 79% of the variation) of trace elements in the core of otoliths of hilsa collected at 6 sites within Bangladesh during 1996. Ellipses represent bootstrapped 95% confidence regions for each site. (CP= Chandpur May and October 1996 grouped; CB= Cox's Bazar; GO = Goalanda May and October 1996 grouped; KH= Khulna; KU= Kuakata; R= Ramgoti July 1996).

Bangladesh (1996)

There was significant variation among samples collected from six sites in Bangladesh in 1996 (MANOVA: Pillai's Trace = 1.4, $F_{40,305} = 2.98$, $P < 0.0001$, Table 3). The mean concentration of four elements differed among sites (Li, Al, Zn and Sr) (all $P < 0.01$). Neither sex nor otolith weight explained significant amounts of the variation among samples for any of these elements ($P > 0.13$). Canonical discriminant function analysis showed that sites grouped into marine (Cox's Bazar), coastal (Ramgoti and Khulna) and riverine sites (Fig. 2). This is consistent with the major differences in water chemistry between these habitats (Table 2). The first two functions explained 79% of the variation between sites (Table 4) and there were significant differences among the mean values of sites on these functions (ANCOVA $P < 0.001$). Li and Zn had the highest positive coefficients on CV1, whereas Al and Sr had high coefficients on CV 2. The Cox's Bazar sample had high values for CV2 for which Sr had a positive coefficient (Table 4). Otolith weight was not significant on either function ($P > 0.4$).

Table 4. Standardized canonical discriminant coefficients of 8 trace metals for the first two CDFs that explained significantly amounts of the variation in the 3 comparisons shown below (P<0.001). The first two comparisons are among Bangladesh samples and the comparison between countries includes Bangladesh samples grouped into distinct regions (see Figs. 2 and 3) as well as all samples from other countries. The amount of variation explained by each CV in each comparison is shown in parentheses.

	Comparisons							
Elements	Between 1996 samples		Between 1997 samples		Between all Bangladesh		Between Countries	
	CV 1 (51)	CV 2 (28)	CV 1 (49)	CV 2 (29)	CV 1 (53)	CV 2 (20)	CV 1 (61)	CV 2 (25)
^{7}Li	0.73	-0.47	-0.85	0.59	0.30	-1.35	0.87	0.05
^{23}Na	-0.49	-0.16	0.13	-0.54	-0.18	0.08	-0.11	0.16
^{24}Mg	0.34	-0.22	-0.24	0.11	0.13	-0.23	0.26	0.48
^{27}Al	-0.41	-0.61	-0.05	0.11	-0.35	0.09	0.28	0.21
^{55}Mn	-0.00	0.19	0.33	0.74	0.13	-0.21	-0.05	-0.15
^{66}Zn	1.27	0.23	0.16	-0.52	1.62	0.19	0.47	-0.41
^{88}Sr	-0.25	1.05	0.57	0.11	0.00	0.60	0.59	0.60
^{138}Ba	-0.34	-0.03	0.67	0.13	-0.20	0.21	-0.57	0.14

Bangladesh (1997)

There were significant differences in the mean concentration of Li, Na, Mn, Zn, Sr and Ba among samples collected from eight sites in Bangladesh in 1997 (Table 5). There was no significant effects of sex or otolith weight for any element (P >0.19). When these data were analyzed by CDA, there were significant differences among the mean variate values of each site for CV1 and 2 (P <0.001). The first two variates explained 78% of the overall variation and sex and otolith weight were not significant (P >0.16). Li and Ba had the largest effect on CV1 and Li, Na, Mn, and Zn on CV2 (Table 4).

The patterns among sites differed for sites sampled in 1996 (Fig. 3). Riverine sites sampled in 1996 and 1997 (Chandpur and Goalanda) were distinct and each grouped with coastal sites whose elemental composition were similar (Table 5). Riverine samples from north-western Bangladesh were also similar but separated from the Bhairab Bazar sample collected in north-eastern Bangladesh (Fig. 3). Fish from Bhairab Bazar had higher Ba and lower Li in their otoliths than the other inland sites (Table 5) and is reflected in the higher coefficients of these elements on CV1 (Table 4).

All Bangladesh samples combined

The analysis of hilsa collected from sites in Bangladesh in 1996 and 1997 revealed three site-groups in each analysis (Figs. 2 and 3). These site-groups were analyzed in a combined analysis of all fish caught in Bangladesh (Fig. 4). This included additional sample collected from Ramgoti and Sylhet in 1999. These analyses showed that there were 3 overall site-groupings among all the Bangladeshi hilsa samples (Fig. 4) and that the variation in CV1 and

CV2 was mostly explained by Zn and Li, respectively (Table 4). Most of the sample collected in 1997 grouped together with the coastal samples from 1996. The other samples from 1996 were statistically different on CV1 and CV2. The single sample from Sylhet separated from both other site-groups.

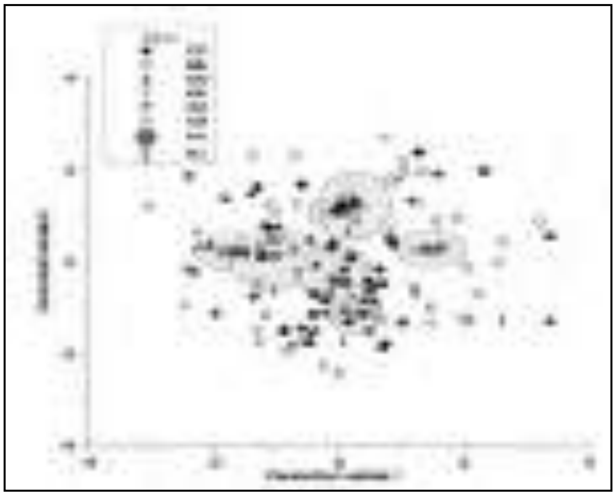

Fig. 3. Plot of the first 2 canonical variates (explaining 78% of the variation) of trace element composition of the otolith cores of hilsa collected at 8 sites in Bangladesh during 1997 (CP=Chandpur; BB=Bhairab Bazar; GO=Goalanda; KH=Khulna; GA=Gaibandha; CH=Chattogram; PA=Paikgacha; RJ=Rajshahi). Ellipses represent the bootstrapped 95% confidence regions.

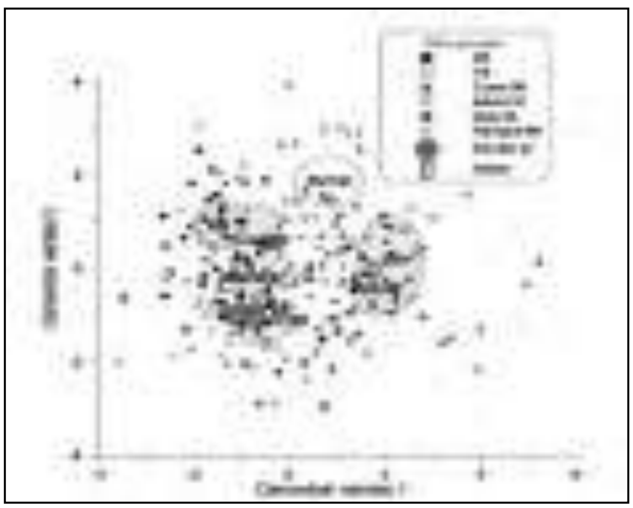

Fig. 4. Plot of the first 2 canonical variates (explaining 83% of the variation) of trace elemental composition of the core of the otoliths of hilsa from site-groups identified in the analysis of 1996 and 1997 samples from Bangladesh (see Figs. 2 and 3) and samples from Ramgoti and Sylhet collected during 1999. Ellipses represent the bootstrapped 95% confidence regions of each group. (BB=Bhairab Bazar; CB=Cox's Bazar; Coast 96= Khulna and Ramgoti samples collected in 1996; Inland 97=Chattogram, Goalanda, Gaibandha, Paikgacha and Rajshahi samples collected in 1997; Meg 96=Chandpur, Goalanda and Kuakata samples collected in 1996; Ramgoti 99=Ramgoti February 1999; SW BD 97=Chandpur and Khulna samples collected in 1997; Sylhet= Sylhet May 1999).

Comparison throughout Range

Samples from Bangladesh collected in 1996 and 1997 were grouped and compared with samples from other parts of the species range (Table 6). There were no significant differences among the three from northern Sumatra, so they were also grouped for the combined analysis.

The MANOVA showed that there were highly significant differences in the elemental composition of otolith cores among countries (Pillai's Trace =1.1, $F_{40,1585}$ =11.3, $P < 0.0001$). All elements differed among countries ($P < 0.001$), except Mn. There was no significant effect of sex or otolith weight for any element, although there was a significant country x sex interaction for Barium ($P < 0.01$). The bootstrapped 95% confidence ellipses of each sample groups mean did not overlap on CV1 and CV2 (Fig. 5) and these functions explained 85% of the variation. Li, Sr and Ba had the largest coefficients on CV1 and Mg and Sr on CV2 (Table 4).

The cross-validation sample allocation from the discriminate function analysis showed a high degree of accuracy assignment of hilsa in some samples (Table 7). The classification accuracy varied from 35% for the Indian sample, to 100% for those from Indonesia and Kuwait. Fish that were misclassified usually were classified into the geographically closest group. Hilsa collected throughout Bangladesh in 1996 and 1997 were classified accurately (75%) and misclassified fish were mostly assigned to the other group. The Indian samples were the fish that were classified with least accuracy. Misclassified fish were either assigned to Bangladesh (53% of fish) or Myanmar.

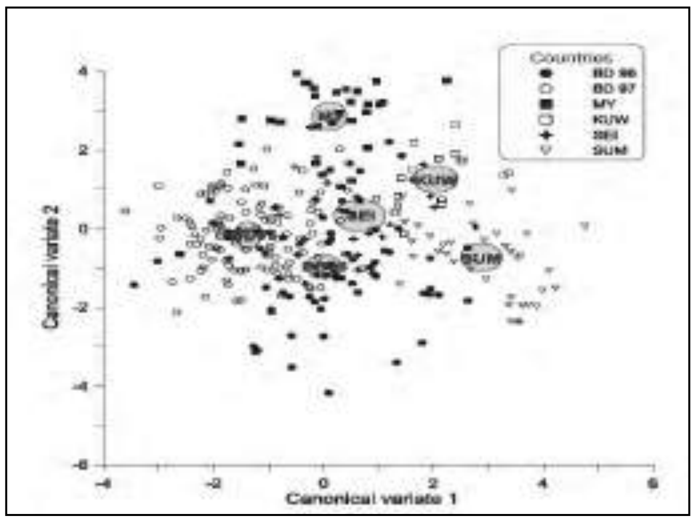

Fig. 5. Plot of the first 2 canonical variates (explaining 78% of the variation) and the 95% confidence ellipses of trace element composition of the cores of otoliths of hilsa collected in 1996 and 1997 from Bangladesh and samples from Myanmar, India, Indonesia and Kuwait. (BD 96= Bangladesh 1996 samples; BD 97= Bangladesh 1997 samples; MY= Myanmar; KUW= Kuwait; SEI= SE India; SUM= NE Sumatra November 1996, April 1997, and November 1997 grouped).

Table 5. The mean [metal:Ca] ratio ± SE of 8 trace metals in the core of otoliths of hilsa collected from Bangladesh in 1997.

Site	Date	n	Li (µmol mol⁻¹)	Na (mmol mol⁻¹)	Mg (mmol mol⁻¹)	Al (µmol mol⁻¹)	Mn (µmol Mol⁻¹)	Zn (µmol mol⁻¹)	Sr (mmol mol⁻¹)	Ba (µmol mol⁻¹)
Bhairab Bazar	Aug	20	10.6±1.1	10.8±0.2	0.13±0.01	44.8±9.3	18.1±2.3	3.7±0.2	0.97±0.07	19.1±2.3
Chandpur	May	9	20.3±1.7	10.7±0.3	0.19±0.04	65.1±21.6	16.0±2.6	4.5±0.9	0.96±0.11	28.9±9.0
Chattogram	May	14	21.8±2.5	10.3±0.3	0.16±0.02	33.8±10.1	7.2±1.0	3.5±0.4	0.86±0.13	8.8±0.7
Gaibandha	Aug	20	13.4±1.8	11.1±0.3	0.17±0.02	33.9±5.0	13.4±2.7	4.4±0.3	0.75±0.09	14.4±1.7
Goalanda	May	10	20.9±2.6	10.4±0.3	0.16±0.02	78.9±24.6	7.8±1.2	4.2±0.7	0.92±0.10	11.2±1.2
Khulna	May	14	19.3±1.7	10.5±0.2	0.18±0.02	66.8±25.1	22.4±3.4	4.9±0.7	0.88±0.10	17.1±2.7
Paikgachha	Aug	19	13.3±1.5	10.9±0.2	0.14±0.01	42.1±10.8	12.1±1.1	5.5±0.7	0.85±0.08	11.6±1.1
Rajshahi	Aug	19	14.6±2.1	11.6±0.2	0.20±0.03	54.0±16.1	11.2±1.3	5.6±0.4	0.85±0.12	13.9±1.8

Table 6. The mean [metal:Ca ratios ± SE] of 8 trace metals in the core of otoliths of hilsa collected from Bangladesh (**) in 1998 and 1999 and sites in other countries where hilsa were collected.

Site	Date	n	Li (µmol mol⁻¹)	Na (mmol mol⁻¹)	Mg (mmol mol⁻¹)	Al (µmol mol⁻¹)	Mn (µmol mol⁻¹)	Zn (µmol mol⁻¹)	Sr (mmol mol⁻¹)	Ba (µmol mol⁻¹)
Kuwait	Jun 96	16	33.0±2.6	13.6±0.4	0.29±0.03	58.7±2.9	10.9±1.0	5.7±0.2	2.2±0.06	6.9±0.8
Myanmar	Aug 98	28	20.9±1.7	11.1±0.4	0.40±0.06	64.2±8.9	11.3±2.0	3.9±0.4	2.3±0.10	18.2±1.3
Sumatra	Nov 96	9	72.8±9.5	10.1±0.3	0.27±0.03	104.5±40.3	8.8±0.8	10.1±1.3	2.1±0.29	5.5±0.8
	Apr 97	20	53.3±7.2	10.1±0.2	0.24±0.01	67.6±10.5	13.9±1.1	11.5±1.0	1.9±0.10	7.5±0.7
	Nov 97	8	70.8±7.2	9.3±0.6	0.17±0.02	140.3±48.9	12.1±1.5	11.6±0.9	2.1±0.23	8.2±2.2
Ramgoti**	Feb 99	12	29.8±3.7	12.8±1.2	0.30±0.05	52.2±10.8	9.5±0.7	4.3±0.2	1.9±0.24	17.1±3.1
S.E.India	Aug 98	26	23.0±2.3	11.7±0.4	0.37±0.05	28.9±5.1	12.1±1.8	9.0±1.5	1.4±0.1	14.7±1.2
Sylhet**	May 99	17	8.8±1.3	12.4±0.5	0.37±0.12	106.2±22.4	15.6±2.3	10.0±07	1.1±0.10	20.5±2.0

Table 7. The classification of Hilsa collected throughout the species' range after linear discriminant function analysis of the elemental composition of the cores of their otoliths. Values indicate cross validation accuracy (%). Samples were from Bangladesh in 1996 (BD 96), 1997 (BD 97) and Sylhet (Sy), Sumatra, Indonesia (ID), Kuwait (KU), Myanmar (MY) and SE India (SEI). Values in bold indicate correct allocation.

Sample source	BD 96	BD 97	Sy	ID	KU	MY	SEI
Bangladesh 1996 (N=58)	**57**	31	5	0	0	2	5
Bangladesh 1997 (N=151)	18	**75**	1	0	0	3	3
Sylhet (N=17)	6	35	**47**	0	0	12	0
Indonesia (N=36)	0	0	0	**100**	0	0	0
Kuwait (N=16)	0	0	0	0	**100**	0	0
Myanmar (N=28)	4	21	0	0	0	**75**	0
SE India (N=26)	12	33	8	0	0	12	**35**

Discussion

The results show that hilsa born in geographically separate areas can be distinguished by differences in the chemical composition in their otoliths. Hilsa collected from sites outside the Bay of Bengal (Sumatra and Kuwait) had more distinctive otolith chemistry than fish collected from most of the other sites and are genetically distinct from hilsa in the Bay of Bengal (Hussain *et al*., 1998; Salini *et al*., unpubl. data).

Within the Bay of Bengal, hilsa from southeastern India and Myanmar could not be genetically separated from fish collected in Bangladesh.

Fish caught at several sites in the main Meghna River system up to 500 km apart within a few days of each other had similar otolith chemistry despite the (metal:Ca) ratios of some elements in the water differing by 3-4 times. This suggests that there is considerable mixing of hilsa in the Meghna river system.

The results confirm that hilsa in most regions migrate mainly to spawn in freshwater during the monsoon season (June-October) and or in winter (December - February) (Jenkins, 1938; Hora 1941; de Graaf *et al*., 1999). The otolith Sr concentration of fish shows that hilsa collected in fresh and coastal waters spawn in waters with a range of Sr concentrations and salinities and a small proportion spawn in the sea as well (Fig 6). Fish caught in the middle reaches of the Padma (Goalanda) can have similar otolith chemistry to fish collected on the coast (Khulna) in one sample but be similar to fish collected offshore of the river mouth or the lower reaches (Chandpur–Chattogram) in another. These patterns are consistent with the results of genetic studies of the same fish that showed no genetic differences among the Bangladesh samples (Hussain *et al*., 1998).

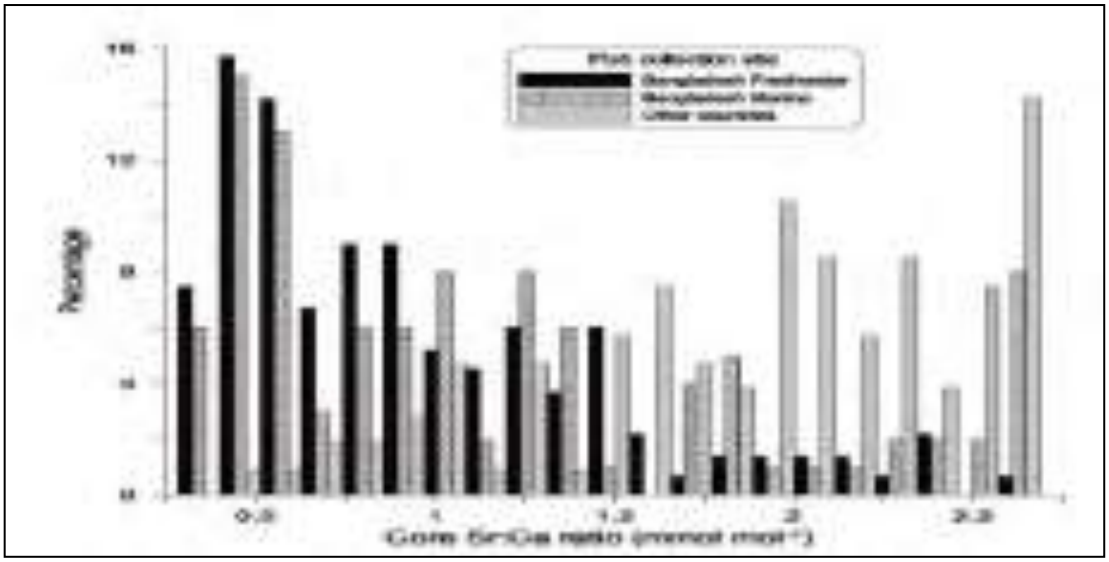

Fig. 6. Percentage frequency distribution of Sr concentration (µg g–1) in the core of hilsa otoliths collected from fish caught in freshwater in Bangladesh (>150 km inland from the coast), marine (coastal and marine fish landed in Bangladesh) and fish collected from other countries.

The sample from Sylhet, the extreme north-eastern part of Bangladesh did not hold this pattern. These fish differed from their nearest sample (Bhairab Bazar) in the concentration of four elements (Mg, Al, Zn and Ba). These differences may be due to inter annual fluctuations in water chemistry or as the local fisher's belief their hilsa are resident and do not migrate (Rahman and Moula, 1992). The genetic and morphometric data for this site conflict; the morphometric results showed a high level of discrimination for the Sylhet sample but no genetic separation from elsewhere in Bangladesh. Low genetic variation found by Hussain *et al.*, (1998) and extreme morphometric variability in clupeids, suggest that if there is limited exchange with fish in this region, it is probably a relatively recent event. Hilsa in the most inland parts of their range in the middle Ganges River are also believed to be resident (Ghosh and Nangpal, 1970).

Morphometric studies (Quddus *et al*., 1984 a; Rahman and Moula, 1992; Rahman *et al*., 1997) suggest that between two and four stocks of hilsa occur in the Meghna River system in Bangladesh – "broad'' and "slender'' (Quddus *et al*., 1984 a) or four broadly overlapping stocks co-occur, but grow at different rates and spawn in different seasons at the same sites (Quddus *et al*., 1984 b, c).

Although many previous studies found high levels of morphological variation among samples within small geographical region, none found any evidence of genetic differences among their samples (Ryman *et al*., 1984; Smith and Jamieson, 1986; Hedgecock *et al*., 1989; Kinsey *et al*., 1994; Tudela, 1999). They all concluded that the observed morphological variation either reflected phenotypic plasticity or environmentally influences (Swain and Foote, 1999). However, present study found that the morphology of Bangladeshi hilsa varied both regionally and inter annually at the same site in a similar manner to the otolith microchemistry.

In this study Cox's Bazar sample separated from fish at other sites had very similar composition to those from Myanmar, India and nearby coastal areas of Bangladesh. Hussain *et al.*, (1998) found no evidence of different Bangladeshi stocks, including samples from these same sites. Dahle *et al.*, (1997) admitted that the difficulty in duplicating RAPD results and their uncertain heritability makes this method the least useful DNA method for detecting stock structure (Dowling *et al*., 1996). Evidence of similar otolith chemistry among fish from a greater range of sites that differ in water chemistry also argues against the likelihood of more than one stock in this small region.

This study provides some encouraging evidence that there may be a close correlation among stock structures derived from complementary genetic and otolith microchemistry data (Fig. 7).

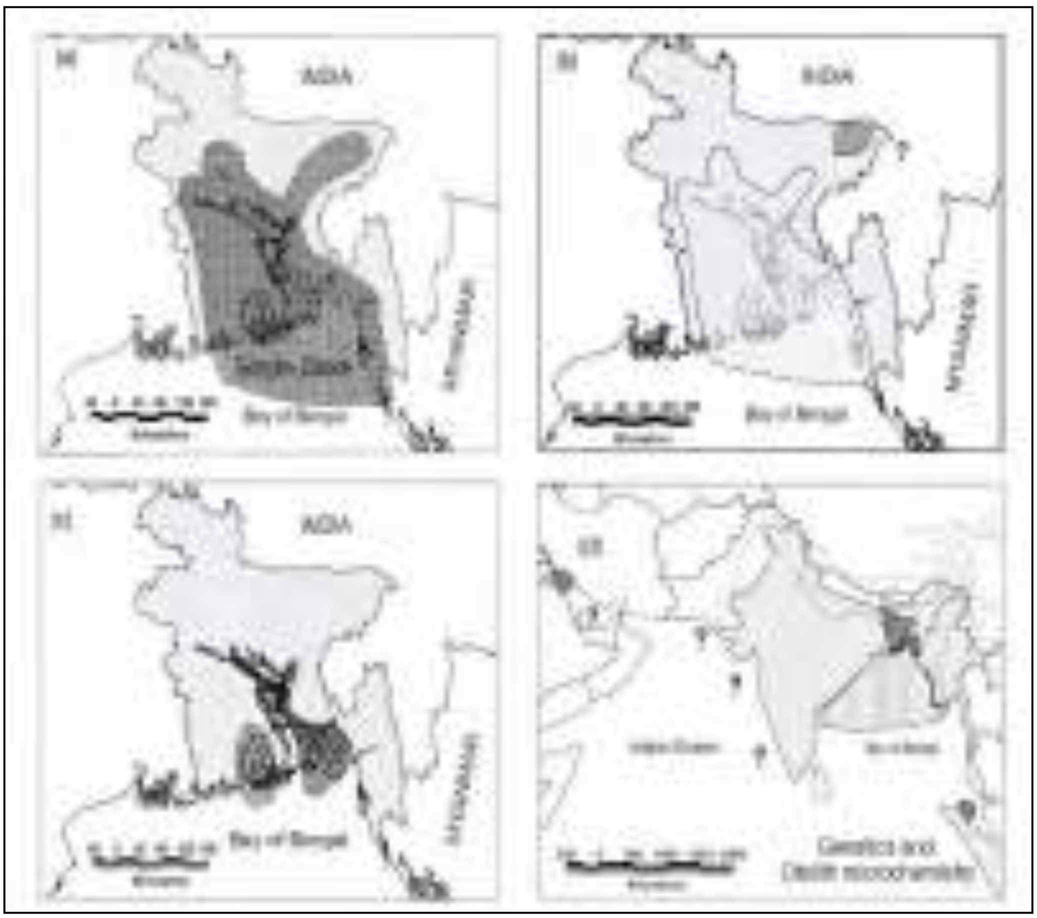

Fig. 7. Summary of the stock structure of hilsa in Bangladesh based on (a) allozymes (b) otolith microchemistry of fish examined during this study and (c) morphometric studies, and (d) the overall stock structure throughout the species' range identified by both genetics and otolith microchemistry is also shown. Countries where samples were collected during the study are shaded; different hatchings represent the stocks identified by each method.

The extensive knowledge of hilsa life history and migratory patterns suggests that there may be groups of fish that may have different migratory patterns (Quddus *et al*., 1984; Rahman *et al*., 1997), but these groups intermingle during at least part of the year and cannot be reliably separated and managed as such. Thus, the population of hilsa in Bangladesh should effectively be treated as a single stock for management purposes.

The present study also highlights the temporal variability in otolith chemistry (Edmonds *et al*., 1992; Milton *et al*., 1997; Dove and Kingsford, 1998) and unlikelihood of repeating the results obtained from samples taken during a single sampling period. This further reduces the credibility of otolith composition as a reliable stock discriminator (Thresher, 1999, Campana 1999, Campana *et al*., 2000). It suggests that the technique may be better at providing a fingerprint of spawning or nursery areas (Thresher *et al*., 1994) that can be recognized among fish mixing during the non-breeding season (Campana *et al*., 2000). This would have greater application in migratory species such as salmonids as fish spawning in different areas may also be genetically isolated from each other.

In conclusion, it has been shown that there is an environmental component to the variability in the chemical composition of otoliths of hilsa from Bangladesh and the patterns of variation differed between repeat samples from the same sites support the large number of previous studies of hilsa that conclude these fish are highly migratory. Samples of fish caught in fresh or marine waters could be a mixture from those and other areas. Hilsa from genetically distinct location (Kuwait and Sumatra) could also be separated by their otolith composition.

Acknowledgements

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Socio-Economic Study of the Hilsa Fisher Folk in Bangladesh

Introduction

The open water capture fisheries play an important role in social and economic life of the people of Bangladesh. The marine and riverine fisheries are two main sources of open water capture fisheries in Bangladesh where large number of poor people are engaged in fishing. The coastal water of Bangladesh is one of the most productive zones in the world. Small scale marine fishing by gillnet, long line, set bag net and other nets operated by small mechanized boats discontinue fishing during the monsoon due to bad weather. Despite that, offshore fishing is done by daily trawler trips.

Hilsa is the largest single species fishery accounting for 27% of Bangladesh capture fishery (2016-17) combining inland and marine captures. An estimated two million people are employed in hilsa fishing as fishermen, middlemen, aratdar, mohajon/dadondar, trader, boat builder, net maker and repairer. Information regarding socio-economic aspect of hilsa fishing community is not available and no detailed study has so far been done on contemporary socio-economic condition of the hilsa trading system, gear/technology used in fishing, loans to the fishermen by the money and power holder, problems and constraints associated with the open water capture fisheries etc. In view of this, the present study was conducted to investigate the socio-economic characteristics of the hilsa fishermen, general features and characteristics of fishing boats, gears, cost of fishing, income sharing from hilsa fishing, problems in relation to hilsa fishing and marketing with the following objectives:

Objectives

- Find out the existing socio-economic status of all types of actors who are engaged in hilsa fishing and trading activities.
- Determine and understand the income sharing arrangement system in hilsa fishing.
- Understand how the fishermen are financed by mohajons/aratdars.
- Understand the major problems and constraints related to riverine and marine hilsa fishing.
- Suggest measures for conservation and sustenance of the hilsa resources in Bangladesh.

Methodology

Research Design

The study uses a descriptive and exploratory approach to secure information from the study area. Questionnaires and observational methods were employed to collect data. Interviews and discussions were done with three categories of actors. Firstly, the aratdar, who is an auctioneer in the selling of hilsa from fishermen/carrier boat to the local and inter-district paiker. Secondly, head mazhi or skipper, who organized the fishermen to catch fish from the river/sea by their fixed contract or sharing system. The head mazhi is usually employed by the boat/vessel owner. Thirdly, crew, who catch fish under the leadership of head mazhi are paid according to a sharing contract.

Sampling Area

The sampling centers/hilsa landing centers selected was Cox's Bazar, Teknaf, Chattogram, Ramgoti, Chandpur, Barguna, Pathorghata, Khepupara, Mohipur, Kuakata, Aricha, and Khulna. Keeping the objectives of this research study in mind, the above places were purposively, selected.

Data Collection

Information was collected through direct interviews in the field from head fishermen, fishing labourers, paikers and aratdars. Several visits were made to these landing centers to collect, correct and validate information related to objectives of the study.

Data Analysis

The collected data were transferred to separate master-sheet and classified tables were prepared on the basis of the aims and objectives of the study. The tabulated data were analyzed and condensed by using arithmetic mean and percentage. Overall socio-economic conditions were classified according to different types of fishermen and traders involved in hilsa fishing and business.

Results

Socio-economic Characteristic of the Hilsa Fishermen and Traders

To identify the main socio-economic characteristics of all actors of the fishery, information regarding size of family, level of literacy, size of land, resource holding, fishing experience, annual cycle of mean mesh sized net used, average hilsa landing, dadon information, annual income etc. were considered for this study. A short description of these characteristics has been given below:

Household Size and Composition

Household size was small with the low-income group of fishermen. The biggest household size belonged to the head mazhi. The average household size of head mazhi was 7.79 of whom 4.81 were male, 2.98 were female and 4.97 were working member. The crews and paikers had the smallest household size. They had average household size of 6.63, 6.61 of which 3.65, 4.22 were male and 2.98, 2.39 were female, respectively.

Educational Status

Illiteracy was more prevalent among fishermen. About 62.61% crew fishermen were fully illiterate followed by 20% aratdar, 32% paiker, and 63.33% head mazhi. About 22.22% aratdar and 16.00% paiker had intermediate and college level education but no other categories had such high level of education. The education level of fishermen is below the national average.

Size of Land Holding

The results show that average farm sizes were 5.04 acre, 2.61 acre, 1.01 acre and 0.94 acre for aratdar, paiker, head mazhi and crew fishermen, respectively. Farm size was large with higher income category of actors. The largest farm size belonged to aratdar, whose income was always the highest. About 60% crew fishermen have no cultivable land.

Fishing Experience

About 68.75% head mazhi, 34.78% crew and 44% paikers having fishing experience more than 10 years. On the other hand, 32% paiker, 25% head mazhi and 26.96% labour/crews had fishing experience for less than 10 years. Above data clearly shows that to become a head mazhi requires more experience than for other crew, and a head mazhi should have a commanding voice to control other crew. The head mazhi also needs a good reputation and skill in finding fish and earning for boat, engine, and gear and reputation for honesty in dealing with the boat owner's, aratdar and crews.

Occupation of Fishermen

Out of 60 head mazhi, only 6 (10%) reported that they had petty trading/business activities as a subsidiary/secondary occupation. In general, fewer crew fishermen had secondary occupation. This indicates that fishermen in the boats had less opportunity and time to employ themselves in other secondary occupations at the fishing period than in the off-season. Perhaps they simply had zero or less capital.

Annual Income of Head Fishermen and Crew

It was found that the head mazhi from Chattogram earn on an average Tk. 47,858 per hilsa season, which is the highest income compare to any other location. On the other hand, income from fishing for crews is about Tk. 18,910 in hilsa season from Chattogram. Both for crew and head mazhi, the earning pattern were different for different places. The pattern of income variation was different, mainly due to the nature of availability of fish and wage pattern of different categories of fishermen at different places.

Dadon/Loan Holding

Dadon is the specific loans from aratdars/mohajons for fishing boat repairs and gear, and working capital to go to sea (fuel, ice, food) in order to tie fish deliveries to lending aratdar. In such critical periods, the head fishermen and crew go to the aratdar/mohajon to get loan for their livelihood. It is evident from the study that 51.32% of head mazhi and 22.61% crew took dadon from aratdar/mohajon. The head mazhi and crew took on an average Tk. 20,959 and Tk. 1,120, respectively per year as dadon. Two to six percent commission was collected on all fish auctioned by the aratdar. The average income of Tk.611,937 was earned from commission by the aratdars of Barisal, which is the highest income from commission compared to the any other location. The average commission earned was estimated to be Tk. 306,285 by providing dadon of an average Tk. 1,204,523 to the head mazhi and crew *i.e.* on average 'one fourth' of the dadon amount is being earned by the dadon provider as commission by auctioning fishermen's fish sale.

Annual Mesh Size Used

It was observed that most of the head fishermen had used 3 to 6-inch mesh sized net for hilsa fishing over the year. More than 30% head fishermen reported that they had used 4 to 6-inch mesh size net at the time of peak hilsa season (14 April to 15 August *i.e.* the Bengali months of Baishak to Srabon). After Ashwin (15 October to 15 November), some head fishermen stopped hilsa fishing in the dry season. Anecdotal evidence from skippers is that they use smaller mesh nets for the mixed species sea fishery in dry season than in the hilsa peak season in the estuaries in monsoon.

Boat Net Ownership Pattern

Forty percent and thirty three percent head fishermen from Barisal and Chandpur, respectively reported that they used their own boat and net in fishing. Twenty five percent and 20% head mazhi from Chandpur and Barisal seasonally rented their fishing crafts and gears. Renting such boat averaged about Tk. 20,000 per boat per season. Many aratdar's reported that they rented out more than one unit of fishing vessel and net for fishing. Aratdars try to keep their vessel and net busy in fishing by providing some credit/dadon to the fishermen through the head fishermen. Twenty five percent and 30% of head fishermen respectively reported from Chattogram and Barisal that they received some credit/dadon from the aratdar with the promise to sell their entire catch to aratdar and at lower prices as well.

Share System

Fishermen generally get their income following a share system. From the total catch value, the aratdar first deducts his commission and recovers dadon debt. In the share system, the owner first cuts from the remainder his proportion from total catch revenue for using his boat and net in fishing. The rest of the revenue is than divided by the number of crew shares. In this system the head fishermen will take 2-3 shares for him, boat driver and labour fishermen will make 1.5 and 1 share, respectively. A different type of sharing system was observed in the Cox's Bazar area. The boat and net owners take Tk. 600-700 for every Tk. 1,000 of hilsa catch revenue, *i.e.* 60-70% of the catch value.

On the other hand, the Cox's Bazar head mazhi, driver and labour fishermen will get respectively Tk. 50-60, Tk. 30 and Tk. 20 each from every Tk. 1,000.00 of catch revenue. If any trip shows a negative earning in comparison to the total input cost, then the loss incurred is deducted either from the previous trip's income or from the next trip's income by the owner of the fishing unit. In other words, the entire loss is borne by the crew fishermen, never by the owner of the fishing units and the head mazhi. It can be stated that the present sharing system leads to low income and hardship to the crew fishermen. Intervention is necessary by the government to support and maintain systems of remuneration that provide a higher share of earnings for the crew fishermen. The ILO views fishing is a part of ‘informal sector’ where wage regulation is not possible and if enforced would cause unemployment.

Production Technologies and Nets and Gear Used in Hilsa Fishing

River, estuary and coastal fishing are carried out by a mix of traditional boats and small mechanized boats and deep-sea fishing by trawlers. Generally, gillnets are used for hilsa fishing. Two types of gillnets are used; they are drift gillnet and set gillnet. The drift gillnets are locally called gulti jal, chandi jal and current jal. Daba jal and gara jal are local names for the set gillnet.

Fishing Craft

Small motorized boat and wooden displacement hull motor gillnet boats locally called "trawler" are the most important methods for hilsa fishing in the riverine and estuary area and deep sea, respectively. Most of the head mazhi (70%) reported that they were fishing hilsa by the 30-45 feet long and 6-12 feet wide drift gillnet "trawler" in the estuaries and the sea. The riverine hilsa fishing craft is naturally smaller than the trawler. The size and shape of crafts vary according to location (river, estuary, and sea), type of the gear used, season and sizes of hilsa fish to be caught.

Gear Used

Various dimensions of beach nets used to catch juvenile hilsa (jatka) and gillnets for adult hilsa. These gillnets are operated by assembling a number of pieces together. Usually chandi jal and current jal is rectangular net made of nylon twine, monofilament synthetic fiber, or tyre cord. The top of the net is seized to a float and the bottom to a weighted footrope of lead or earthenware discs to maintain the vertical stretch of the net.

Cost of Hilsa Fishing

Cost items are classified as fixed cost and variable cost. The costs of hilsa fishing consist the cost of boat, cost of net, engine (capital cost), and fuel, ice, food, and maintenance cost of boat, net and engine (variable cost). The average cost of hilsa fishing were Tk. 196,509, Tk. 608,975, Tk. 424,780 and Tk. 295,912 per year at Chandpur, Chattogram, Cox’s Bazar, Barisal and Khulna, respectively. Out of total cost, the operating cost is about 68% for hilsa fishing. However, the marine hilsa fishing by gillnet “Trawler”, the total cost is three times higher than the riverine hilsa fishing.

Economic Return from Hilsa Fishing

The gross economic return from hilsa fishing were Tk. 1,501,100, Tk. 1,672,594, Tk. 1,389,100, Tk. 1,767,466 and Tk. 1,215,202 for marine hilsa fishing respectively for Chandpur, Chattogram, Cox’s Bazar, Barisal and Khulna and Tk. 350,497, Tk. 823,956, Tk. 515,062 and Tk. 519,205 for riverine hilsa fishing respectively for Chandpur, Chattogram, Barisal and Khulna. The annual net return was calculated by subtracting all costs from the gross returns and were found to be Tk. 1,032,043 and Tk. 421,139 for marine and riverine hilsa fishing, respectively. So, it can be concluded that hilsa firms from those locations earned considerable amount of profit.

Major Hilsa Landing Centers and Marketing System

Major coastal hilsa landing centers are located at Cox's Bazar, Chattogram, Teknaf, Kutubdia, Hatia, Sandwip, Ramgoti, Bhola, Patuakhali, Khepupara, Mohipur/Kuakata, Pathorghata, Khulna, Chandpur and Dhaka. Most of the catches from the rivers, estuaries and sea are landed at these centers and hilsa is the main species. After meeting the local demands, surplus hilsa from these centers is sent to the different districts which are determined by market price.

Marketing System

The hilsa marketing is generally conducted by the aratdar/fish auctioneers, either individually or as groups or fish traders/aratdars associations. Roughly, four levels of marketing system are observed in the distribution channels of hilsa trade. These are the Primary, Secondary, Higher Secondary and Final consuming market. The marketing channels of hilsa is shown in a flow chart in Fig. 1.

Primary Market

This is marketing place at the 'mach ghat' or fish landing point, usually, in estuarine inland areas. Fishing boats come to the landing station to sell their catch through the mohajons/aratdars of these areas. Mohajons/aratdars of the landing station auction the catch to the local paiker, traders who then transport catch to re-sell it elsewhere. Often part of the catch may be locally sold by the catcher to a floating paiker/bapari fish trader in the river if the trip returned with few fish, or so that the skipper and crew can sell part of the catch without knowledge of the aratdar and boat owner.

Secondary Market

The collectors bring the fish from the primary market to the landing ghats, usually to the nearest thana market or at a place which is well linked by rivers/road. The buyers of the primary market again sell the fish to the inter-district paiker/bepari with price set by auction conducted by big aratdar or commission agents.

Higher Secondary Market

The beparies transport the fish from secondary market to a near or distant city/town market by road, rail or boat. These types of market are the main distribution centers and the paiker/beparies re-sell the fish to the set of distributors known as paikers, again at a price set by auction through the aratdars/commission agents.

Final Consuming Markets

The paikers from the higher secondary market again sell fish to the retailers. There are two channels of retailing: the urban retailers sell the fish in the urban marketplaces and other retailers take the fish to suburban places or to the villages around the city/town.

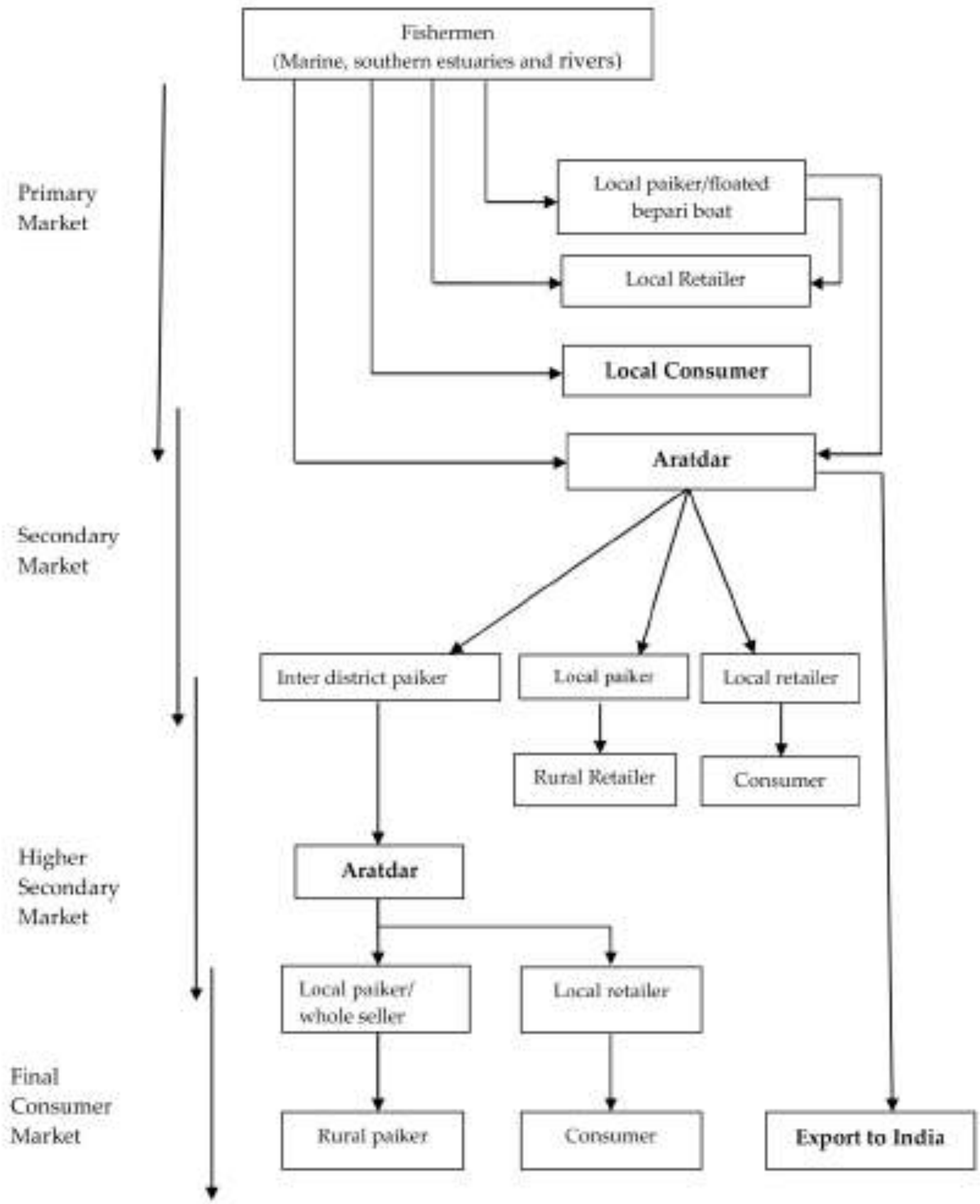

Fig. 1. Marketing channels of hilsa.

Existing Auction System

As soon as the fishermen land the fish in the landing center, the aratdars take care of landing, handling, sorting, and auctioning by size groups. The aratdars sell the fish through the open bidding system to the highest bidder, by the help of their employees. There are other types of price-auction systems, which are being followed by some trader's associations in some selected markets. The auction systems are as follows:

Open Bids

The auctioneer calls out the bid by the bidders loudly in the presence of the buyers. The incremental system is followed; the highest bidder buys the fish. It is the most competitive form of auctioning and ensures better prices for fishermen at all levels of hilsa marketing except in retailing. The auctioneer gets 4-6% commission on sales value.

Price Fixing

In the landing centers of coastal areas, especially in Cox's Bazar, Chattogram and Barisal, the aratdars have recognized Association's which fix the price of hilsa either in the evening or in the morning, after meeting about the local demand and supply. The fishermen are bound to sell their catch at that price and follow the system, since he is tied to the auctioneer by credit given to him.

Limited Bidding

In this system, the auctioneer fixes the price by negotiation or partial bidding, usually in the absence of the seller. The auctioneer does not make loud calls, but he whispers about the prices to the intending buyers present. The aratdar/auctioneer then decides the highest price and sells the fish to the so-called higher bidder.

Problems and Constraints of Marine Fishing

During the last two decades, fishing with mechanized boat has been introduced and the number of fishing boat has increased very rapidly, which indicate that more and more people are coming in the fisheries sector to live on. Mainly two categories of fishermen are involved in small scale riverine/marine fishing; those are head fishermen who usually organized the crew fishermen who catch fish as a member of fishing team. The problems mentioned by boat owner or head mazhi and crews were almost similar, but differences were found with the aratdars. The problems stated by them are briefly discussed below.

Piracy

During the investigation, more than 80% head fishermen claimed that they were attacked by pirates during fishing period. Some pirates throw fishermen into the sea and take all fishes and money from them is a highly cruel act. They also reported that no help or protection was rendered by the law enforcing agency.

Cyclone and Bad Weather

Natural calamities are common in the Bay of Bengal. Almost all fishermen mentioned that it was a major constraint for marine fishing. More than 70% head fishermen and crew reported that they fell in a great trouble and disaster situation in the time of bad weather.

Disorder of Engine

Head fishermen and crews reported that lack of original parts of engine and good set of engines in the markets create problems during fishing period. Fifty-five of head fishermen reported this is a great problem.

Illegal Tax Collector

When fishermen remain engaged in fishing, illegal tax collectors often come to the fishing boat and forced them to pay money. They reported that such type of problem very often occurred in the Hatia-Sandwip channel and Khulna forest area. The toll collectors appear to be the men of izaradars (investors) who have purchased at auction from Dept. of Land Revenue, or in Sundarbans from Dept. of Forests, a jalmohal right to collect tolls on all boats, gears, and persons exploiting a defined area. Although the jalmohal system was officially abolished under the New Fisheries Management Policy, some izaradars persist in extorting tolls.

Conclusions and Recommendations

The study has revealed some valuable socio-economic information regarding small-scale hilsa fishing in Bangladesh, which has policy implications. It was revealed that hilsa fishing is profitable, but the distribution of profits appears to be biased, inequitable and exploitative. The boat and net owner received more than 60% of gross fishing income of hilsa fishing. The annual net return was found to be Tk. 1,032,043 and Tk. 421,139 for marine and riverine hilsa fishing, respectively. The Benefit Cost Ratio (BCR) for marine and riverine fishing was found to be 2.84 and 2.75, respectively. The fishing crew income from catch share is very low. The sharing system has created low income for the actual fishermen. Most of the skippers received loan without interest from aratdar/mohajon as dadon on condition to sale their entire catch through them. The piracy and illegal tax collector are the main problems in hilsa fishing that should be removed by government by enforcing law strictly.

Based on the findings, to increase hilsa production as well as to improve the socioeconomic conditions of fishing community, the following suggestions have been made to help develop a suitable management plan for the conservation of the hilsa resources in Bangladesh. There may be direct conflict between:

a. Increasing production, versus
b. Managing the fishery for sustainable yield. Good management may require reducing the number of boats and reducing the production, *i.e.* catch.
    - Management system of public open water resources should be improved, and the conservation of fisheries resources should be strengthened. In this respect, fishermen

and the public must be made fully aware of the fisheries laws and potential consequences of their violations.

- The income sharing systems should be more equitable and at least 75% of total fishing income should be distributed among the crews as salary.
- Institutional credit program should be made available to the actual fishermen to meet the requirements of the fishing community. NGOs and government should encourage organizing small fishermen into viable groups or cooperatives and provide them credit so that they can purchase fishing boats, gears etc.
- The open water capture fisheries are seasonal. Government and NGOs should come forward to create employment opportunities for the fishermen and their family members that they can earn throughout the year.
- To identify the needs of the fishermen, active participation of the small-scale fishing communities must be ensured in planning and implementation of development programs. It is necessary to continue research to update data and information on different aspects of fisheries sector including socio-economics.

Recommendations here have shifted from

- The project's central concern to manage fisheries for sustained yield to social welfare concern to increase crew income by reducing share of capital (boat owners, aratdars, lenders).
- Increasing production by credit for more boats and increasing the quantity of hilsa catch.

However, if the stock of hilsa is further reduced by over-production, then all participants in the hilsa fishery along with fish consumers will suffer a reduction in welfare. The main problem in over-production is that there are too many boats catching too many fish. That may require reduction in the number of boats, or at least prevent further increase.

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Chapter IV

Water Quality and Primary Productivity of Major Hilsa Ecosystem

Introduction

Bangladesh is a huge delta of 144,000 sq. km formed by 3 rivers *viz.* the Padma, Meghna and Jamuna-Brahmaputra. These rivers and their tributaries are intricately associated with the existence of Bangladesh. Fishery resources of these rivers are the main source of livelihood and food supply for the people of Bangladesh. The ecosystem of these rivers is still better than many upstream rivers. But it is apprehended that industrial pollution, agro-chemicals and untreated discharges flowing from the upstream rivers may gradually affect the ecosystem of these rivers and decrease the open water capture fisheries. Therefore, it is important to maintain appropriate water quality for production of fish and other aquatic organisms.

The presence of heavy metals *viz*. copper, chromium, cadmium, lead and mercury has been reported from different polluted rivers in Bangladesh. Fish can accumulate significant amount of toxic metals both from water and other aquatic food organisms. Pollutants have been shown to exert a wide range of effects on fish metabolism, physiology and ecology. In view of this, physico-chemical parameters, primary productivity and heavy metal pollution have been assessed in the present study to know the health status of the Padma and Meghna river ecosystem for conservation, management and development of the hilsa fisheries in Bangladesh.

Materials and Methods

Physical, chemical and biological parameters of the 6 selected sampling locations from the rivers Padma and Meghna (Table 1) were studied following the standard protocols. For heavy metal analysis, water and sediment samples were collected and stored in plastic bottles and bag. Similarly, for the detection of heavy metals in fish samples, fresh hilsa (*Tenualosa ilisha*) were collected from different sampling sites. Approximately 50 g tissue was taken out from the fish removing the skin below the dorsal fin. The collected tissue was immediately kept in ice at – 4°C. From collected tissue, 5 g sample was taken and mixed with 25.5 ml tri-acid (21 ml HNO_3 : 3 ml $HClO_4$: 1.5 ml H_2SO_4), and left-over night. Sample was then digested at 150°C for 2 hours and filtered through Whatman 42 filter paper, washed with 2% HNO_3 and made to 25 ml in polypropylene bottles. The sample was then analyzed by Atomic Absorption Spectrophotometer (AAS, Shimadzu, Japan).

Table 1. Sampling locations of the rivers Padma and Meghna with GPS point.

Rivers	Sampling locations	GPS point (Latitude, Longitude)
Padma	Mawa (Munshiganj)	N-23°27.36' E-90°15.27'
	Godagari (Rajshahi)	N-24°29.321' E-88°18.176'
	Pakshi (Kushtia)	N-24°05.443' E-90°01.404'
Meghna	Padma-Meghna confluence (Chandpur)	N-23°14.616' E-90°37.818'
	Meghnaghat (Narayanganj)	N-23°26.108' E-90°36.859'
	Bhairab (Kishorganj)	N-21°03.104' E-90°59.918'

Results

Physico-chemical Properties of Water

Physico-chemical parameters of 6 sampling sites of the Padma and Meghna rivers were studied and wide range of temoral and spatial variations were observed. Water quality parameters of the rivers have been furnished in Table 2 to 7. The overall water depth ranged from 16.3±10.6 ft to 25.9±13.26 ft and 14.9±6.1 ft to 70.5±38.5 ft in the Padma and Meghna rivers, respectively. The highest water depth was recorded (70.5±38.5 ft) at Meghna ghat of the Meghna river in 2012-13. Water temperature was found lowest (23.3±6.5°C) at Godagari point of the Padma river in 2012-13 and highest (30.1±8.5°C) at Bhairab of the Meghna river in 2011-12. The lowest conductivity (103.1±18.2 µs/cm) was found at Bhairab and the highest (466±557.7 µs/cm) at Chandpur and Meghna ghat of the Meghna river in 2012-13. The highest (59.6±61.4 NTU) and the lowest (8.2±32.6 NTU) turbidity were found at Mawa of the Padma river in 2012-13 and 2014-15, respectively.

Total Dissolved Solids (TDS) was found highest (229.9±273.7 mg/l) at Chandpur in 2012-13 and the lowest 88.4±76.2 mg/l at Bhairab in 2011-12 the Meghna river. Dissolved oxygen content ranged between 5.7±0.6 mg/l and 7.7±0.3 mg/l, with the highest DO at Pakshi of the Padma river in 2012-13. The presence of toxic ammonia was almost close to nil in most of the sampling sites, however; at Meghna ghat and Bhairab of the Meghna river 0.1±0.01 mg/l and 0.2±0.1 mg/l ammonia was found in 2011-12 and 2012-13, respectively. Total alkalinity was found lowest (51.5±16.6 mg/l) at Bhairab of the Meghna river in 2013-14 and highest (206.2±64.2 mg/l) at Pakshi of the Padma river in 2014-15. Biological Oxygen Demand (BOD), B was found highest (6.7±1.9 mg/l) at Pakshi in 2013-14 while (BOD), N was highest (7.8±2.4 mg/l) at Godagari in 2014-15 in the Padma.

Table 2. Physico-chemical parameters of water at Mawa, Padma river.

Parameters	Mawa (Mean±SD)			
	2011-12	2012-13	2013-14	2014-15
Water depth (ft)	21.5±7.8	19.7±6.3	23.9±6.5	19±7.2
Air temp (°C)	30.2±12.5	28.3±3.9	32.5±8.9	28.3±9.3
Water temp (°C)	28.4±6.7	25.7±4.1	29.3±7.9	26.4±8.3
Water colour	Light green	Light green	Brownish	Brownish
Odour of water	Fresh	Fresh	Fresh	Fresh
Bottom Type	Sandy	Sandy	Sandy	Sandy clay
Transparency (cm)	40.5±18.4	36.4±16.4	45.9±20.5	30.7±17.8
Conductivity (µs/cm)	318.6±220.3	390.2±411	315.7±247.9	295.3±203.8
Turbidity	25.8±12.7	59.6±61.4	16.5±36.3	8.2±32.6
TDS (mg/l)	187.4±110.5	190.4±196.9	152.7±118.5	137.9±97.7
DO (mg/l)	6.81±1.1	6.8±0.9	6.85±1.9	7.1±2.1
Free CO_2 (mg/l)	3.7±1.3	3.6±0.5	3.8±1.4	4.5±1.4
pH	8.0±2.4	8.2±0.2	8.1±2.5	8±2.4
NH_3 (mg/l)	0±0	0±0	0±0	0±0
Total alkalinity	110.5±55.2	111.4±43.1	98.2±36.7	142.5±40.9
Total hardness	120.3±56.7	83.4±45.9	122.1±43.2	134.9±45.6
BOD (B) (mg/l)	6.2±1.6	5.5±1.5	6.18±1.7	6.2±1.7
BOD (N) (mg/l)	6.8±2.0	6.9±0.6	6.9±2.1	7.5±2.1
COD (mg/l)	15.6±6.5	18.9±13.1	13.1±8.6	7.8±7.8

Table 3. Physico-chemical parameters of water at Godagari, Padma river.

Parameters	Godagari (Mean±SD)			
	2011-12	2012-13	2013-14	2014-15
Water depth (ft)	22.4±10.3	20.1±13.8	25.9±13.2	16.8±10.7
Air temp (°C)	29.6±13.1	24.9±6.8	31.2±8.9	28.7±9.2
Water temp (°C)	28.4±13.9	23.3±6.5	27.2±7.8	26.6±8.1
Water colour	Light green	Light green	Brownish	Muddy
Odour of water	Fresh	Fresh	Fresh	Fresh
Bottom Type	Sandy	Sandy	Sandy	Sandy clay
Transparency (cm)	38.2±16.3	35.1±15.1	36.7± 13.1	40.3±13.1
Conductivity (µs/cm)	357.2±113.5	304.3±73.2	361.7±104.3	353.3±103.6
Turbidity	18.5±7.2	16.8±0.9	18.3±6.1	19.5±6.1
TDS (mg/l)	182.3±52.4	152.3±37.1	184.7±53.3	181±53.7
DO (mg/l)	7.2±2.5	7.6±0.7	7.1±2.4	7.6±2.3
Free CO_2 (mg/l)	3.0±0.5	3.1±0.5	2.4±1.4	4.4±1.5
pH	8.1±2.3	8.2±0.3	8±2.7	7.9±2.5
NH_3 (mg/l)	0±0	0±0	0±0	0±0
Total alkalinity	190.3±77.4	178.5±67.8	192.4±65.1	204.6±61.2
Total hardness	207.5±111.2	136.6±37.7	203.8±64.9	170.5±59.6
BOD (B) (mg/l)	5.2±2.6	5.1±2.5	5.8±1.8	5.7±1.7
BOD (N) (mg/l)	7±0.8	7.8±0.9	6.8±2.6	7.8±2.4
COD (mg/l)	16.7±7.9	12.9±3.8	18.4±6.6	10.3±5.9

Table 4. Physico-chemical parameters of water at Pakshi, Padma river.

Parameters	Pakshi (Mean±SD)			
	2011-12	**2012-13**	**2013-14**	**2014-15**
Water depth (ft)	18.5±8.5	23.7±18.5	16.3±10.6	16.4±9
Air temp (°C)	30.4±15.1	28.8±5.6	32.7±19.6	26.7±9.9
Water temp (°C)	26.3±12.1	24.7±5.8	29.3±8.4	25.7±8.7
Water colour	Light green	Light green	Light green	Greenish
Odour of water	fresh	Fresh	Fresh	Fresh
Bottom Type	Sandy	Sandy hard	Sandy	Sandy
Transparency (cm)	50.5±23.8	38.7±12.5	51.3±15.4	63.5±18.3
Conductivity (μs/cm)	360.3±132.6	308.7±76.7	365±106.1	339.5±106.7
Turbidity	23.2±10.4	19.9±2.2	23.8±7.6	23.5±7.4
TDS (mg/l)	182.1±130.5	153.3±39.3	185.7±54.1	187.5±55.5
DO (mg/l)	7.2±0.6	7.7±0.3	6.5±2.5	7.1±2.5
Free CO_2 (mg/l)	3.7±1.3	3.9±1.1	3.8±1.4	4.3±1.5
pH	7.8±2.3	8±2.5	8±2.7	8±2.7
NH_3 (mg/l)	0	0	0	0
Total alkalinity	190.1±98.3	177.7±52.9	193.4±61.4	206.2±64.2
Total hardness	201.3±98.2	135.3±42.1	205.5±64.9	191.1±63.6
BOD (B) (mg/l)	6.2±1.2	5.6±1.1	6.7±1.9	6.2±2
BOD (N) (mg/l)	7.8±2.2	7.6±0.5	7.6±2.1	7.5±2.5
COD (mg/l)	19±9.2	15.4±15.6	18.5±7.9	11.7±7.3

Table 5. Physico-chemical parameters of water at Chandpur, Meghna river.

Parameters	Chandpur (Mean±SD)			
	2011-12	**2012-13**	**2013-14**	**2014-15**
Water depth (ft)	15.5±4.0	15.9±4.1	14.9±6.1	18.2±5.9
Air temp (°C)	26.8±8.2	27.4±6.6	28.8±8.2	26.5±8.6
Water temp (°C)	25.1±5.5	26.2±4.9	25.6±7.8	24.5±8
Water colour	Light green	Muddy	Light green	Brownish
Odour of water	Fresh	Fresh	Fresh	Fresh
Bottom Type	Sandy clay	Sandy hard	Sandy clay	Sandy
Transparency (cm)	45.2±20.5	44.3±32.6	49±21.7	35±19.2
Conductivity (μs/cm)	310.5±110.2	466±557.7	284.5±315.8	233.6±265.9
Turbidity	50.7±23.5	54.4±31.2	46.5±26.5	48.6±24.5
TDS (mg/l)	160.4±80.2	229.9±273.7	153.6±149.6	118.2±130.7
DO (mg/l)	7.5±1.8	7.3±0.2	7.4±2.5	6.8±2.3
Free CO_2 (mg/l)	3.0±1.1	3.7±1.2	2.8±1.2	4.5±1.4
pH	8.0±2.3	7.8±0.4	8.4±2.3	8±2.5
NH_3 (mg/l)	0	0	0	0
Total alkalinity	115.5±65.2	110.7±59.9	119.6±41.9	176.9±48.3
Total hardness	138.3±45.2	107.2±37.2	143.7±47.7	169.3±51.1
BOD (B) (mg/l)	6.2±2.0	5.4±2.1	6.1±1.9	6.3±2
BOD (N) (mg/l)	6.5±2.3	6.7±0.7	7.7±2.4	6.2±2.4
COD (mg/l)	10.2±6.8	17.4±13.2	8.7±8.1	10.8±7.2

Table 6. Physico-chemical parameters of water at Meghna ghat, Meghna river.

Parameters	Meghna ghat (Mean±SD)			
	2011-12	2012-13	2013-14	2014-15
Water depth (ft)	65.2±22.7	15.9±4.1	14.9±6.1	19.4±6.7
Air temp (°C)	29.5±4.7	27.4±6.6	28.8±8.2	27.5±5.6
Water temp (°C)	28.3±5.2	26.2±4.9	25.6±7.8	25.6±8
Water colour	Light green	Muddy	Light green	Brownish
Odour of water	Fresh	Fresh	Fresh	Fresh
Bottom Type	Clay	Sandy hard	Sandy clay	Sandy
Transparency (cm)	64.3±22.3	44.3±32.6	49±21.7	42.4±20.5
Conductivity (µs/cm)	123. 4±52.4	466±557.7	284.5±315.8	230.6±245.4
Turbidity	27.6±10.4	54.4±31.2	46.5±26.5	51.3±22.3
TDS (mg/l)	90±42.5	225.9±273.7	153.6±149.6	116.2±126.7
DO (mg/l)	5.8±0.4	7.3±0.2	7.4±2.5	6.6±2.7
Free CO_2 (mg/l)	4.3±1.0	3.7±1.2	2.8±1.2	4.0±1.3
pH	7.5±2.1	7.8±0.4	8.4±2.3	8.3±2.4
NH_3 (mg/l)	0.1±0.01	0±0	0±0	0±0
Total alkalinity	65±32.7	110.7±59.9	119.6±41.9	171.4±45.3
Total hardness	80.1±34.5	107.2±37.2	143.7±47.7	170.6±50.4
BOD (B) (mg/l)	4.4±1.4	5.4±2.1	6.1±1.9	5.8±2.4
BOD (N) (mg/l)	6.4±0.8	6.7±0.7	7.7±2.4	5.9±2.4
COD (mg/l)	25.2±11.2	17.4±13.2	8.7±8.1	10.3±6.2

Table 7. Physico-chemical parameters of water at Bhairab, Meghna river.

Parameters	Bhairab (Mean±SD)			
	2011-12	2013-14	2012-13	2014-15
Water depth (ft)	55.2±28.7	14.9±6.1	70.5±38.5	18.2±5.9
Air temp (°C)	30.5±5.7	28.8±8.2	29.2±5.6	26.5±8.6
Water temp (°C)	27.3±7.1	25.6±7.8	26.6±4.2	24.5±8
Water colour	Light green	Light green	Light green	Brownish
Odour of water	Fresh	Fresh	Fresh	Fresh
Bottom Type	Clay	Sandy clay	Soft clay	Sandy
Transparency (cm)	65.3±25.6	49±21.7	68.5±21.6	35±19.2
Conductivity (µs/cm)	120. 4±58.3	284.5±315.8	103.1±18.2	233.6±265.9
Turbidity	22.6±11.5	46.5±26.5	25.9±12.3	48.6±24.5
TDS (mg/l)	89±48.5	153.6±149.6	88.4±76.2	118.2±130.7
DO (mg/l)	5.7±0.6	7.4±2.5	5.9±0.5	6.8±2.3
Free CO_2 (mg/l)	4.5±1.0	2.8±1.2	4.5±1.1	4.5±1.4
pH	7.6±2.1	8.4±2.3	7.4±0.6	8±2.5
NH_3 (mg/l)	0.1±0.01	0±0	0.2±0.1	0±0
Total alkalinity	68±39.4	119.6±41.9	51.5±16.6	176.9±48.3
Total hardness	82.1±37.5	143.7±47.7	43.2±11.1	169.3±51.1
BOD (B) (mg/l)	4.6±1.3	6.1±1.9	4.9±1.6	6.3±2
BOD (N) (mg/l)	6.2±0.8	7.7±2.4	6.4±0.6	6.2±2.4
COD (mg/l)	23.2±12.8	8.7±8.1	22.2±8.1	10.8±7.2

Plankton and Benthos Study

Abundance of plankton in the Padma and Meghna river systems showed a wide range of variations. More than 75 genera of plankton under 6 families were identified from these two major river systems of Bangladesh. In the Padma river, Bacillariophyceae was found as the dominating family followed by Chlorophyceae, Cyanophyceae, Euglenophyceae, Myxophyceae and Dinophyceae (Fig. 1). Average density of plankton (nos./l) was found as 5850±978.4, 5580±650.3, 5550±720 and 6220±480.6 in 2011-12, 2012-13, 2013-14 and 2014-15, respectively in Padma. On the contrary, Chlorophyceae was found as dominating family along with Bacillariophyceae, Cyanophyceae, Euglenophyceae, Myxophyceae and Dinophyceae in the river Meghna (Fig. 2) and the average density of plankton (nos./l) was 3550±255.6, 3600±310.4, 4400±190.6 and 3450±220.2 in 2011-12, 2012-13, 2013-14 and 2014-15, respectively.

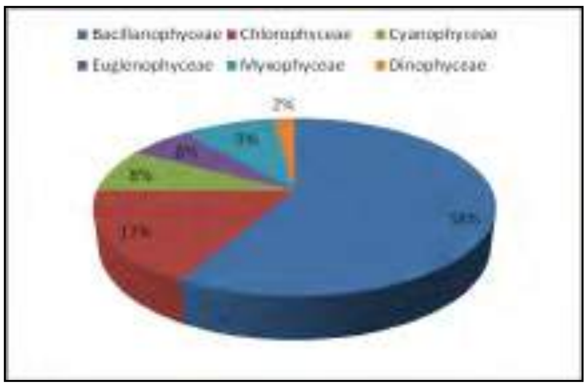

Fig.1. Phytoplankton composition of the river Padma.

Fig.2. Phytoplankton composition of the river Meghna.

Among the zooplankton, about 22 genera under 4 families were found in the Padma and Meghna river while Rotifera dominated in the river Padma and Copepod in the river Meghna (Figs. 3 and 4). Average total plankton density (nos./l) of the river Padma was higher (5800±310.80) than that of the river Meghna (3750±437.7975). Phytoplankton largely dominated over zooplankton throughout the study period. The mean contribution of phytoplankton was more than 91.33% in the rivers and zooplankton contributed the rest.

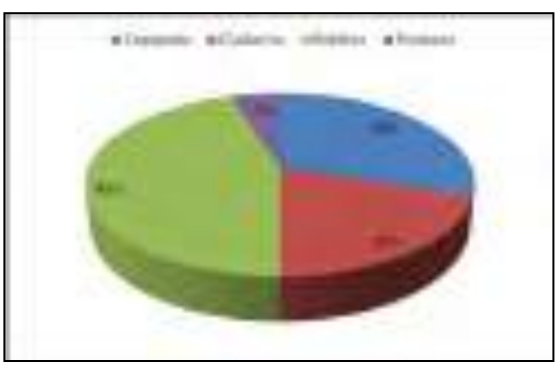

Fig. 3. Zooplankton composition of the river Padma.

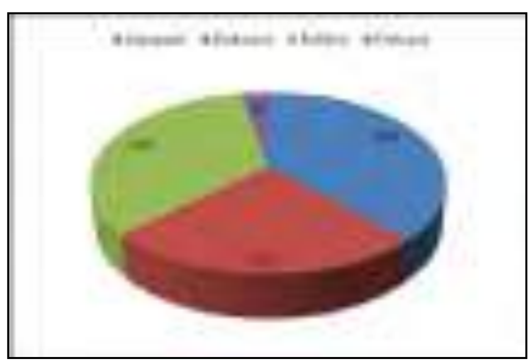

Fig. 4. Zooplankton composition of the river Meghna.

The benthos and macro-invertebrate samples of the selected sites were collected and identified in the laboratory. Among the benthos community only 12 genera were observed under 7 families in the river Padma; here Lepidopteridae was the dominating family followed by the Chironomidae and others (Fig. 5). On the other hand, about 13 genera of benthos were observed under 7 families in the river Meghna, dominated by the Bulimidae family followed by Pleuroceridae, Lepidopteridae, Chironomidae, Unionidae, Viviparidae and Sphaeridae (Fig. 6). Inter river comparison of macro-invertebrates during the study period showed that about 60% of benthos in the river Padma belongs to the Lepidopteridae while about 25% belongs to the Bulimidae family in the river Meghna. In addition, Chironomus larvae (Red blood and others), Nematoda, Oligochaeta, Polychaeta, Bristle worm, Coleopteran larvae, Dragon and Stone fly nymph were identified in the rivers.

Fig. 5. Benthos composition of the river Padma.

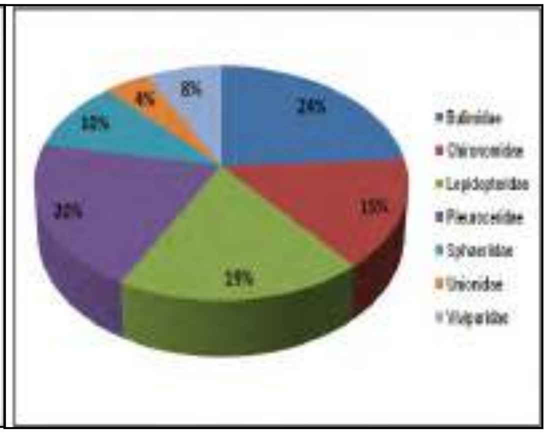

Fig. 6. Benthos composition of the river Meghna.

Heavy Metal Contents in Water, Sediment and Fish

Heavy metal contents in water were analyzed in 2012-13, 2013-14 and 2014-15 and sediment and fish tissues were analyzed in 2012-13 and 2013-14. The results of the analyses are furnished below:

Heavy Metal Contents in Water

The results of average heavy metal contents (mg/l) from the selected river water samples in 2012-13, 2013-14 and 2014-15 are presented in Tables 8-9. Among the all heavy metals (Zn, Mn, Pb, Cr, Cu, Fe and Cd) studied in water, Cd and Cr had the least occurrence at each sampling stations while Fe and Mn level had the highest occurrence. In the Meghna river, lowest Pb concentration (0.0±0.0 mg/l) was found at Chandpur point and the highest (0.060±0.020 mg/l) in the Meghna ghat, whereas in the Padma river the lowest concentration (0.020±0.010 mg/l) was found at Godagari and the highest (0.050±0.040 mg/l) was observed at Mawa. Copper content in water of the Meghna river was found highest 0.210±0.066 mg/l) at Meghna ghat and the lowest at Chandpur (0.020±0.010 mg/l). Similarly, the highest Cu content (0.210±0.080 mg/l) was found at Mawa and the lowest (0.080±0.040 mg/l) at Godagari of the Padma river. Among the heavy metals, iron (Fe) concentration was found highest in both Padma and Meghna rivers. Comparing all 6 sites of the rivers, the highest occurrence (0.521±0.411 mg/l) was observed at Chandpur point of the river Meghna.

Manganese (Mn) concentration was found highest (2.02±0.13 mg/l) at Bhairab and the lowest (0.310±0.164 mg/l) at Chandpur of the Meghna river, whereas the highest Mn content (1.410±0.620 mg/l) was found at Mawa and the lowest (0.801±0.319 mg/l) at Pakshi of the Padma river. Nevertheless, the concentration of Zn was found highest (0.482±0.263 mg/l) at Bhairab and the lowest (0.112±0.005 mg/l) at Chandpur of the Meghna, whereas the highest Zn content was observed (0.413±0.131 mg/l) at Mawa and the lowest (0.211±0.101 mg/l) at Pakshi of the Padma river system.

Table 8. Concentration of heavy metals (mg/l) in water in Meghna river.

Parameters	Chandpur (Mean±SD)	Meghna Ghat (Mean±SD)	Bhairab (Mean±SD)
Pb	0.0±0.0	0.060±0.020	0.020±0.110
Cd	0.0004±0.0002	0.0005±0.0004	0.010±0.006
Cr	0.020±0.010	0.002±0.002	0.008±0.007
Cu	0.020±0.010	0.210±0.066	0.067±0.113
Fe	0.521±0.411	0.314±0.251	0.463±0.383
Mn	0.310±0.164	1.80±0.810	2.02±0.129
Zn	0.112±0.005	0.420±0.220	0.482±0.263

Table 9. Concentration of heavy metals (mg/l) in water in Padma river.

Parameters	Mawa (Mean±SD)	Godagari (Mean±SD)	Pakshi (Mean±SD)
Pb	0.050±0.040	0.020±0.010	0.030±0.010
Cd	0.004±0.002	0.0008±0.0006	0.0008±0.0006
Cr	0.030±0.030	0.003±0.002	0.004±0.002
Cu	0.210±0.080	0.080±0.040	0.095±0.043
Fe	0.382±0.273	0.345±0.231	0.366±0.282
Mn	1.410±0.620	0.850±0.330	0.801±0.319
Zn	0.413±0.131	0.220±0.110	0.211±0.101

Heavy Metal Content in Sediment

The average results of the heavy metal analysis in the sediments from 6 representative sampling sites of the Padma and Meghna river systems in 2012-13 and 2013-14 are shown in Tables 10-11. Among the total heavy metals (Zn, Mn, Pb, Cr, Cu, Fe and Cd) studied from the sediment of the Padma and Meghna rivers, Pb and Cd showed the least occurrence at each sampling stations while Fe and Mn showed the highest occurrence. In Meghna river, Pb concentration was found highest (25.5±14.7 mg/kg) at Chandpur point and the lowest (9.4±6.91 mg/kg) at Bhairab, whereas in the Padma river, the highest Pb content (5.5±2.91 mg/kg) was found at Pakshi and the lowest (3.5±2.8 mg/kg) at Mawa. Cadmium concentration was found lowest (0.004±0.01 mg/kg) at Godagari of the river Padma and highest (1.1±0.8 mg/kg) at Bhairab of the river Meghna. In Meghna river, Cr concentration was found lowest (22.6±14.5 mg/kg) at Chandpur and highest (46.9±5.9 mg/kg) at Bhairab, whereas in the Padma river highest Cr content (27.831±16.43 mg/kg) was found at Mawa and the lowest (24.472±7.22 mg/kg) at Godagari. The highest and lowest Cu content in sediment was also found in the same sites of the Padma and Meghna rivers. Iron concentration in sediment was considerably higher than the other heavy metals in the selected sites of the rivers where the lowest concentration (20987.9±3197.4 mg/kg) was recorded at Godagari of the river Padma and highest (35441.5±6468.2 mg/kg) at Bhairab of the river Meghna.

The highest concentration of Mn (233.106±173.61 mg/kg) was found at Meghna ghat and the lowest (165.519±115.81 mg/kg) at Chandpur point of the Meghna river, whereas in the Padma river the highest Mn content (265.513±73.11 mg/kg) was observed at Mawa and the lowest (221.133±34.66 mg/kg) at Godagari. Nevertheless, Zn was found lowest (40.623±21.310 mg/kg) at Chandpur and the highest (54.580±28.75 mg/kg) at Bhairab of the river Meghna. And in the Padma river, the lowest (51.328±34.71 mg/kg) occurrence of Zn was noticed at Mawa and the highest (57.306±11.72 mg/kg) at Godagari.

Table 10. Concentration of heavy metals (mg/kg) in Sediments in Meghna river.

Parameters	**Chandpur (Mean±SD)**	**Meghna Ghat (Mean±SD)**	**Bhairab (Mean±SD)**
Pb	25.5±14.7	9.6±0.1	9.4±6.91
Cd	0.090±0.04	0.102±0.04	1.1±0.81
Cr	22.634±14.46	42.375±5.81	46.861±5.90
Cu	17.263±13.88	29.152±6.03	32.841±4.75
Fe	22151.58±12702.35	30898.863±4220.68	35441.537±6468.15
Mn	165.519±115.81	233.106±173.61	229.442±118.06
Zn	40.623±21.31	53.706±39.75	54.580±28.75

Table 11. Concentration of heavy metals (mg/kg) in Sediments in Padma river.

Parameters	**Mawa (Mean±SD)**	**Godagari (Mean±SD)**	**Pakshi (Mean±SD)**
Pb	3.5±2.8	3.8±2.4	5.5±2.91
Cd	0.070±0.04	0.004±0.01	0.03±0.01
Cr	27.831±16.43	24.472±7.22	25.963±6.50
Cu	29.169±11.34	20.358±2.04	25.741±8.70
Fe	27453.49±8353.31	20987.863±3197.38	257491.931±8886.55
Mn	265.513±73.11	221.133±34.66	252.437±97.10
Zn	51.328±34.71	57.306±11.72	52.389±9.85

Heavy Metal Contents in Fish

The results of the heavy metal analysis in fish tissues of the Padma and Meghna river systems are presented in Tables 12-13. Among the heavy metals (Zn, Mn, Pb, Cr, Cu, Fe and Cd) analyzed in fish, Cd and Pb showed the least occurrence of at each sampling sites while Fe and Zn demonstrated the highest occurrence. In the river Meghna, Pb was beyond the detectable limit; while in the Padma, Pb was found only at Mawa (0.006±0.003 mg/kg). Cadmium concentration was found lowest (0.020±0.020 mg/kg) at Bhairab and highest (0.2±0.007 mg/kg) at Meghna ghat of the Meghna river, whereas in the Padma river the lowest Cd content (0.020±0.005 mg/kg) was found at Mawa and the highest (0.030±0.010 kg/l) at Godagari. In Meghna river, Cr concentration was found lowest (1.020±0.210 mg/kg) at Chandpur point and highest (1.070±0.030 mg/kg) at Meghna ghat, whereas highest Cr content (1.100±0.410 mg/kg) was found at Mawa and the lowest (0.540±0.010 mg/kg) at Pakshi in the Padma river.

In the river Meghna, the maximum concentration of Cu was found (1.510±0.009 mg/kg) at Meghna ghat and minimum (1.012±0.200 mg/kg) at Bhairab, whereas it was highest (1.201±0.060) at Mawa and lowest (0.711±0.007 mg/kg) at Pakshi in the Padma river. Iron (Fe) and Mn had the highest contents (24.101±14.611 and 2.510±1.813 mg/kg) at Chandpur and Zn showed highest occurrence (7.984±3.360 mg/kg) at Bhairab in the Meghna. On the contrary, in the Padma river, Fe, Mn and Zn demonstrated the highest and lowest occurrence in the same sites.

Table 12. Concentration of heavy metals (mg/kg) in fish of the river Meghna.

Parameters	**Chandpur (Mean±SD)**	**Meghna Ghat (Mean±SD)**	**Bhairab (Mean±SD)**
Pb	0.0±0.0	0.0±0.0	0.0±0.0
Cd	0.030±0.030	0.200±0.007	0.020±0.020
Cr	1.020±0.210	1.070±0.030	1.040±0.030
Cu	1.201±0.030	1.510±0.009	1.012±0.200
Fe	24.101±14.611	12.710±0.110	14.400±6.581
Mn	2.510±1.813	0.700±0.310	1.500±0.110
Zn	6.113±3.003	5.428±0.320	7.984±3.360

Table 13. Concentration of heavy metals (mg/kg) in fish of the river Padma.

Parameters	**Mawa (Mean±SD)**	**Godagari (Mean±SD)**	**Pakshi (Mean±SD)**
Pb	0.006±0.003	0.0±0.0	0.0±0.0
Cd	0.020±0.005	0.030±0.010	0.030±0.007
Cr	1.100±0.410	1.020±0.050	0.540±0.010
Cu	1.201±0.060	1.010±0.002	0.711±0.007
Fe	18.601±4.210	13.210±2.900	8.600±0.581
Mn	0.910±0.512	0.800±0.210	0.800±0.410
Zn	7.313±2.710	7.228±2.421	7.482±2.300

Discussion

According to Fakayode (2005), the pH of a water body is very important in determining water quality as it affects chemical reactions such as solubility and metal toxicity. Adequate DO is necessary for good water quality, survival of aquatic organism and decomposition of waste by microorganism (Islam *et al.*, 2010 and Rahman *et al.*, 2012). The average value of DO (6.5 mg/l) was found suitable (APHA, 2005) in the present study.

Total Dissolved Solids (TDS) are the direct measurement of particle concentration that quantifies the diffraction of light caused by particles in water (Chapman, 1996). Increased TDS can clog the gills of fish and serve as a carrier of pollutants and pathogens and may be associated with lower levels of DO. In the present study, TDS values were found lower than the recommended concentrations (USEPA, 500 mg/l). Unpolluted and natural waters should have a BOD of 5 mg/l or less. BOD directly affects the amount of DO in rivers and streams. In the present study, BOD values were less than the recommended standards (10 mg/l) for Bangladesh (ADB, 1994). The level of COD determines the quantities of organic matter found in water and is considered as a useful indicator of organic pollution in surface water. In the present study, COD values indicate that organic pollution is gradually increasing in the rivers.

The contribution of phytoplankton and zooplankton was 91.3% and 8.7%, respectively. Shafi *et al.* (1978) found 76.0-93.6% phytoplankton and Ahmed *et al.* (2003) found 3% zooplankton from the Meghna river that complies with the present findings. Among the phytoplankton, Chlorophyceae was found as dominating group in the rivers followed by Bacillariophyceae. Mahmud *et al.*, (2007) also found similar results. On the contrary, among the zooplankton, Copepods were the dominating group in the Meghna river. Ahmed *et al.,* (2003) also observed Copepods (51.2%) as the most dominant group among total zooplankton abundance.

The Cr and Cd concentrations in water and sediment samples recorded in this study are similar to the findings of Obire *et al.* (2003). Suspension of sediments into the water body may increase the metal concentration in the water. Sediment is the major depository of metals in some cases, holding more than 99% of total amount of a metal present in the aquatic system (Odiete *et al.*, 1999). Alam *et al.*, (2003) found that in Buriganga river the Pb concentration varied between 0.1 to 0.7 μg/l in rainy season and 5 to 14.4 μg/l in dry season, which are mostly near to the findings of the present study. Among the heavy metals (Zn, Mn, Pb, Cr, Cu, Fe and Cd) in water, Cd and Cr had the least occurrence at each sampling site while Fe was the highest. These results agreed with the permissible limit of WPCL (2004).

In the present study, heavy metals concentrations were found higher in sediment compared to water and fish. The higher concentration of Fe in the sediment might be due to presence of clay materials which forms the riverbed. The Fe content found in fish might have been accumulated from the deposition of riverbed through food chain (Adefemi *et al.*, 2008 and Adeniyi *et al.*, 1982). However, in sediments the permissible limits of Cd, Pb, Cu, and Zn were found with the recommended Danish standards (Tabinda *et al.*, 2013).

The heavy metals in fish tissues were minimum at each sampling site while Fe and Zn were found maximum. High concentrations of Fe generally cause inky flavor, bitter and astringent taste in fishes (Hassan, 2012). However, evidence of such claim is not yet established from the fish of Meghna river in Bangladesh.

Conclusion

The river Padma and Meghna play a vital role in inland open water capture fisheries, particularly for hilsa the national fish of Bangladesh. However, the maintenance of water quality and primary productivity of the two mighty rivers are a great concern for the development of fisheries resources. The results of the present study indicate that these rivers are not polluted and still congenial for fisheries resources including hilsa. Considering the present study and previous results, it can be concluded that the Padma and Meghna river are productive in the context of the abundance of planktonic population. In addition, no heavy metal above the acceptable limits was detected in hilsa fish.

Chapter V

Food and Feeding Habits of Hilsa

Introduction

The importance of knowledge of food and feeding habits of a fish in understanding its fishery biology is well established. Often it helps in finding out the seasonal variation in the distribution of a fish species. The nature of food composition of a fish also throws light on the possible habitats it frequently moves. Hilsa, *Tenualosa ilisha* is an important and popular commercial fish in Bangladesh (Fig. 1). Although food and feeding habits bear much importance in understanding its biology, but it has not been well studied for hilsa in Bangladesh.

Hilsa primarily is a plankton feeder and its food include blue-green algae, diatoms, desmids, copepods, cladocera, rotifers, etc. Hilsa spend their different life stages in different habitats. Therefore, food and feeding habits may be different in different ecosystems and may vary according to the season and age of the fish (larvae, juvenile and adult). Feed composition may vary as well with seasonal succession of different food organisms in the water bodies.

Fig. 1. *Tenualosa ilisha*

Hilsa is the most abundant fish in the Ganges-Brahmaputra drainage system of Bangladesh and India, forming one of the most important commercial fisheries of single species in the countries around the Bay of Bengal. However, this highly popular fish declined in almost all major river systems of Bangladesh during 1987-2003 due to severe fishing pressure (DoF, 2019). Hilsa is a migratory fish and it normally migrates for breeding and feeding purposes. So, it is important to have a complete knowledge of food and feeding habits of hilsa at different stages of life cycle at different environment for better management of the fishery.

Materials and Methods

In order to study the food and feeding habit of hilsa, 124 live specimens of *T. ilisha* was collected from the experimental fishing conducted in the river Padma, Meghna and Meghna estuary of the Gangetic river system of Bangladesh (Fig. 2). The selected areas were Aricha and Mawa from Padma section; Chandpur and Hajimara from Meghna section and Tajumoddin and Hatia from Meghna estuary section.

After collecting the fish, total length (cm) and weight (g) were measured and the gut was dissected out and the sex and stages of maturity were noted. The stomach was separated out and preserved in 6% formalin. In the laboratory, the food organisms were identified up to the genus and family level when identification could not be made further by microscopic examination.

Fig. 2. Map of Bangladesh showing the sampling locations.

The food of this species was analyzed by Hynes (1950) point's method. Accordingly, by eye estimation the stomachs were allotted points in relation to their fullness, such as full stomach (F), 3/4 full, 1/2 full, 1/4 full and trace (T). No fish with gorged stomach was noticed during the study. These points were distributed among individual food items according to the estimated volume. The points gained by one individual food item during a month were added up and divided by the number of fish examined to ascertain the average food contents on a particular item of food. The identification of food materials consumed by the fish was done according to Needham and Needham (1962) and APHA (1966).

Results

The mean percentage composition of food of adult and juvenile hilsa in the Gangetic river system is shown in Fig. 3 that illustrates algae, organic debris, diatoms and rotifers were found as the major constituents of food for both adult and juvenile hilsa. The sand grains were obviously accidental inclusions with debris. Hilsa is generally considered as a plankton feeder though Hora and Nair (1938 and 1940) inferred that juvenile hilsa feed at the bottom. The juvenile hilsa studied belong to the size range from 5.0 to 20.0 cm and adults had appreciable quantities of food in the stomach were mostly virgin maturing (stage II). Therefore, it may be concluded that the fish mostly feeds at the bottom throughout the life commencing on 5.0 cm size albeit feeding is not restricted to the bottom zones as is evident from the predominance of planktonic organisms like algae, diatoms and rotifers, which obviously could have been obtained from the surface zones.

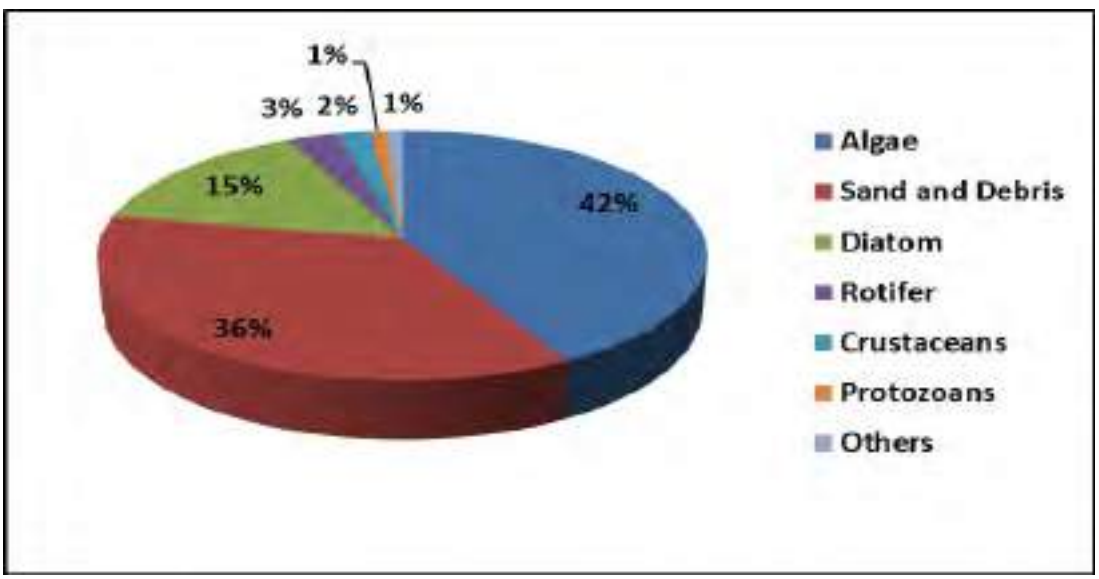

Fig. 3. Food composition of hilsa.

The main genera of algae found in the gut of hilsa are listed month wise in Table 1. A total 26 phytoplankton genera were identified including Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae, Xanthophyceae and Dinophyceae (Fig. 4). *Spirogyra,* *Ulothrix* and *Cyclotella* were the most common form out of which *Spirogyra* found throughout the year except in the month of June, August and November. *Ulothrix* and *Cyclotela* occur in the stomachs for eight months in the year. The other genera of algae were found only two to five months in a year. Among the zooplankton, 12 genera were identified including Rotifera, Cladocera, Copepoda and Protozoa (Fig. 5). Copepods and Cladocerans formed the bulk of the crustaceans in the gut contents. *Keratella, Diaptomus, Bosmina* and *Daphnia* were most common. Nauplii of copepods were also present in the guts almost throughout the year. The occurrence of different genera of phytoplankton and zooplankton in the guts during different months has been presented in Tables 1 and 2.

The feeding intensity of the condition of feed was determined by observations of the degree of distension of the stomachs described by Pillay (1952) and classified as empty, traces, 1/4, 1/2, 3/4 and full. The data relating to month wise fluctuations in the intensity of feeding during the period of observation are shown in Table 3. From June to November hardly any specimen was found to consume much food, most of them had empty stomach or only traces amount of food. From January to April feeding appears intensive with the peak in February and March.

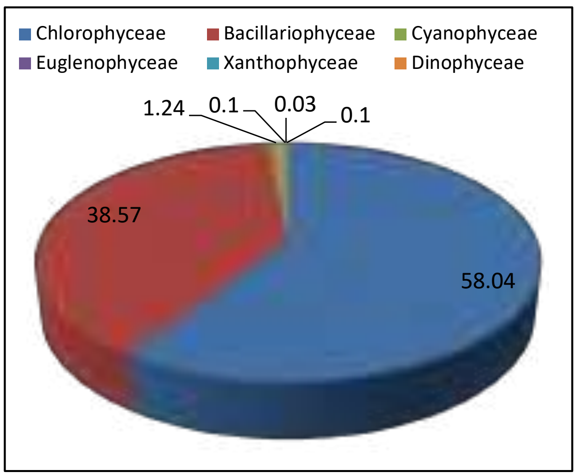

Fig. 4. Percentage composition of phytoplankton.

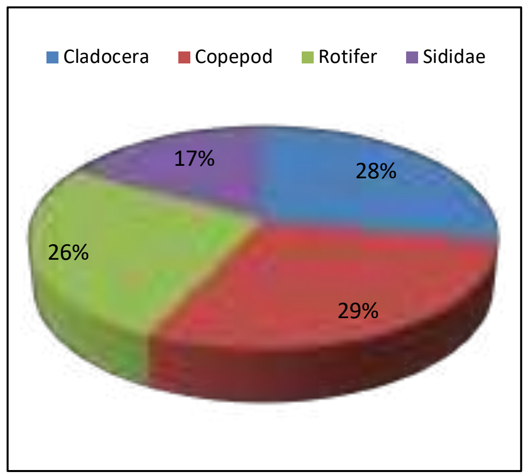

Fig. 5. Percentage composition of zooplankton.

Table 1. Occurrence of phytoplankton in guts of hilsa during September 1990 to August 1991.

Genus	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Phytoplankton												
Spirogyra	*	*		*	*	*	*	*	*		*	
Ulothrix				*	*	*	*	*	*	*		*
Spirulina						*	*	*		*		
Pediastrum						*	*	*				
Pleodorina						*	*	*				
Gomphonema				*	*	*	*	*	*			
Melosira					*	*	*	*		*	*	
Diatoma								*				
Navicula						*	*	*				
Moqoetia							*	*				
Microcystis					*	*	*	*				
Cyclotella					*	*	*	*	*	*	*	*
Genicularia					*	*	*					
Synedra					*							
Asterionella					*							
Microspora					*							
Volvox					*	*	*					
Chlorella						*	*	*				
Udorina						*	*	*				
Closterium						*						
Richterella							*					
Botryococcus							*					
Anacystis							*					
Phacotus							*					
Synura								*				
Euglena								*				

Table 2. Occurrence of zooplankton in the guts of hilsa during September 1990 to August 1991.

Genus	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
<u>Zooplankton</u>					*	*	*	*	*	*		
Keratella						*	*	*				
Brachionus						*	*		*	*	*	
Diaptomus							*					
Filinia				*		*	*	*				
Bosmina				*		*	*	*				
Daphnia												
Diaphanosoma						*	*				*	
Cyclops				*		*						
Sida							*	*				
Alonella						*	*					
Polyarthra									*	*		
Ceriodaphnia						*						

Table 3. Monthly fluctuations in the intensity of feeding (in percentage)

Months	Full	3/4 Full	1/2 Full	1/4 Full	Traces	Empty
Sep'90					83.33	16.67
Oct				25.00	50.00	25.00
Nov					25.00	75.0
Dec		25.00	25.00		25.00	25.00
Jan'91		60.00	10.00	30.00		
Feb	30.78	34.46		23.08	7.68	
Mar	40.00	40.00	5.00	5.00	10.00	
Apr	14.29	7.14	28.57	35.71	14.29	
May			10.00	30.00	60.00	
Jun		7.68		15.38	61.54	15.38
Jul		7.14		14.29	64.28	14.29
Aug				8.33	66.67	25.00

Adults as well as juveniles (jatka) were found to have greater feeding intensity during the spring season when there was abundant plankton in the river. A period of lesser plankton growth in the river *i.e.* during monsoon, which forms the main breeding season of the fish, the feeding intensity was generally low. It was observed that during the spawning season, hilsa almost cease to feed. Moreover, a good number of adults and juvenile fish were found with empty stomachs throughout the year. However, it does not indicate any complete relation with spawning. It may be assumed that the food has been emitted out due to the shock at the time of capture.

Discussion

The young stages of hilsa are mostly confined to the rivers and the upper reaches of the estuary and feed on both phytoplankton and zooplankton. Hora (1938, 1940) observed that the young hilsa between 20-40 mm in length mostly feed on diatoms and sparingly on crustaceans. Larger specimens up to 100 mm were found to feed on smaller crustaceans and also on insects and polyzoa. He also inferred that the young hilsa fed on the bottom as well. Shafi *et al.* (1977) recorded that the juveniles were voracious eaters and bottom feeders, and that the food and feeding habits changed with the increase in size of the fish and changes of the season. The jatka are often found in the lower reaches of the freshwater rivers and in the brackish water estuaries as well. They also prefer the planktonic food, mostly depend on the phytoplankton with small portion of zooplankton. In a review Rahman (2006) mentioned that diet of hilsa varies with season and size of fish. Juvenile hilsa up to 20-40 mm (TL) feed mostly on diatom and sparingly on Copepods, *Daphnia* and Ostracods; jatka fish up to 100 mm (TL) was found to feed on small crustaceans, insect larvae, chironomid larvae and polyzoa, while large fish up to 150 mm (TL) included shrimp in their diet along with other food organisms. De and Datta (1990) stated that hilsa is a strainer type of feeder that supports the planktivorous feeding habits of this species.

The adult fish live mostly in the sea, where they feed on the marine algae. When they become adult, they migrate to the rivers for breeding purpose. Reports on the feeding of adult hilsa during upstream migration are rather mixed. Pillay and Rosa (1963), Quereshi (1968) and Shafi *et al.* (1977) have found that adult hilsa cease to take any food during upstream migration and rather they depend on the fat deposit in their body. Furthermore, Chacko and Ganapati (1949) and Chacko and Krishnamurthy (1950) have also observed that during the spawning season *T. ilisha* ceases to feed. The probability of the low intensity of feeding during the spawning season is being due to the scarcity of food organisms in the river during the rainy season. On the contrary, Pillay (1958) and Haldar (1968) found no evidence of cessation or even any significant decrease in the feed uptake during upstream spawning migration.

In the present study, it was found that the diets of jatka include both phytoplankton and zooplankton; diets of the post-jatka consist mostly of phytoplankton. Narejo *et al.* (2005) in their studies of land locked *T. ilisha* found that the adults (138-328 mm TL) feed exclusively on phytoplankton with Bacillariophyta dominating the diet with 70% occurrence that support the present findings. However, Narejo *et al.* (2005) did not quantify the maturity status of these land locked hilsa.

Mazid and Islam (1991) noted that relatively large but immature hilsa preferred phytoplankton and jatka were voracious feeders. They further mentioned that hilsa become gradually phytoplankton feeder as they grow. Rahman (1992) reported the juveniles are plankton feeders, eating blue green and green algae, diatoms and desmids among the phytoplankton, and copepods, cladocerans and rotifers among the zooplankton.

The study on stomach content analysis of *T. ilisha* conducted from Chilka, India revealed that the food items recovered from the stomachs consisted of copepods, detritus, algae, mysis, molluscan larvae, diatoms, rotifers and mud and sand particles (Karna *et al.,* 2012). Out of which copepods were found the most preferred food items in all seasons. From the overall food items recovered from the stomachs of the species, copepods alone constitute 34.94% followed by detritus (29%), algae (10.47%), mysis (10.29%) and molluscan larvae (4.76%). Diatoms and rotifers observed very rarely that constituted together only 3% of all food items. So, the study indicated that *T. ilisha* is a microphagus, bottom feeder and prefer mostly copepods than other food items.

Hasan *et al.* (2016) recorded 56 genera of phytoplankton in the analysis of hilsa guts and 17 genera of zooplankton. The combined analysis of hilsa gut contents revealed that hilsa mainly feed on phytoplankton (98.08%) with a small quantity of zooplankton (1.92 %). Chlorophyceae was the most common (58.04%) among the phytoplankton followed by Bacillariophyceae (38.57%), Cyanophyceae (1.24 %), Euglenophyceae (0.1%), Dinophyceae (0.1%) and Xanthophyceae (0.03%). Among the zooplankton, Cladocera (0.77%) dominated in the gut contents, followed by Rotifera (0.56%), Copepoda (0.52%) and Protozoa (0.06%).

These finding also support the earlier record of food items observed in hilsa stomach by Rahman *et al*., 2012.

Chapter VI

Population Dynamics and Stock Assessment of Hilsa, *Tenualosa ilisha*

Introduction

The magnitude, dynamics and resilience of any fish stock pose a great challenge to their assessment as well as management. The fishery resources are unique at least on three factors: (i) many species have wide spatial distribution, (ii) several species show wide temporal variations in abundance, and (iii) as the resources cannot be seen visually, gaining an insight into the population structure and function of the resources is a challenge. Therefore, to exploit, manage, develop, and conserve the fish stocks, it is essential to have accurate information on the stocks. In Bangladesh, the information and knowledge on its Maximum Sustainable Yield (MSY), Total Mortality (Z), Natural Mortality (M), Fishing Mortality (F), Recruitment Pattern (R), Yield per Recruit (Y/R), Relative Biomass per Recruit (B/R), and Exploitation Rate (E) of hilsa are still inadequate for development of proper management guideline for the hilsa fishery resources and to maintain a steady flow of production in future. The estimation of population parameters assists to know the present fishing level of any fish population, and whether the fishery is under-fished or over-fished. Thus, stock assessment of hilsa can provide crucial information on Optimum Exploitation Level (OEL). Recent hilsa production trend is showing a positive impact of different management interventions that might have reshaped the structure of hilsa population in Bangladesh. Simultaneously, the ecological parameters that support and nourish the hilsa fishery might be changed as well in the realm of global climate change. Besides, dissolved and suspended contaminants from the upstream rivers may also disrupt the ecological balance of hilsa nursery and spawning grounds. Therefore, studies on population dynamics and stock assessment are absolutely necessary for successful management and sustainable production of hilsa.

Materials and Methods

Monthly length frequency data of *T. ilisha* were collected from the commercial catches of twelve landing sites of Bangladesh, *i.e.* Godagari, Rajshahi; Dalutdia, Rajbari; Mawa, Munshiganj; Chandpur Sadar, Chandpur; Alexander and Ramgoti, Laxmipur; Daulatkhan and Monpura, Bhola; Barisal Sadar, Barisal; Mohipur and Khepupara, Potuakhali; Pathorghata, Borguna; BFDC Ghat, Khulna; BFDC Ghat, Chattogram and BFDC Ghat, Cox's Bazar from July 2018 to June 2019 (Fig.1). The GPS coordinates of all sampling locations are presented in Table 1. In addition to the landing sites, length frequency data were also collected from the catch of river cruise conducted by M.V. Rupali Ilish (Hilsa Research Vessel of BFRI). On each sampling occasion, efforts were made to measure at least 200 individuals in order to ensure the presence of all size groups of the population in the sample (King, 1992). The data were then pooled monthly from different landing sites and subsequently grouped into classes of 1-centimeter intervals. The data were analyzed using

FiSAT II (FAO-ICLARM Stock Assessment Tools) as explained in detail by Gayanilo Jr. *et al*. (1996).

For each individual, total length (TL) of fish was measured (after Ricker, 1979) to the nearest centimeters with slide calipers and the weight of individual fish (BW) was determined using a digital balance. The relationship between TL and BW were calculated using the expression: $BW = a \times TL^b$,

Where a and b are the constants of the equation. Parameters *a* and *b* will be estimated by linear regression analysis based on natural logarithms: $\ln(BW) = \ln(a) + b \ln(TL)$.

Fulton's condition factor (K_F) was calculated using Fulton's equation (1904): $K_F = 100 \times (BW/TL^3)$. Statistical analyses were performed using Microsoft® Excel-add-in-DDXL.

Growth was calculated by fitting the von Bertalanffy growth function to length frequency data. The von Bertalanffy growth equation is defined as follows (Sparre and Venema, 1998): $L_t = L_\infty [(1-\exp(-K(t-t_0))]$,

Where L_t is the length at time t, L_∞ is asymptotic length, K is growth coefficient and t_0 is the hypothetical time at which length is equal to zero.

The t_0 was value estimated using the empirical equation (Pauly, 1980).
$\text{Log}_{10}(-t_0) = -0.3922 - 0.2752 \text{Log}_{10}L_\infty - 1.038 \text{Log}_{10}K$

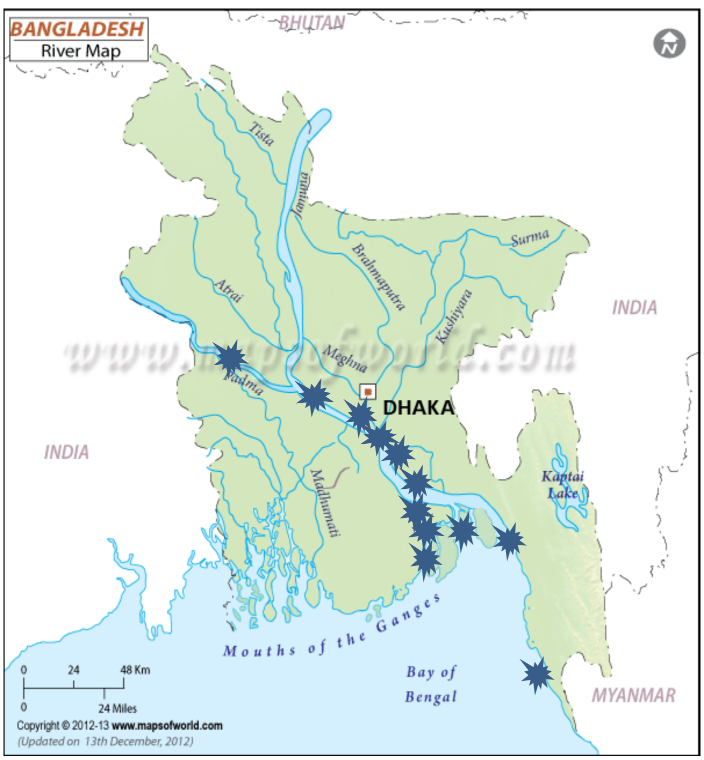

Fig. 1. The asterisk marks on the map of Bangladesh indicates selected sampling locations.

Table 1. GPS coordinates of all sampling locations.

Sl No.	Districts	Source	Sampling sites	GPS Position
1	Cox's Bazar	Bay of Bengal	BFDC Landing Station	N: 21°27´07.26´´ E: 91°58´05.42´´
2	Chattogram	Bay of Bengal	BFDC Landing Station	N: 22°19´09.18´´ E: 91°50´19.56´´
3	Laxmipur	Meghna river	Alexander	N: 22°39´16.47´´ E: 90°54´24.23´´
		Meghna river	Ramgoti	N: 22°38´47.07´´ E: 90°55´53.57´´
		Meghna river	Monpura	N: 22°15´26.16´´ E: 90°57´41.21´´
4	Bhola		Dalautkhan	N: 22°35´38.33´´ E: 90°45´19.28´´
5	Barisal	Meghna, Tetulia, Paira, Kirtonkhola, Arialkhan,	BFDC Landing Station	N: 22°41´36.00´´ E: 90°22´23.62´´
6	Borguna	Bishkhali river and Bay of Bengal	Patharghata Landing Station	N: 22°3´6.59´´ E: 89°58´19.81´´
7	Potuakhali	Andharmanik river and Bay of Bengal	Mohipur and	N: 21°5´23.89´´ E: 90°7´21.24´´
			Khepupara	N: 21°58´56.86´´ E: 90°13´29.61´´
8	Khulna	Kocha, Shibsha, Rupsha, Poshur rivers and Sundarban areas	BFDC Landing Station	N: 22°48´31.26´´ E: 89°34´42.46´´
9	Rajshahi	Padma and Mohananda rivers	Gudagari	N: 24°27´25.54´´ E: 88°19´ 39.06´´
10	Rajbari	Padma river	Dalutdia	N: 23°45´53.38´´ E: 89°46´55.38´´
11	Munshiganj	Padma river	Mawa	N: 23°27´57.08´´ E: 90°16´46.98´´
12	Chandpur	Meghna river	Boro Station,	N: 23°13´47.34´´ E: 90°38´35.93´´
			Horina Ghat	N: 23°09´50.94´´ E: 90°38´44.09´´

The fitting of the best growth curve was based on the ELEFAN I program (Pauly and David 1981), which allows the fitted curve through the maximum number of peaks of the length-frequency distribution. With the help of the best growth curve, growth constant (K) and asymptotic length (L_∞) were estimated.

The growth performance (ϕ) of *T. ilisha* population in terms of length growth was computed using the index of Pauly and Munro (1984).

$$\phi = \text{Log}_{10} K + 2\,\text{Log}_{10} L_\infty$$

The annual instantaneous rate of total mortality (Z) was calculated using length converted catch curves adapted to incorporate seasonal growth patterns (Gayanilo and Pauly, 1997). Pooled length frequency samples were converted into relative age frequency distributions using parameters of the von Bertalanffy growth function. The annual instantaneous rate of natural mortality (M) was estimated using the empirical equation derived by Pauly's empirical equation (Pauly, 1980).

$Log_{10} M = 0.0066 - 0.279 Log_{10} L_{\infty} + 0.6543 Log_{10} K + 0.4634 Log_{10} T$,

Where, L is expressed in cm and T is the mean annual environmental water temperature in °C. Here it is 28°C. Fishing mortality (F) was obtained by subtracting M from Z and exploitation rate (E) was obtained from F/Z [E=F/Z=F/(F+M)] (Gulland, 1971). Recruitment pattern was attained by backward projection on the length axis of a set of length-frequency data as described in the FiSAT II routine.

Relative yield per recruit (Y/R) and relative biomass per recruit (R/B) values as function of E were determined from the estimated growth parameters and probability of capture by length (Pauly and Soriano, 1986). The calculation was carried out using the complete FiSAT II software package.

Virtual Population Analysis (VPA) and cohort analysis were done according to the FiSAT II routine following the method of Fry (1949). The values of L_{∞}, K, M, F, a (constant) and b (exponent) for the species were used as inputs to a VPA analysis in the FiSAT II routine. The t_0 value will be taken as zero.

The MSY of *T. ilisha* was also estimated. For this purpose, at first exploitation rate (E) was estimated using the equation given by Beverton and Holt (1957) and Ricker (1975) as E = F/Z $(1-e^{-z})$. Using the values of E, F and estimated annual catch (Y), the total annual stock (Y/E) and average standing stock (Y/F) were determined. Relative Y/R model of Beverton and Holt (1957) as modified by Pauly and Soriano (1986) was used and data was incorporated in the FiSAT II software to estimate the current state of the stock and the yield and biomass according to (Troadec, 1980). The yield isopleth diagram was used to assess the impact on yield created by changes of exploitation rate E and the ratio of length at first capture to asymptotic length (L_c/L_{∞}) in relation to changes in mesh size to recommend appropriate management regimes.

Results

Length-weight Relationship of Male and Female Hilsa

A total of 50,990 species of *T. ilisha* were collected and the range of total length, weight, values of "a" and "b" and correlation coefficient were measured and calculated. The overall length of male hilsa was found to be ranged from 11.5 cm to 52.5 cm and for female hilsa, overall length ranged from 18.0 cm to 59.6 cm. The length-weight relationship (LWRs) of pooled data for all months for male and female hilsa were- body weight (BW) = 0.0084 total length $(TL)^{3.06}$ with $r^2 = 0.930$ and BW = 0.0054 $^{TL3.19}$ with $r^2 = 0.940$, respectively (Fig. 2). The regression parameters and 95% confidence interval for b of the LWRs, exhibited considerable variations and the growth pattern ranged from negative to positive allometric (Table 2).

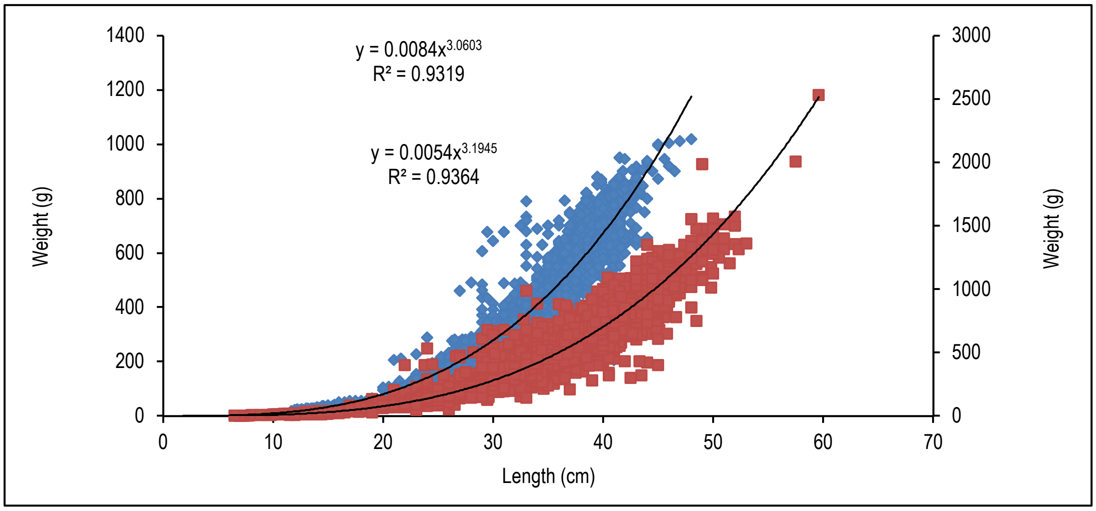

Fig. 2. Length-weight relationship of male and female hilsa for all months (primary axis) and locations (secondary axis).

Condition Factor of Male and Female Hilsa

The average Fulton's condition factor (K) was determined according to Pauly (1983) and it ranged from 0.86±0.14 to 1.03±0.2 for male and 1.02±0.13 to 1.18±0.2 for female. In general, the conditions of female were comparatively better than the male hilsa (Fig. 3).

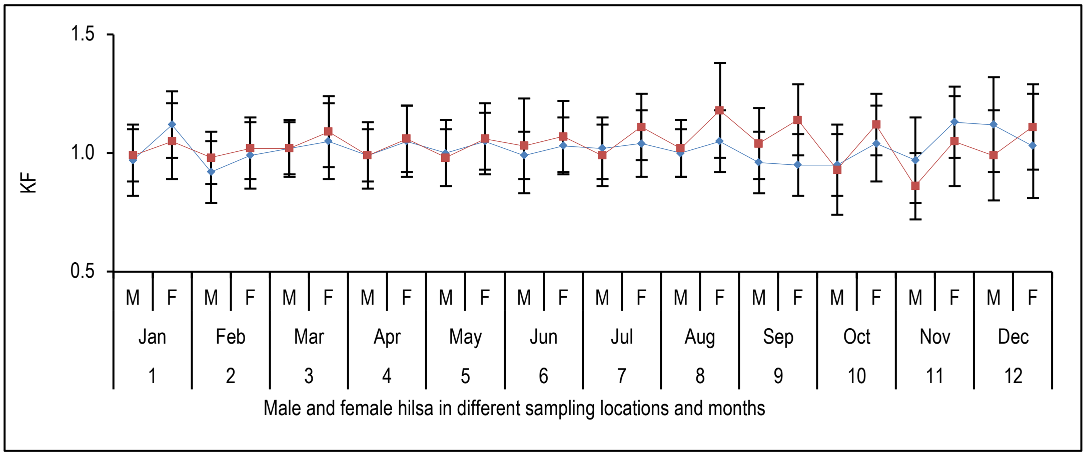

Fig. 3. Fulton's condition factor (K_F) of male and female hilsa in different months and locations.

Table 2. Length–weight relationships for both sexes of *T. ilisha* in different months.

Months	Sex	n	Length (cm)		Weight (g)		Regression parameters		95% CI of *b*	r^2	Growth type
			Min	Max	Min	Max	*a*	*b*			
Jan	F	2200	20.0	52.3	34.0	1316.0	0.009	3.02	2.97 to 3.06	0.910	I
	M	970	15.0	41.0	52.0	760.0	0.007	3.10	3.06 to 3.14	0.970	+A
Feb	F	2362	19.0	52.0	78.0	1354.0	0.005	3.14	3.10 to 3.18	0.920	+ A
	M	890	19.0	42.0	48.0	702.0	0.008	3.02	2.94 to 3.10	0.920	I
Mar	F	2550	21.2	48.0	95.0	1180.0	0.006	3.15	3.10 to 3.20	0.870	+ A
	M	1350	23.5	39.8	110.0	657.4	0.006	3.14	3.03 to 3.26	0.910	+ A
Apr	F	2830	19.0	49.0	61.0	1320.0	0.005	3.18	3.13 to 3.23	0.880	+ A
	M	1694	15.0	43.0	32.0	830.0	0.010	2.98	2.96 to 3.00	0.990	− A
May	F	2502	18.1	52.0	65.0	1571.0	0.004	3.26	3.22 to 3.31	0.870	+ A
	M	1211	15.0	45.5	32.0	1000.0	0.013	2.89	2.82 to 2.95	0.910	− A
Jun	F	2996	23.0	60.0	114.0	2532.0	0.010	3.00	2.94 to 3.06	0.840	I
	M	2504	21.0	53.0	86.0	1075.0	0.019	2.81	2.72 to 2.90	0.890	− A
Jul	F	3128	22.0	53.0	100.0	1450.0	0.007	3.09	3.04 to 3.14	0.880	+ A
	M	1642	17.0	43.0	78.0	900.0	0.008	3.04	2.89 to 3.19	0.820	I
Aug	F	3255	23.5	52.0	124.0	1501.0	0.005	3.20	3.11 to 3.20	0.930	+ A
	M	1536	18.0	38.5	76.0	620.0	0.006	3.14	3.08 to 3.21	0.910	+ A
Sep	F	2830	23.0	51.0	100.0	1555.0	0.004	3.25	3.20 to 3.29	0.910	+ A
	M	1292	21.0	36.5	90.0	640.0	0.001	3.56	3.43 to 3.69	0.960	+ A
Oct	F	3550	18.0	48.0	58.0	1350.0	0.007	3.09	3.04 to 3.15	0.900	+ A
	M	1317	12.0	37.0	90.0	590.0	0.002	3.44	3.36 to 3.52	0.960	+ A
Nov	F	2144	19.0	46.0	56.0	1170.0	0.052	2.54	2.44 to 2.64	0.910	− A
	M	1430	19.0	39.0	52.0	525.0	0.006	3.05	2.88 to 3.22	0.910	+ A
Dec	F	2245	21.0	44.0	95.0	950.0	0.004	3.28	3.21 to 3.34	0.870	+ A
	M	1132	20.0	42.0	220.0	950.0	0.184	2.13	1.96 to 2.31	0.630	− A
Overall	F	34022	20.6	50.6	81.7	1437.4	0.0084	3.10	3.09 to 3.10	0.930	+ A
	M	16968	22.7	41.7	80.5	770.8	0.005	3.20	3.15 to 3.18	0.940	+ A
	B	50990	21.7	46.2	81.1	1104.1	0.006	3.10	3.09 to 3.18	0.960	+ A

Length Frequency Distribution

The total lengths of 50,990 individuals of *T. ilisha* were measured in the size range 11.5 to 59.6 cm. The percentage of different size classes of *T. ilisha* has been presented in Fig. 4. The highest production of hilsa was contributed by 35-36 cm size group followed by 37-38 and 33-34 cm size groups, respectively.

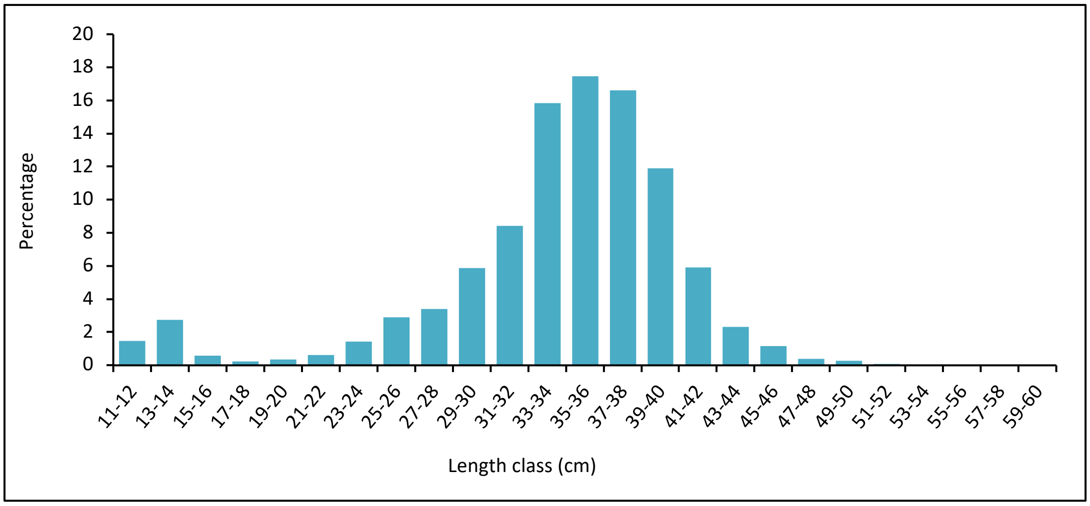

Fig. 4. Length frequency distribution of *T. ilisha* during the study period.

Growth Studies

Growth parameters of von Bertalanffy growth formula for *T. ilisha* were estimated as $L_\infty = 60.85$ cm and $K = 0.85$ yr^{-1}. For these estimates through ELEFAN II, the response surface ($R_n = 0.098$) was used. The computed growth curves produced with those parameters are shown over its restructured length distributions in Fig. 5. The calculated growth performance index was found 3.50 (Pauly and Munro, 1984).

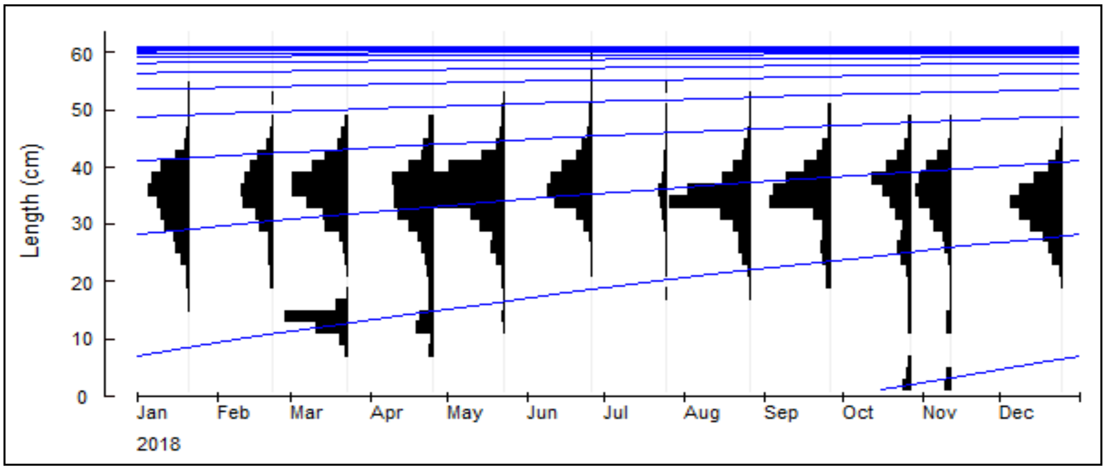

Fig. 5. Growth curve of *T. ilisha* from Bangladesh by ELEFAN II superimposed on the restructured length-frequency diagram ($L_\infty = 60.85$ cm and $K = 0.85$ yr^{-1}.).

Mortality Estimate

The annual natural mortality (M), fishing mortality (F) and total mortality (Z) were computed 1.32, 3.21 and 4.53, respectively using the length converted catch curve (Fig. 6). The darkened circles were used in calculating the value of *Z* through the least square linear regression. Good fit to the descending right-hand limits of the catch curve was considered. The fishing mortality rate (F) taken by subtracting M from Z and was found to be 3.21 yr^{-1} (Fig. 6).

Exploitation Rate

The estimated exploitation rate (E) was 0.71 that of the E_{max} value recorded as 0.59. The higher value of *E* indicates overfishing during the study period. This assumption is based on Gulland (1971). He stated that suitable yield is optimized when F=M, *i.e.*, when E is more than 0.50, the stock is generally considered to be overfished.

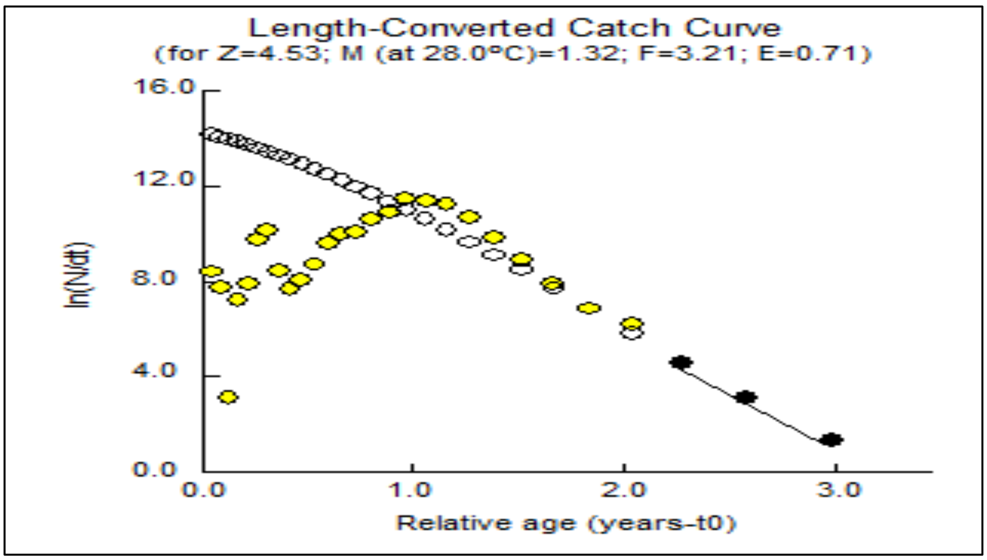

Fig. 7. Length-converted catch curve of hilsa.

Recruitment Pattern

Hilsa spawns throughout the year with two major peaks, one in October-November and another in between January-February. Therefore, it is obvious that hilsa will have two recruitment bulges in a year. The recruitment pattern (Fig. 8) shows that this species recruits in the fishery throughout the year with two major peaks. The peak pulse produced 19.81% of the recruits on the average.

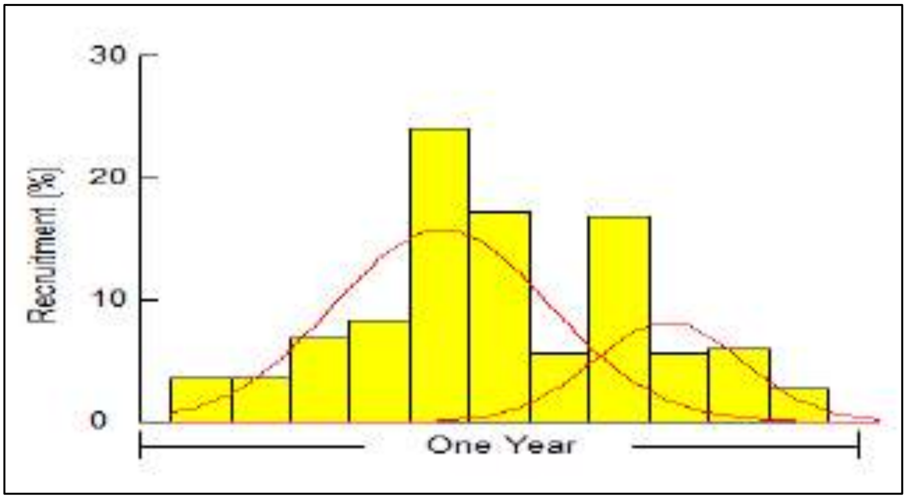

Fig. 8. Recruitment pattern of hilsa.

Yield per recruit and biomass per recruit

The values of the sizes of fish where the probability of capture was 50% (L_{50}) and 75% (L_{75}) were 27.79 and 31.22 cm (TL), respectively (Fig. 9). The relative yield-per-recruit (Y/R) and relative biomass-per-recruit (B/R) were determined as a function of L_c/L_∞ and M/K was 0.38 and 1.55, respectively. Figure 9 shows that the present exploitation rate (E = 0.71) exceeds the maximum exploitation level (E_{max} = 0.59) which produces the maximum yield (Fig. 10).

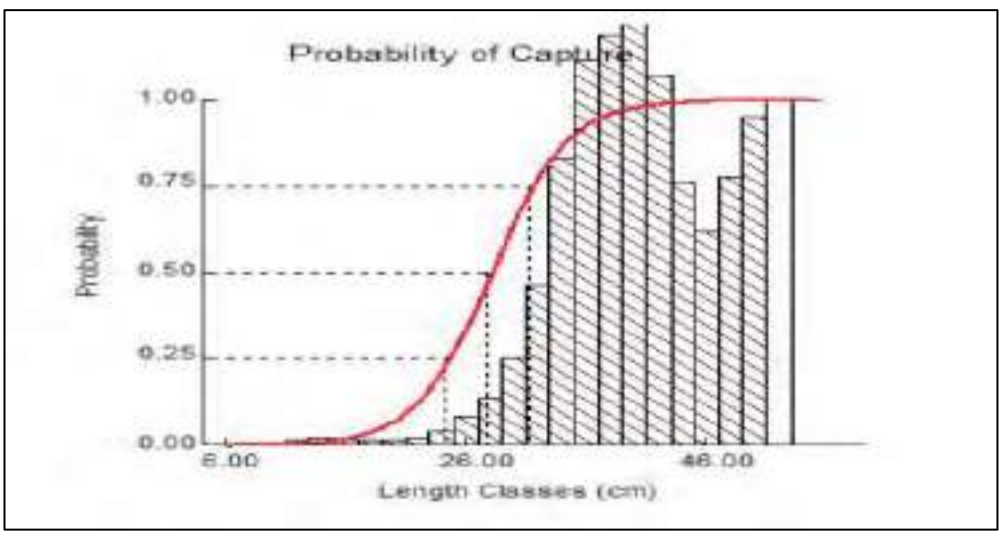

Fig. 9. Probability of capture against length-classes of hilsa to estimate length at first capture ($L_c = L_{50}$ = 27.79 cm TL) in Bangladesh waters (L_∞ = 60.85 cm TL, K = 0.85 yr^{-1}).

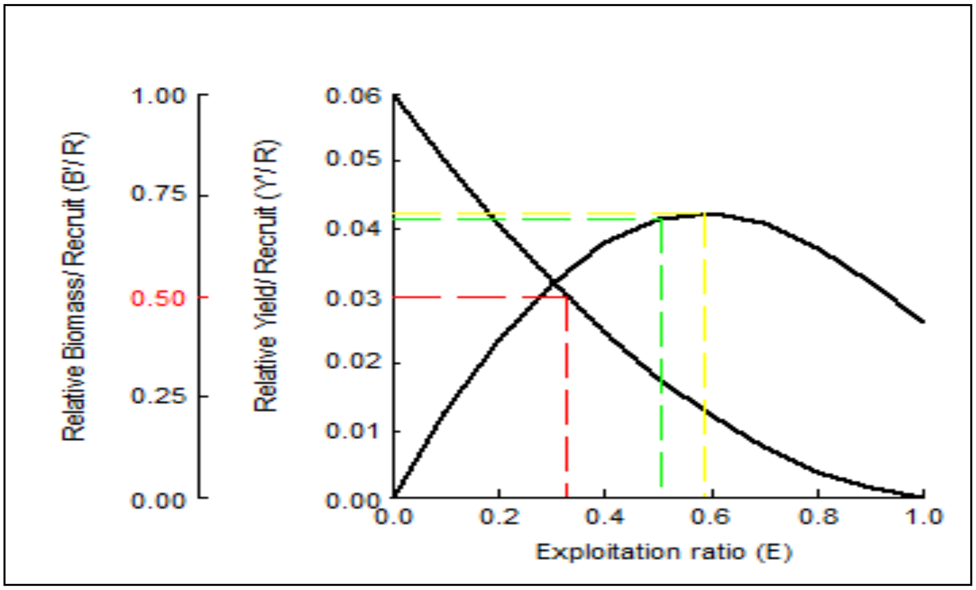

Fig.10. Relative yield per recruit (Y/R) and biomass per recruit (B/R) of *T. ilisha* in Bangladesh.

Virtual Population Analysis (VPA)

The length structured VPA is a powerful tool for stock assessment by which the size of each cohort is estimated along with the annual mortality caused by fishing. The results of VPA indicate that the maximum number of hilsa shads that are caught belongs to between 31 and 45 cm length group, with values of F exceeding 3.21 yr^{-1} (Fig. 11) which might be associated with excessive use of current jal (mono filament synthetic net, mesh size 6 to 10 cm).

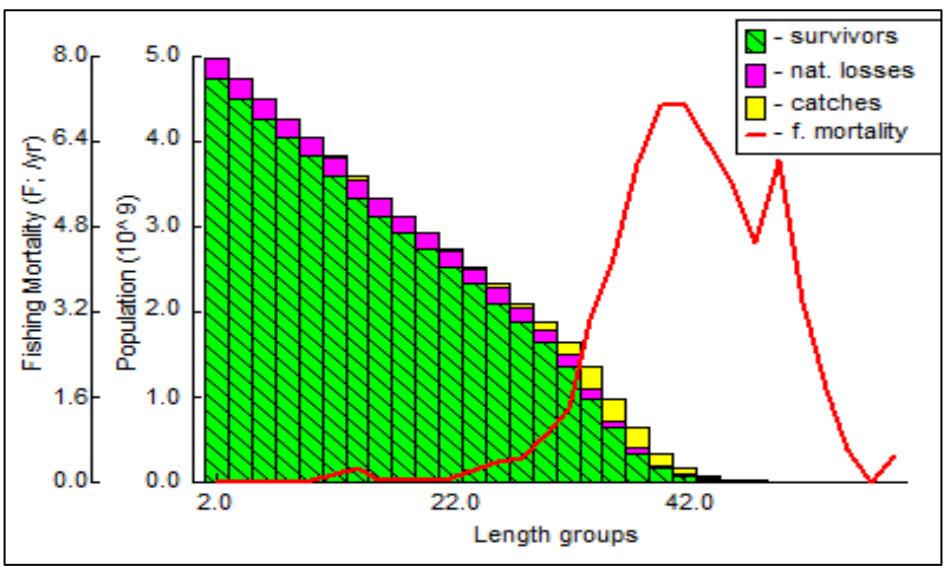

Fig. 11. Virtual population analysis of hilsa.

Stock Assessment

From the probability of capture analysis using selection curves, the estimated optimum TL of hilsa at first capture (L_c = L_{50}) was 27.79 cm (Fig. 9). The estimated total Standing Stock Biomass (SSB) using the length-structured virtual population analysis (VPA) routine of FiSAT II was 296,683.40 tonnes (269,146.703 MT). The SSBs for different size-class presented in Table 3, shows the changes in population number and SSB with size. The MSY of hilsa was estimated at 609,617.30 MT, if the recommended length at first capture (L_c = 27.79 cm TL) is maintained.

The MSY was estimated using the following formula:

$MSY = Zt * 0.5 * B_t$ = 609,617.3 MT (Troadec, 1980)

Where, Z_t is total mortality in year t = 4.53

B_t is the standing stock in year t = 296,683.40 tonnes (269,146.703 MT)

Table 3. Population number by size (TL) and steady state biomass (SSB) of hilsa at different levels of fishing mortality (*F*) in Bangladesh waters.

Mid Length	Population (N)	SSB (tonnes)
2-10	11,282,212,608.00	2,794.76
12-20	8,417,350,784.00	32,003.87
22-30	5,798,910,144.00	112,125.60
32-40	2,480,530,432.00	131,501.80
42-50	141,879,577.50	17,034.92
52-60	2,134,701.97	1,222.43
Total	28,123,018,247.00	296,683.40

Discussion

The relationship between body length and weight of fish is useful in assessing the wellbeing of the individuals and in determining the possible differences among different stocks of the same species (King, 2007). The Length-Weight relationships (LWRs) are effective in fishery assessments for predicting length distributions into weights for biomass estimates (Gerritsen and McGrath, 2007). In the present study, the length-weight relationship exhibited considerable variations in *T. ilisha*. In most of the cases, the relationship was positive allometric. However, isometric to negative allometirc relationship was also observed. In fact, the fish usually grows proportionately in all directions, and therefore, as the value of b increases, the size of the fish also increases. In a typical fish that maintains a constant shape, b will be 3.0, *i.e.*, growth is isometric (Andrade and Campos, 2002). However, the changes in fish weight are greater or more than the length of the fish and the same pattern is found in hilsa as well. The body shape of hilsa tends to be changed as the length increases. The value of b is a reflection of the general condition of appetite and gonad content of the fish (Pervin and Mortuza, 2008). The weight of fish increased when they utilize the food items that are available for growth and energy (Kamaruddin *et al*., 2012; Offem *et al*., 2007). However, the condition of fish is subject to exhibit substantial variations with a number of factors such as sex, growth phase, stomach contents and gonad development (Hossain *et al*., 2006; Leunda *et al*., 2006; Pervin and Mortuza, 2008; Thompson, 1943; Rounsefell and Everhart, 1953; Lagler, 1956; Morato *et al*., 2001). Such variations may also be related to the environmental factors and the age and physiological state of the fish (Brown, 1957).

The condition factor or ponderal index, or co-efficient of correlation expresses the condition of a fish, such as the degree of wellbeing, relative rubustness, plumpness or fatness in numerical terms. The condition factor (K_F) of hilsa ranged from 0.86±0.14 to 1.03±0.2 for males and from 1.02±0.13 to 1.18±0.2 for females. The condition factor reflects, through its variations, information on the physiological state of the fish in relation to its welfare. From nutritional point of view, it reflects accumulation of fat and gonadal development (Laleye, 2000). From reproductive point, some species even reach to the highest condition factor (Angelescu, *et al*., 1958). Since Fulton's condition factor, K_F is a measurement involving the length and weight for a particular fish; therefore, it could also be influenced by the factors that affect LWR. When K value is 1.00, the condition of the fish is supposed to be poor, long and thin (Barnham and Baxter, 1998). K value of 1.20 indicates the moderate condition of the fish. A good and well-proportioned fish would have a K value approximately of 1.40. According to Gupta *et al.* (2011), the differences in condition factor might be due to the availability of food organisms and gonadal development.

In the present study, the estimated asymptotic length (L_∞) was 60.85 cm and growth co-efficient (K) was 0.85 yr^{-1} for hilsa. Comparisons with a range of published estimates demonstrated that differences exist for K and L values of hilsa with other fish of different regions of the world or with the same species of Bangladesh waters (Rahman *et al*., 1998, 2000; Amin *et al*., 2002; Rahman and Cowx, 2008). Growth parameters differ from species to species, but they may also vary from stock to stock within the same species, *i.e*. the growth parameters of a particular species may take different values in different parts of its habitat range (Rahman and Cowx, 2008). Differences between recorded L_∞ and K might have influenced by ecological characteristics, population size and gene frequency of species considering their habitat, natural selection, and adaptation pattern during their life stages (Adams, 1980). Furthermore, successive cohorts may grow differently depending on environmental conditions. Growth parameters also often assume different values based on sexes (Rahman, 2001).

The instantaneous total mortality (Z) obtained for hilsa in the present study was 4.53 yr^{-1}. This value is higher than the Z values estimated for the same species, which were 2.61 yr^{-1} (Rahman *et al*., 1998); 2.03 yr^{-1} (Miah and Shafi, 1995); 2.49 yr^{-1} (Amin *et al*., 2002) and 2.38 yr^{-1} (Rahman and Cowx, 2008). Higher fishing mortality of hilsa (F=3.21 yr^{-1}) obtained in the present study could be attributable to this.

The instantaneous natural mortality (M) of hilsa (1.32 yr^{-1}) did not show much difference when compared to the instantaneous natural mortality (M) estimated by other authors for the same species (Miah and Shafi, 1995; Rahman *et al.*, 1998, 2000; and Amin *et al*., 2002). Fish species with a high K-value generally have a high natural mortality (M) value, and vice versa (Sparre *et al.*, 1989). This indicates that there is increasing fishing pressure in the hilsa fishery and therefore, the fishery is moving towards over exploitation.

The recruitment pattern of hilsa was continuous with two major pulses. The major pulse occurred in October-November and the minor in January-February. The two pulses are assumed to be associated with two peak spawning period. Thus, it can be said that the offspring born during the peak spawning period (October-November) are recruited in the fishery during March-May, forming the main recruitment pulse. Similarly, the offspring born during the second peak of the spawning (January-February) are recruited during November-January, forming the second pulse in the recruitment pattern.

The present exploitation level of E=0.71 indicates that there is over exploitation of hilsa fishery in Bangladesh. Similar results were found in some previous investigations, for instances, E = 0.56 (Miah *et al*., 1997), E = 0.66 (Rahman *et al*., 1999) and E = 0.60 (Rahman *et al*., 2000). However, the fishery should maintain the biologically optimum exploitation level of E = 0.55 for the riverine and E = 0.62 for marine population. Therefore, for sustainability of the fishery, fishing pressure must be regulated, especially in the riverine segments where fishing mortality is high. And to maintain a large exploited open water fishery, a sound management plan linked to the socio-economic conditions of the fishing communities and other parties involved in the fishery is essential.

Chapter VII

Hilsa Fisheries Management and Conservation Research Under Fourth Fisheries Project

Introduction

Fish production from inland open water started declining at the onset of 21st century in Bangladesh and also the production from captive water bodies were low compared to China, Thailand, India and some other countries of the world. However, the demand for fish being the main source of protein was increasing due to ever growing population of the country. To cater to the demand of increased fish supply, Department of Fisheries (DoF) implemented a preparatory project supported by government of Japan and the World Bank. This preparatory project led to formulation of a larger development project in the name of Fourth Fisheries Project (FFP). Hilsa Conservation and Management Studies was one of the components of FFP under the Aquatic Resource Development Management and Conservation Studies (ARDMCS).

The Hilsa Conservation and Management studies were implemented in cooperation with the Bangladesh Fisheries Research Institute (BFRI) under a Memorandum of Understanding (MoU) signed between the project-coordinating Director, FFP of DoF and Director of BFRI on 16 September 2002. The main conditions of the MoU were that the BFRI would provide resource persons, field and laboratory research facilities from all its research stations, logistic supports etc. and share research information as and when necessary for carrying out hilsa research and the FFP would provide the incremental cost to BFRI for implementation of research undertaken jointly by BFRI and ARDMCS. Both the parties would acknowledge the joint research efforts in all relevant internal documents, reports and scientific publications.

Objectives

The main objective of the study was to develop Hilsa Fisheries Management Action Plan for Bangladesh through investigation of the population structure, ecology and fishing mortality outlying the technical, legal and institutional activities DoF and other relevant organizations to sustain the fishery.

The detail objectives were:

- Implementation of different studies required for development of hilsa fisheries management action plan;
- Development of a bio-diversity friendly hilsa management action plan;
- Development of hilsa fisheries management action plan and mitigation program;
- Assessment of the potential social impact on hilsa fishers due to implementation of different actions and interventions; and
- Review and improvement of catch monitoring system of hilsa.

Achievement of Conservation and Management Studies

Taxonomic Status and Species Diversity of Hilsa and alike Fishes

The popular name Hilsa, virtually is the generic name of the Clupeid fish belonging the Sub-family-Alosinae, Family- Clupeidae of the Order Clupeiformes. Earlier, the generic name *Hilsa,* has been used for more than a half century. However, Fisher and Bianchi, 1984, have revised the systematic name of the genus *Hilsa* as *Tenualosa*. There are five species of fish of the genus *Tenualosa* in the world. Among them, two species of the genus *Tenualosa viz.* the *T. ilisha,* and *T. toli,* and one species of the genus *Hilsa*, *Hilsa kelee/kanagurta* are available in Bangladesh.

Fig. 1. *Tenualosa Ilisha.*

Fig. 2. *Tenualosa toli* (Photo source, FishBase).

Fig. 3. *Hilsa kelee/kanagurta* (Photo source FishBase).

Hilsa like other Fish Available in Bangladesh

Besides the genus, *Tenualosa* and *Hilsa,* 4 species of fish belonging the genus *Ilisha viz.,* the *Ilisha filigera, I. elongata, I. melastoma, I. megaloptera* and one species of the genus *Pellona*, the *P. ditchela* are reported to be caught in Bangladesh. The catch and other detail status of the above species so far are not clearly known. Based on observations on landings, it is assumed that their catches are decreasing. Detail investigations are required to conserve the diversity of these species.

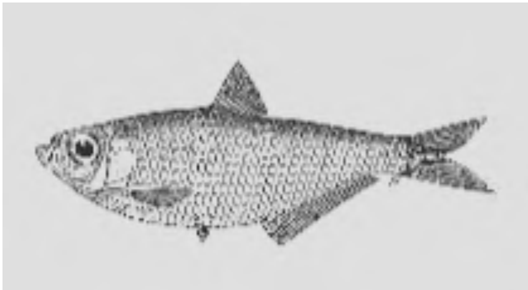

Fig. 4. *Ilisha melastoma.*

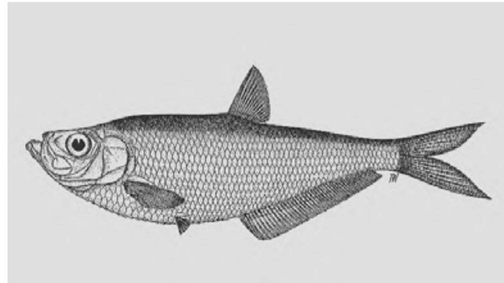

Fig. 5. *Ilisha megaloptera.*

Fig. 6. *Ilisha elongate.*

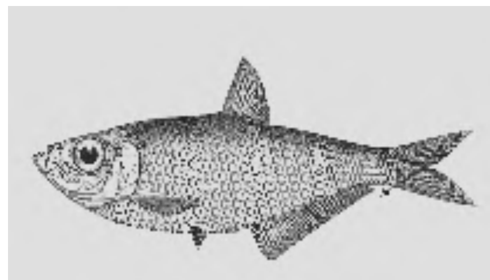

Fig. 7. *Ilisha filigera.*

Global Distribution and Present Status of Fish of the Genus, Tenualosa and Hilsa

The global distribution and present status of the genus *Tenualosa* and *Hilsa* based on FishBase is given in Table 1 below:

Table 1. Global distribution and status of fish of the genus Tenualosa and Hilsa.

Scientific and local name	Global distribution	Present status/Remarks
1. *Tenualosa ilisha (Hilsa, Ilish, Ilisha* in Bangladesh).	Myanmar to Arabian (Persian) Gulf, Indonesia, mainly in the Bay of Bengal.	Widespread and well-studied species, production appears to be static in the region. Recently reported presence in the coastal waters of Malaysia.
2. *T. toli,* (Chandana ilish in Bangladesh and Terubok in Malaysia).	Bay of Bengal; Sarawak Province of Malaysia and Indonesia.	Now very rare in Bangladesh, catches declined in Malaysia and Indonesia.
3. *T. macrura* (Terubok in Malaysia and Indonesia).	Coastal waters of Indonesia and Sarawak, Malaysia.	Catch declined in Malaysia and Indonesia.
4. *T. reevesii.*	Southern China Sea.	Very rare, detail status report not available.
5. T. thibaudeaui (*Laotian shad*).	Mekong River of Vietnam, Cambodia, Lao PDR and Thailand.	Very rare, threatened (Warren, 2001).
6. Hilsa kelee/kanagurta, (Gurta ilish in Bangladesh and India).	Indo-West Pacific; all coast of Indian Ocean, Bay of Bengal, Gulf of Thailand, Java Sea and East Papua to New Guinea, and Lower Mekong.	Catch status not available.

The hilsa fishery of Bangladesh mainly consists of *T. ilisha* and this species contributes more than 99% of the total catches. Earlier, a considerable amount of *T. toli* (Chandana ilish) was caught in Bangladesh, especially in Cox's Bazar region. Hossain *et al.* (1987) reported about 0.08% and 6.01% contribution of *T. toli* in the gillnet fishery at the Chattogram and Cox's Bazar landing centers and *T. ilisha* were around 85%. Recently, *T. toli*, are almost absent in commercial and subsistence catches at these two centers. As a result, it is apprehended that this species became endangered in Bangladesh. Decline of *T. toli* catch is a loss to production and their complete absence is loss to hilsa species diversity. Therefore, a comprehensive management measures are required to be developed for protection and conservation of this species in Bangladesh.

Hilsa Fishing Population

The inland distribution and number of hilsa fishers involved in fishing surveyed under the project reached up to the union level. The detail list of the hilsa fishers and the number of families up to village level in different districts as found is given in Table 2.

Table 2. Division-wise hilsa fishers in Bangladesh

Sl No.	Division Name	Total Dist.	No. Upazila	No. Union	No. Hilsa Village	Hilsa Fishers Family	Total Hilsa Fishers	Occupation	
								Full Time	Part Time
1	Dhaka	12	34	374	579	8902	17454	26%	74%
2	Chattogram	8	27	277	773	66608	142649	56%	44%
3	Barisal	6	38	337	1743	100270	285001	65%	35%
4	Rajshahi	7	24	227	307	2897	6372	24%	76%
5	Khulna	5	18	172	260	4570	11783	10%	90%
6	Sylhet	2	2	17	41	383	825	10%	90%
	Total	**40**	**143**	**1,404**	**3,703**	**183,630**	**464,084**	**32%**	**68%**

Under the study, 464,000 hilsa fishers belonging to 183,000 families, 3,700 villages, 1,400 unions, 143 upazilas under 40 districts were found in Bangladesh. In the recent years, hilsa production has increased more than two folds. Concomitantly, the number of fishing boats and gears has also been increased and so increased the number of hilsa fishers. The present number of hilsa fishers is more than one million.

Distribution of Hilsa

Hilsa occurs in inland, marine and coastal waters of Bangladesh almost throughout the year. Until the introduction of mechanized 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. Now, the main catches are concentrated in the estuaries, coastal zones and in the seas. Depending on their catches, the distribution of hilsa in Bangladesh is briefly discussed below:

Inland Distribution

Hilsa were abundant in the inland open waters of Bangladesh almost round the year. During the last fifty years since 1960s, major changes occurred in abundance and distribution of hilsa in the inland waters of the country. Earlier, hilsa were available in all the major rivers and tributaries. Besides the major rivers (the Padma, Jamuna, Brahmaputra and Meghna), hilsa were also abundant in the Karnaphuli, Feni, Surma, Kushiyara, etc. (Ahsanullah, 1964, Quereshi, 1968, Haldar *et al.*, 1992). The range of migration of hilsa in the Brahmaputra River extended up to Tezpur of Assam province of India. The hilsa of the Ganges river system reported to migrate as far as Agra and Delhi.

In Bangladesh, hilsa was reported to ascend the full span of the Ganges river system (Pillay and Rosa, 1963). Ahmed (1954) reported that except the districts of Rangpur, Dinajpur, Bogura and Chattogram Hill Tracts, which are not fed by the large rivers, all other districts got a good quantity of hilsa in some parts of the year.

To determine the abundance and distribution of hilsa in the riverine habitats, a survey was conducted along with estimation of the number of hilsa fishers in 160 upazilas of the coastal and inland areas through which the major or minor rivers are flowing. From the survey, hilsa was found to be available in 96 rivers and their tributaries of Bangladesh.

The distribution of hilsa mainly depends on water flow and nature of flooding of the rivers. In years of heavy flood, hilsa are also caught in the small channels and even sometimes in the flood plains. Although, hilsa occurs in 96 rivers of Bangladesh, but their main concentration is in the lower Meghna, Tetulia and in some other rivers of Barisal division and in the estuaries. A considerable amount of hilsa are also caught in the lower Arialkhan, Madhumati and Padma and a little in the Jamuna and Brahmaputra. Besides the above rivers, hilsa were also abundant in Gorai, Kushiyara, Feni, Horasagar, Ichamati, Karnaphuli, Shitalakhya and Dhaleswari earlier. However, in the last fifty years, the abundance of hilsa has been lost from a good member of the above rivers. The details of lost hilsa habitats in the inland sector has been discussed in the section "Lost and endangered hilsa habitats in Bangladesh" of this Chapter.

Marine Distribution

The details of marine distribution of hilsa in Bangladesh are not available. Although in earlier days, the marine hilsa catch was restricted in the coastline, but now, it has dispersed in the wider areas of the Bay of Bengal and extended up to 200-250 km from the coastline. The *T. toli* is truly a marine species. Thus, a detail investigation on the abundance and distribution of hilsa in the Bay of Bengal, especially their major fishing grounds, spawning and nursery areas are required for further management and development of the fishery.

Biological Studies of Hilsa

Migration and Movement Pattern

The hilsa of the Bay of Bengal region belongs to a highly mixed single population. The general pattern of migration of hilsa is that, most of the fish of *T. ilisha* born in freshwater during October-November remains in freshwater for feeding; being these areas are highly rich in planktonic food. When the fish grow to a size of 10.0 cm to 16 cm within 6 to 7 months stay in the rivers and they suddenly migrate to the sea at the onset of first shower of monsoon (usually in mid or late April) and flowing of Himalayan ice melted cool water. The fish remain in the sea for few weeks or few months, and again migrate to the estuaries and the rivers for breeding and feeding. After breeding, again the spent fish migrate to the sea (Fig. 8). During upward breeding and post breeding migration, huge numbers of pre-adult/adult and spent fish are caught by the fishers. However, not all hilsa fish follow the same pattern. Analysis of recruitment pattern indicates that some hilsa enter the freshwater and stay throughout the year (Fig. 8). The BFRI-Australia joint study of otolith micro-chemistry results indicate that some hilsa do not ever enter the freshwater and some hilsa permanently reside in the freshwater rivers such as Surma and Kushiyara of Sylhet district (Blaber and Mazid, 2001).

Fig. 8. Migration pattern of hilsa from freshwater to marine and vice versa.

Sex of Hilsa

Between the two species of hilsa available in Bangladesh, the *T. ilisha* is heterosexual (Gono chronistic). However, Chacko and Krishnamurty reported one instance of hermaphroditism of *T. ilisha* in 1949. The other species, *T. toli* is sex reversal hermaphrodite. During one year of their age, all the *T. toli* are male and their transitional gonad changes into female gonad at the standard length of 14.0 to 31.0 cm and semelparity was observed by S.M. Blaber, 1997. This may happen to the Chandana ilish (*T. toli*) of Bangladesh.

Thus, if the small sizes of Chandana ilish are caught, there will be no mother fish in the fishery and ultimately, the species will be completely lost from Bangladesh. It may be mentioned that due to strict implementation of the jatka fishing ban, the decreasing trend of Chandana ilish has ceased and the species started reappearing in the fishery. Detailed research on biology of Chandana ilish and identification of their breeding and nursery grounds including marine distribution is required for development of management and conservation policy of the fish to obtain a healthy hilsa fishery in Bangladesh in particular, for the marine sector.

Age and Maturity

Very conflicting views existed regarding the first maturity age and size of hilsa. Earlier, most of the scientists opined that hilsa mature at 1+ to 2+ years of age and 20.0 to 35.0 cm length (Pillay and Rao, 1963; Mathur, 1964; Shafi, Quddus and Islam, 1978). However, a few exceptions also existed like Jones and Menon (1951), who disclosed that male hilsa become mature at length of 21.59 to 25.4 cm whereas, the female become mature at the length of 26.67 to 30.48 cm at their presumed age of over one year in the Hooghly, Mahananda River and Chilka Lake. Under the BFRI-GEF studies, the minimum size of maturing hilsa was recorded 17 cm in length and 43.0 g in weight (Fig. 9) in Tetulia River. Males of this size also found mature and milt easily came out on mild stripping at their belly (Haldar, 2004a). In the Meghna River, the minimum size of hilsa recorded 20.9 cm and 120 g in March 2002. Using von Bertalanffy's growth equation, the age of this size of hilsa was calculated to be about 8 months. Thus, it may be concluded that hilsa, *T. ilisha* may become mature below one year of their age, although, the minimum size of first maturity depends on area, food availability and population health status. Maturing age of the Chandana ilish initiate within 1 year of age, being they reverse their sex and the female attains sexual maturity at about 2 years of age.

Fig. 9. Minimum size of maturing hilsa.

Sex Ratio

There are conflicting views about the sex ratio of hilsa in earlier studies. To determine the sex ratio of hilsa, a detailed study was conducted under the FFP, DoF and BFRI studies during 2002 and 2003 by collecting 13,231 and 21,212 hilsa fish from 8 landing centers of Bangladesh round the year and male-female ratio was found to be about 1:2 (Figs. 10 and 11).

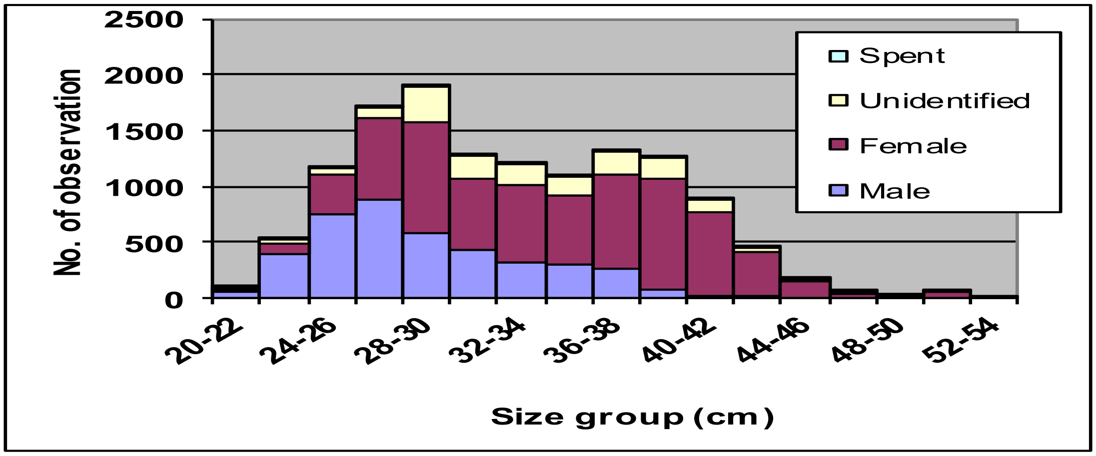

Fig. 10. Sex ratio at different size group (2002).

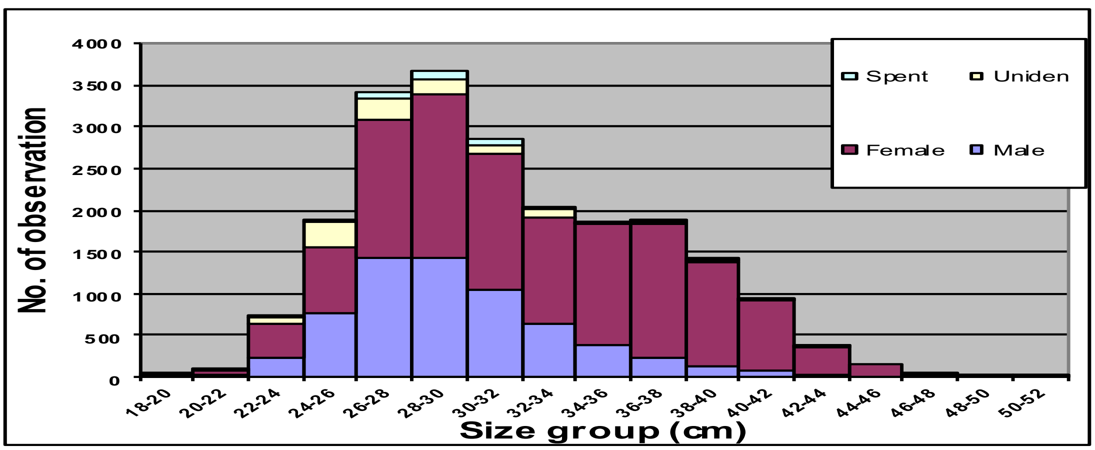

Fig. 11. Sex ratio at different size group (2003).

Under the study, the male fish were predominant within the 20-22 cm to 26-28 cm size groups and the females found predominant from 28-30 cm to 52-54 cm size groups. Above 48.0 cm size, no male fish were observed in the commercial catches of hilsa during 2002. During 2003 also, the dominance of male fish found up to 26-28 cm size groups and the female fish above 28-30 cm size groups and the combined sex ratio was about 1:2. The sex ratio of the fish below 10 cm size fish was found more even by S. M. Blaber, 2000 and no evidence of sex reversal observed in histological studies. Thus, it could be concluded that the sex ratio of hilsa varies with their sizes. The bias in sex ratio is attributed to lower growth rate of the males, higher mortality and place from where the fish are caught. The findings indicate that conservation of smaller sizes of hilsa is required to maintain a balance of sex ratio of male and female to obtain the highest fertilization rate in the natural population.

Fecundity

Fecundity of hilsa is directly dependent on their size and weight. Under the BFRI-GEF studies, the lowest fecundity of 144,800 was found in a fish of 28 cm length and 280 g in weight. However, the highest fecundity 2,286,508 was found in a fish of 44.5 cm length and 1,180 g in weight and the GSI value was found 14.0 at Ramgoti region in November 2003 (Haldar, 2004). The highest fecundity of hilsa of the Indus River was reported 2,917,000 by Bhuyian and Talbot in 1968. The historical evidence of hilsa fecundity is shown in Table 3.

Table 3. Fecundity of hilsa fish reported by different authors.

Reference	Habitat/Place	Size of hilsa		Fecundity	
		Length (mm)	Wt. (g)	Egg numbers	Nos./g BW
Kulkarni, (1950)	Narmada river	-	-	1,864,000	-
Pillay, (1958)	Hoogly estuary	315-396	-	373,120-1,686,220	-
Swarup, (1961)	Ganga and Yamuna	315-506	-	289,000-1,168,622	-
Pillay and Rao, (1963)	Godavari	401-548	-	400,000-1,300,000	-
Mathur, (1964)	Ganga, Allahabad	310-436	-	316,316-1,840,179	-
Bhuyian and Talbot, (1968)	Indus River	-	-	755,000-2,917,000	-
Qureshi, (1968)	Padma-Meghna	225-483	-	900,000-2,000,000	-
Doha and Hye, (1970)	Padma	-	-	334,318-1,465,957	-
Ramakrishna, (1972)	Chilka Lake	353-515	-	390,000-1,120,000	-
Shafi *et al.*, (1977)	Meghna	380-520	-	382,702-1,821,420	-
De, (1980)	Hooghly estuary	343-450	-	373,120-1,323,550	828
Quddus, (1982)	Padma-Meghna	330-510	-	600,000-1,500,000	-
De, (1986)	Hoogly estuary	343-522	536-1925	373,120-1,475,676	-
	Padma (Goalunda)	266-511	228-1635	179,000-1,302,000	841
Moula, (1992)	Meghna (Chandpur)	287-533	275-1715	226,000-1,931,000	940
	Bay of Bengal (Chattogram)	325-492	425-1600	375,000-1,423,000	877
Rahman *et al.*, (1998)	Meghna	287-523	-	226,000-1,931,000	-
Haldar *et al.*, (2001)	Chandpur	250-400	-	144,800-2,286,508	-
Blaber *et al.*, (2001)	Bangladesh	171-415	-	108,500-1,993,846	1000 600
Khan *et al.*, (2001)	Hoogly estuary	286-566	-	385,782-1,465,760	-

Peak Breeding Season and Lunar Relationship

The peak-breeding season of hilsa was determined by combining the gonado-somatic index values, highest egg diameter of the most gravid fish and year-round observation of the spent fish. The peak breeding period of hilsa was found during the full moon of Ashwini Purnima in October and continued up to November and the second peak in February (Table 4 and Fig. 12).

Table 4. Number and percentage of spent hilsa found during 2003.

Months	No. of fish observed	No. of spent hilsa	% of spent hilsa
Jan	528	4	0.76
Feb	**522**	**14**	**2.68**
Mar	1034	7	0.68
Apr-Sept	4804	0	0.00
Oct	**1012**	**37**	**3.66**
Nov	**982**	**19**	**1.93**
Dec	803	3	0.37
Total	9685	84	0.87

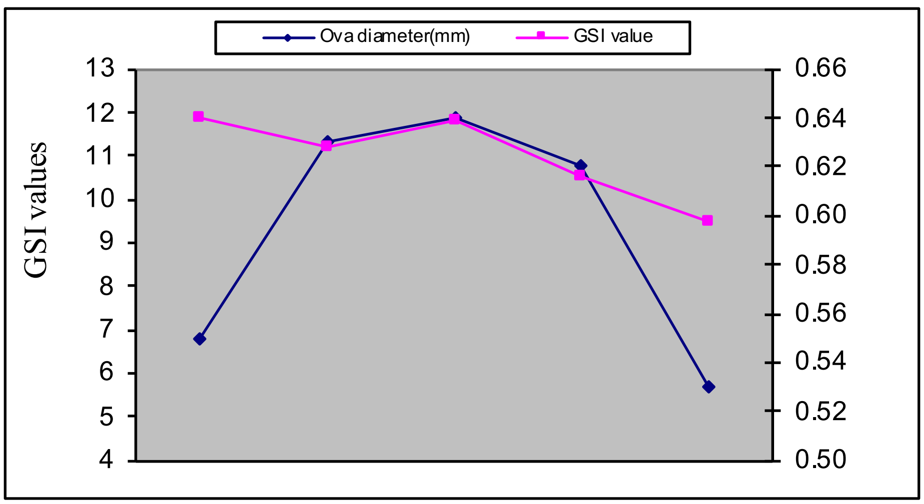

Fig .12. Ova diameter and GSI value

Shedding of Hilsa Eggs

To determine the shedding of hilsa eggs, the number of eggs and diameter of eggs of anterior, middle and posterior part of ovaries were counted and measured. However, no significant difference in number and diameter of eggs in different parts of the ovary was found and thus concluded that the hilsa fish are single shedding.

Major Spawning Grounds

Earlier studies indicated that hilsa breed year-round almost in all the major rivers of Bangladesh. BFRI studies from Riverine Station identified the lower stretches and estuarine part of the Meghna River as the major spawning grounds of hilsa (Miah *et al*., 1999; Haldar *et al*., 2001). The Meghna estuary study-II (CNRS-2001) also found hilsa concentration with bigger eggs in and around the mudflats of South Nijhum Dwip and lower stretches of

Shahbazpur channel (Meghna river) and west Hatia channel and reported the areas as the spawning grounds of hilsa. The major spawning grounds identified by BFRI are the i) Surroundings of Dhalchar Island (Charfashion, Bhola), ii) Surroundings of Monpura Island (Monpura, Bhola), and iii) Kalirchar Island (Fig.13). The Global Environment Facility (GEF) study also reconfirmed these areas as the major breeding grounds of hilsa by collecting larvae and post larvae with Set Bag Net (Haldar, 2004) for implementation of fishing ban during the peak breeding season. However, BFRI/Australia studies found that some hilsa also breed in the estuarine area. The exact location and magnitude of spawning of hilsa in the estuarine areas and the upper rivers are yet to be determined. This information is necessary for the management and conservation of brood hilsa for uninterrupted spawning.

Fig. 13. Major spawning grounds of hilsa.

Nursery Grounds

In previous section, it has been stated that hilsa and jatka (hilsa juvenile) occurs in 96 rivers and river sections of Bangladesh. However, jatka are not equally available in all these river sections throughout the year. After spawning, the fertilized eggs drift up and down by the current of high and low tides of the river, and similarly the spawn drifts until the larvae become active swimmer. When the spawns become active swimmer, they migrate towards the upstream rich in plankton food, disperse into the different rivers, and sometime enter the floodplain areas depending on the food base, environmental factors and water flow and quality. In the above context, the major nursery grounds of hilsa were determined by experimental fishing and counter checked with the jatka catches of riverine set bag nets from 13 river sections of the southern region of Bangladesh under the BFRI and FFP studies. The combined results reflected that the lower Meghna River is the most important nursery grounds of jatka followed by Tetulia, Shahbazpur channel, Arialkhan, Dharmaganj, Andharmanik and other rivers of Barisal and Patuakhali districts (Fig.14). BFRI also reported that these rivers are the most important nursery grounds of hilsa and about 60% of the total jatka were caught earlier from the Meghna River in between Shatnol of Chandpur district to

Char Alexzander and Laxmipur part of the Meghna River. The jatka grazes in the river area up to mid or end of April and at the onset of monsoon shower and when ice melted cold water from upper region (Himalayan area) flows through the rivers, immediately most of the jatka migrate to the sea.

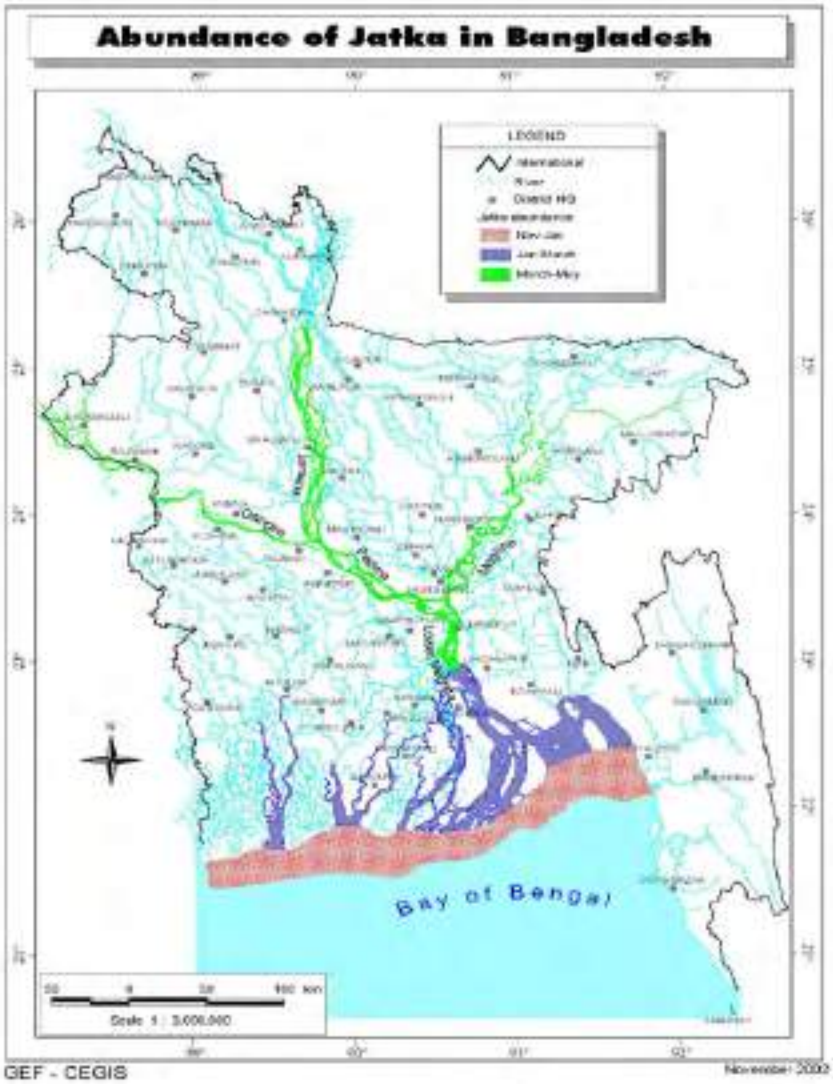

Fig.14. Abundance of jatka during different stages of life cycle in the river system.

Age and Growth

The growth rate of hilsa at different length and age estimated by using von Bartalanffy's inverse growth equation using the length frequency data was found moderately faster. The growth rate of hilsa is the highest during the first and second year of their life, when they attain the sizes of 15-28 cm at the age of one year, followed by 36-43 cm at two years of age (Table 5 and Fig. 15). Thus, to obtain the highest yield, hilsa should not catch below the size of at least 28.0 cm.

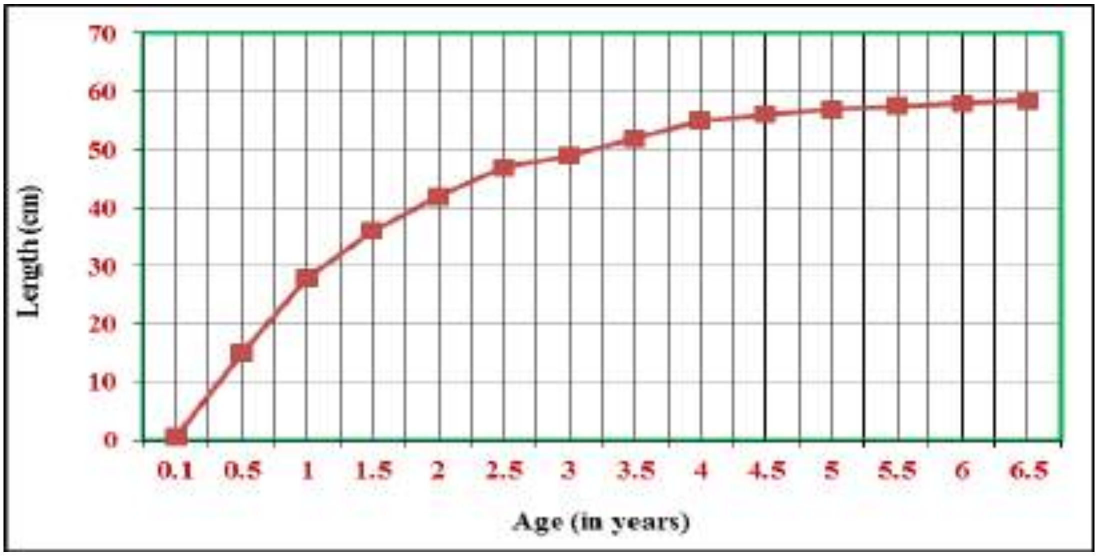

Fig. 15. Growth of hilsa at different age and length.

Table 5. Comparative age and growth of hilsa.

Age (year)	Length range (cm)	Growth/month (cm)	Remarks
0.5	15-16	2.9	highest
1.0	27-28	2.3	2nd highest
1.5	36-37	2.0	high
2.0	42-43	1.8	low
2.5	47-48	1.6	lower
3.0	51-52	1.4	do
3.5	53-54	1.3	do
4.5	55-56	1.0	do
5.0	56-56.5	0.8	do
6-6.5	7-58	0.6	lowest

Key Stock Assessment Parameters of Hilsa Fishery

Stock assessment parameters are the indicators of natural health of a fish population. Thus, the length-based stock assessment method was followed for the present study. Length-frequency data of male and female *T. ilisha* was collected monthly from five different commercial landing sites *viz.* Chandpur, Ramgoti, Barisal, Bhola and Kuakata during January to December 2002 and 2003. To avoid gillnet selectivity, the above landing sites were selected because, different meshes of gillnets are used by the fishers to catch hilsa on the availability of different size group of fish at different places. The data from different landing sites was pooled month wise, grouped into 2 (two) cm length class intervals and analyzed using the FiSAT (FAO-ICLARM Stock Assessment Tools) software as explained in detail by Gayanilo

Jr. *et al.*, 1996. The number of samples was 13,340 and 15,000 for the year 2002 and 2003, respectively. The results obtained in this study were compared with the previous findings and provided in Table 6 below.

Table 6. Comparative population parameters of hilsa fish.

Parameters	**1985/86**	**1995/2000***	**2002**	**2003**
Asymptotic length (L_∞) cm	58.0	61.3	57.7	53.6
G. constant (K)	0.83	0.80	0.86	0.60
T. mortality/yr.	1.90	3.20	3.50	3.03
N. mortality/yr.	1.27	1.26	1.36	1.09
F. mortality/yr.	0.60	1.90	2.20	1.94
Exploitation rate (E)	0.33	0.60	0.61	0.64
E max/year	-	0.58	0.58	0.63
1^{st} capture size (L_c) cm	38.1	25.6	19.9	21.2

* Average values of 1995-2000, BFRI result; Knaap *et al*. 1985/86; FFP- BFRI studies, 2002 and 2003.

The results of stock assessment studies indicated that the rate of over exploitation of hilsa continued until 2003. However, the maximum E_{max} value (0.63) was found in 2003 whereas, the observed E_{max} value was 0.58 in 2002. The first capture size of hilsa increased to 21.2 cm in 2003 over 19.9 cm in 2002. This indicates that the size of first capture and maximum yield/recruit of hilsa increased due to protection of jatka by enforcement of law during 2003.

Recruitment Pattern

The recruitment patterns of *T. ilisha*, analyzed for 2002 and 2003 found that recruitment occurs more or less continuously throughout the year with one major peak during May and June for the male and female combined. However, the females have two-peak recruitments, the major during March to May and the second during July to September. The males have one major recruitment during May to July. Rahman *et al.* (2000) also observed the peak recruitment of this species in the summer months.

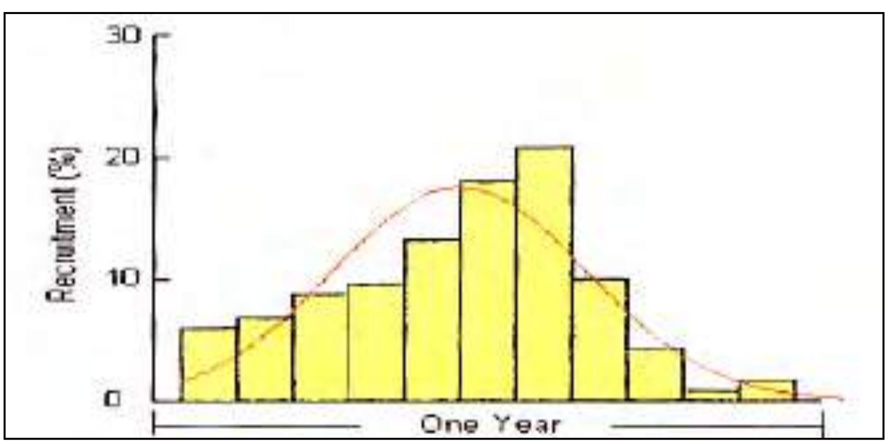

Fig. 16. Recruitment pattern of hilsa.

Suggestions Derived from Population Studies

- The over exploitation rate of hilsa is required to be reduced; and maximum yield/recruit (Y/R) can be increased by protecting the juvenile hilsa (jatka);
- The length at first capture (L_c) should be increased at least to 31.0 cm for maximum sustainable yield of hilsa;
- The length at first capture size of hilsa can be increased by implementing gillnet mesh size selective fishing; and
- The optimum size of gillnet mesh size was found 8.0 cm to 12.0 cm.

Hilsa Fishing Crafts and Gears

Gears used for hilsa fishing varies with fishing season and availability and choices of male or female fish to be caught. The different types of nets and gears used for hilsa fishing in the inland and coastal waters of Bangladesh are given in Table 7. Among the various nets and gears, mechanized Chandi boat is most commonly used for hilsa fishing almost round the year.

Table 7. Fishing craft and gears used for hilsa fishing.

Area	Types of net	Local name	Craft used	Nos. crew	Operation season	Fishing type
Rivers and Estuary	Set gillnet	Gara jal	Kosha	6-8	Nov-Feb	Gilling and Selective
		Dhara jal	Kosha	4-6	May-Oct	Gilling and Selective
		Daba jal	Kosha	4-6	May-Oct	Gilling and Selective
	Drift gillnet	Current jal	Dingi/kosha	2-4	Year round	Gilling and Selective
		Gulti jal	Chandi	8-10	May-Oct	Pocketing
		Kona jal	Chandi	8-10	May-Oct	Gilling and Pocketing
	Clap net	Shangla jal	Dingi/kosha	2	Aug-Oct	Trapping
		Kharki jal	Kharki	2	Aug-Oct	Trapping
	Seine net	Jagatber	Chandi	40-50	Jan-May	Encircling
		Ber jal	Chandi	8-10	Jan-May	Encircling
	Lift net	Khara/Bhesal	Dingi	1-2	Jan-May	Lifting
	Set bag net	Behundi jal	Dingi	1-2	Jan-May	Cod end
	ESBN	Behundi jal	Dingi	1-2	Jan-May	Cod end
Marine	Drift gillnet	Chandi jal	Mechanize	15-20	Year round	Gilling and selective
	Set gillnet	Gara/Dhara jal	Chandi			Gilling and selective
			Chandi	15-20	Jan-May	Gilling and selective
	MSBN	Behundi jal	Chandi	2-3	Sep-March	Cod end

Hilsa Catch Trends in Bangladesh

At present hilsa are exploited both from inland and marine waters of Bangladesh. However, before introduction of gillnet in marine fishery, hilsa were mainly caught from the inland waters. Before starting of the catch assessment survey system by DoF in 1983-84, there were no systematic data on hilsa landings. However, different scientists and DoF personnel recorded some data and information on hilsa production. These data and information as collected and collated by consulting different journals and proceedings to obtain an idea on historical catches of hilsa production which are briefly discussed below:

Historical Hilsa Catch Trends from Inland Waters

During the 1960s, the hilsa landings from inland waters ranged from 124,951 to 147,065 tonnes (Ahsanullah, 1964) and the average was 135,972 tonnes/year. Since then hilsa landings from inland waters decreased continuously up to 2001/02 and the lowest reduction of 48% was recorded in 2000/01 to 2001/02 (Table 8 and Fig. 17).

Table 8. Hilsa landings from inland waters (1956/57-2001/02).

Years	Av. Catch (tonnes)	% Change
1956/57 to 1959/60	135,972	0
1960/61 to 1961/62	96,070	- 29
1983/84 to 1989/90	88,862	- 35
1990/91 to 1999/2000	76,430	- 44
2000/01 to 2001/02	71,655	- 48

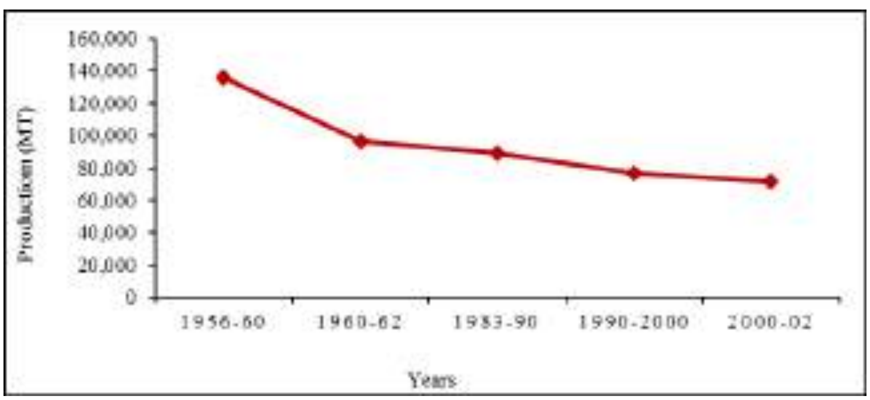

Fig. 18. Historical trends of hilsa production from inland waters.

Historical Trends of Marine Hilsa Production

In the marine sector, hilsa are mainly caught by gillnets and mechanized boats. Very small quantities of hilsa were caught by gillnets and mechanized boats during 1970s to 1990s. During that time, marine hilsa fishing was restricted to the area around Cox's Bazar and that catch was actually representing as the catch from the marine sector. The hilsa catches of Cox's Bazar between 1967/68 and 1982/83 are provided in Table 9 as per Mohiuddin *et al.* (1980).

Table 9. Hilsa catches at Cox's Bazar by mechanized boats.

Period	Catch (tonnes)	Period	Catch (tonnes)
1967-68	59.5	1976-77	498.6
1968-69	98.6	1978-79	835.8
1969-70	145.7	1979-80	1434.6
1970-71	179.6	1980-81	992.4
1971-72	180.9	1981- 82	1139.1
1975-76	933.2	1982-83	1058.4
Average	299.44	-	1031.02

The average hilsa catch at Cox's Bazar during 1960s to 1980s showed an increasing trend (Table 9). The intensity of gillnet fishing increased due to the introduction of synthetic nylon twines during the period from 1977 to 1981 by BFDC and Bangladesh Jatio Matshyajibi Samabaya Samity (Raja, 1985) and mechanization of Chandi boats from 1982 by BFDC and BOBP (Hall and Kasem, 1994).

Recent Past Trends in Hilsa Production from Inland and Marine Sectors

The catch statistics of hilsa are being collected by FRSS/DoF and systematically reported in the FRSS yearbook since 1983/84. During 1983-84 to 2000-01, total hilsa landings ranged between 146,082 and 229,714 tonnes with an average of 196,898 tonnes/year (Fig.19). The average landings from inland and marine sectors were recorded 81,179 and 115,719 tonnes/year, respectively. The total hilsa production in Bangladesh increased by 35% compared to the production of 1983/84. However, during this period, production from inland waters declined by about 17.0% up to 2000-01. The highest and lowest hilsa landing from inland waters recorded as 112,408 and 66,809 tonnes during 1989-90 and 1990-91, respectively. The decreasing trend was almost continuous except few years.

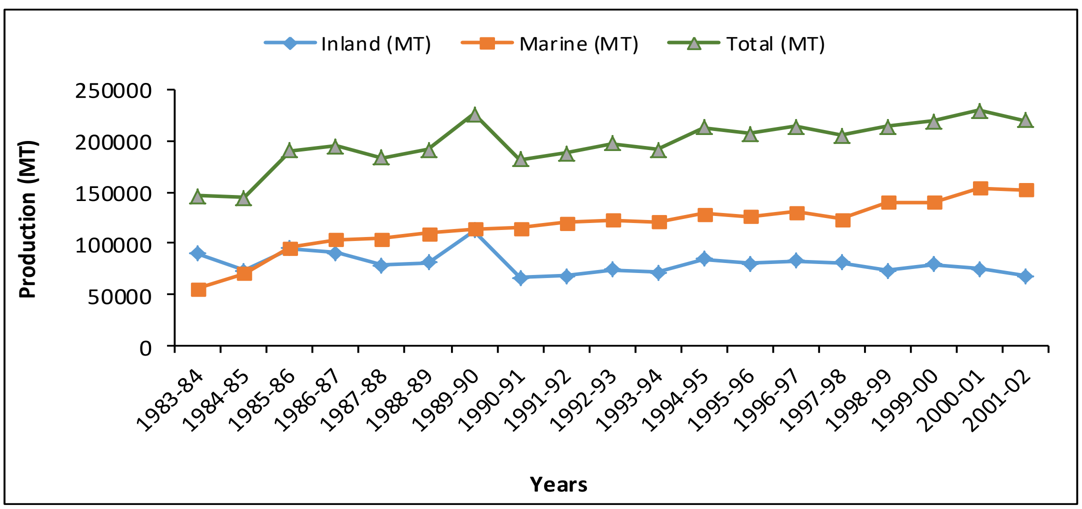

Fig. 19. Trend in hilsa production (total, inland and marine) (1983/84-2000/2001).

Review of Hilsa Catch Assessment Survey System

Under the catch assessment survey of DoF an improved method was proposed for implementation of fish resource survey in Bangladesh. Catch assessment survey is the process of collection of catch data for a fishery without referring to the status of management or development measures. However, catch monitoring system involves the collection and analysis of fishing activities which include catch statistics, species composition, fishing efforts, discards and areas of operation including the information on fisheries habitat, number of fishers, census of gears and fishing vessels, catch verification and displaced fishery activities (population, cages, and fish pens). Monitoring is usually considered within the broader context of management of natural resource used in sustainable conditions.

Background of Catch Assessment Survey

Until early 1980s, there were no dependable fishery statistics or even a statistical system for the collection of fisheries data in Bangladesh. In the above context, Fisheries Resources Survey System (FRSS) project was launched in 1980-81 for a period of 5 years with financial and technical assistance from FAO/UNDP (BGD/79/015). The project objectives were:

1. Preparation of an inventory of all types of water bodies, fishing efforts and fishers;
2. Development of a statistical system for the collection of fisheries data;
3. Presentation of fisheries data in the form required for preparation of development schemes and fisheries management; and
4. Estimation of fish production by types of water bodies.

Under this project, six surveys such as water body, tidal area, socio-economics, fish markets, Kaptai lake and literature review on aquaculture, fish spawning and water pollution were conducted during 1980 to 1985. Finally, a system for the collection of catch statistics, fish production data from different types of water bodies, and an operating manual was developed. Afterwards, following the operating manual, the catch statistics data are being collected and reported annually as the Fish Catch Statistics of Bangladesh by the Fisheries Resources Survey System (FRSS) established by the Department of Fisheries.

Hilsa Catch Assessment

At present, hilsa catch data are collected along with other riverine and marine fish, and as such, there is no separate system for collection of hilsa catch data in Bangladesh. Therefore, in order to verify the catch statistics of hilsa, determine error and to develop an improved catch monitoring system, the present study was undertaken.

Sample Collection System for Riverine Fisheries

The system based on a frame survey consists of three stages of sampling *viz.* the primary, secondary and tertiary. In the first stage, sample villages and in the second and third stages, survey days and sample fishing units are selected. To collect riverine catch data, 212 sample villages and 11,689 fishing boats were selected by FRSS out of 3,228 sample village and 98,514 fishing boats from 61 administrative districts (Table 10).

Table 10. River types, districts, villages and fishing boats established by FRSS for collection of fisheries data.

Sl. No.	Type of river	No. of rivers	No. of districts covered*	No. of sample village	No. of fishing boats
1	Principal rivers	6	14	752	36,755
2	Major rivers	43	16	1349	40,159
3	Minor rivers/others	51	18	1,077	21,600
	Total	102	17	3,228	98,514

*Source: List of principal, major and minor rivers, FRSS, DoF old districts (17).

In the sampling procedure, the percentage coverage of sample villages and sample boats were 6.6 and 11.9, respectively. However, the present sample collection schedule covers 133 sample villages and 4,095 boats and the percentage coverage of the sample villages and sample boats are 4.1 and 4.2, respectively. In the sample collection procedure, some of the important districts such as Rajbari, Madaripur, Munshiganj, Satkhira, Bagerhat, Bhola, Pirojpur, Barguna are not covered. Under the study, it was found that hilsa fisheries exist in 40 districts and the total number of hilsa fishing villages was about 4,000.

Changes in Sample Villages and Boats in Inland Sector

Under the above studies, a considerable change was found in the sampling villages and sampling boats. Overall, 8.5% reduction of sampling villages was found, and the number of boats increased by 0.75 and 61.8% in Barisal and Chattogram division, respectively. Whereas, the number of boats were found to be decreased by 37.6, 54.9, 29.4 and 96.7% in Dhaka, Rajshahi, Sylhet and Khulna divisions, respectively. The study recommended for urgent revision of the sample village and boats.

Changes in Sample Boats in the Marine Sector

Hilsa from the marine sector of Bangladesh are caught mainly by artisanal gillnets operated by mechanized and non-mechanized boats. The hilsa catches from the marine sector increased by 2.7 times between the base year 1984-85 and 2002. The number of mechanized and non-mechanized boats in the artisanal fishery and the gear they use remained almost same compared to 1983/84 and 1998/99. However, the number of mechanized boats has increased by about 5.7 times in 1999/2000 and in 2001-02; the number of gears increased to 106,316 from 3,347 *i.e.* an increase by 31.8 times (Table 11).

Table 11. Mechanized and non-mechanized fishing boats and gears of the marine sector.

Years	Number of boats			No. of units (gear/net)		
	MB	NMB	Total	MB	NMB	Total
1983/84	3,347	No data	3,347	3,347	No data	3,347
1984/85	3,000	No data	3,000	3,000	No data	3,000
1985/87	2,882	3,800	6,682	2,882	3,802	6,689
1998 /99	2,880	3,509	6,389	2,880	3,800	6,682
1999-2000	18,992	7,177	26,169	75,968	3,509	79,477
2001-2002	18,992	6,377	25,369	71,763	44,923	106,316

Catch per Unit Effort of Hilsa in the Marine Sector

The catch per unit effort estimated under the study was found 16.73 tonnes per boat per year during 1983-84, and ranged from 15.5 to 49.9 tonnes in 1998-99 for the mechanized boats. However, the catch per unit effort for the mechanized boats decreased to 6.3 tonnes and remained within 6.3 to 6.93 tonnes during 1999-2000 to 2001-2002 (Fig. 20). The catch per boat per year found 2.08 tonnes during 1985-86 and ranged between 2.08 and 5.35 tonnes per year per boat (Fig. 21) and it ranged between 2.94 and 3.67 tonnes during 1999-2000 to 2001-2002. The main reasons behind the decrease of catch per unit effort are the increase in number of boats and gears both for the mechanized and non-mechanized boats. The catch/boat/year was calculated from total numbers of boats and total catch/year as per FRSS statistics.

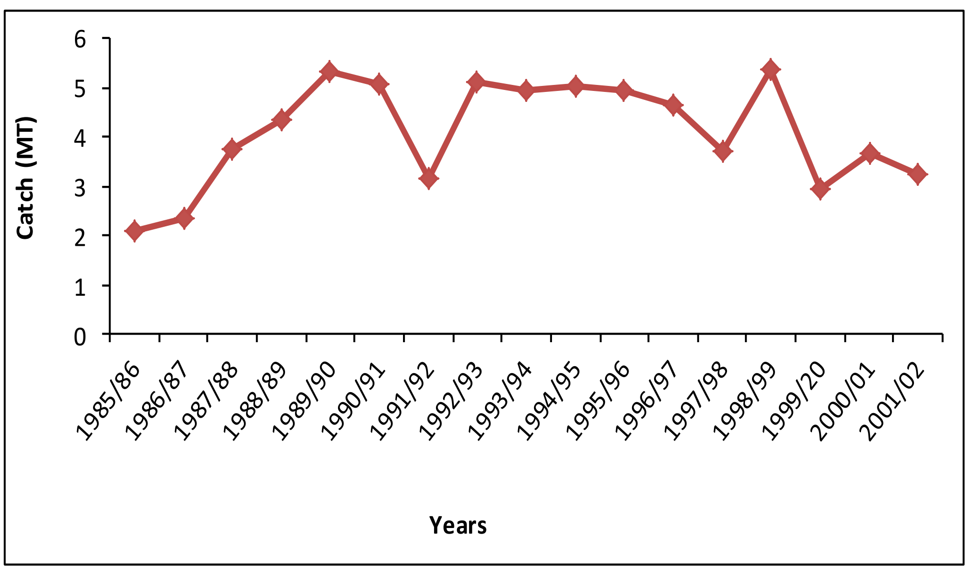

Fig. 20. Average catch per mechanized boat/year of the marine sector.

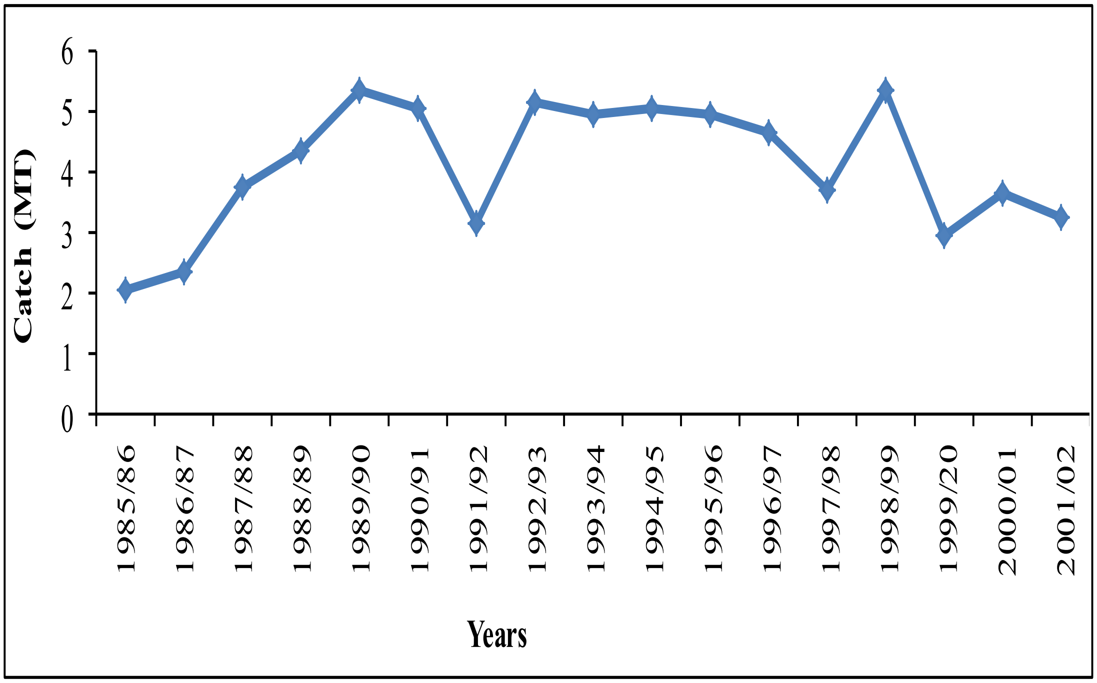

Fig. 21. Average catch per non-mechanized boat/year of the marine sector.

Major Constraints of Hilsa Catch Assessment System

As mentioned above, the catch assessment system was established during 1980-81 by DoF. By now, significant changes have occurred in the inland open water ecosystem, but the catch assessment system was not upgraded. During reviewing the process, the flaws that were identified for fish catch assessment system of Bangladesh are mentioned below:

- Sampling system is stratified up to district level and then directly to the sampling villages (unit). Stratification of sampling system up to upazila level would lead to better and more authentic results;
- Only two villages covered from each district in sample collection framework and fishing unit coverage of 1 to 5 for each type of gears/village appear insufficient;
- Specified sampling timeframe has little chance of inclusion of night fishing in the sample. Hilsa fish are more abundant during full moon and new moon and catching time varies with tidal fluctuations. Thus, the actual catches may not be reflected in the catch data under such specified sampling conditions;
- Overall, data collection frame, sample villages, numbers of boat and net and sample size require upgrading to obtain realistic and dependable data for better management of the fishery;
- The Fisheries Survey Officers (FSO's) access to the fish landing centers is limited due to the shortage of logistic support and hence, insufficient field visits are made for catch observation and estimation;

- The Fisheries Survey Officers (FSO's) are supposed to be on board of one or two fishing vessels to observe the actual catches. However, they rarely observe the catches on board of fishing vessel due to various limitations;
- For the marine sector, there is a provision to register all the mechanized and non-mechanized fishing boats and give fishing license by DoF. However, a few boats remain unregistered and no fishing license is given by DoF;
- Logistic support for enforcing and implementation of fishing rules and regulations as well as registration and licensing of hilsa boats are insufficient;
- The fitness of the mechanized boats is certified by the Mercantile Marine Department (MMD) under the Marine Shipping Ordinance. However, fishing licenses are issued by DoF. But there is limited co-operation and co-ordination between these two departments in respect of issuing fitness certificate and fishing license. There should be a joint certification system;
- Fish landing centers are unregistered, scattered, isolated and huge in numbers and controlled by the Aratdar (wholesaler);
- For the marine sector, hilsa catch data are collected from Cox's Bazar and Chattogram landing centers. However, considerable amount of marine hilsa catches are landed at Ramgoti, Bhola, Alipur, Mohipur, Khepupara, Kuakata and at other places. Some of these landings centers are required to be included in the sample collection framework; and
- Overall, fish catch assessment system needs further updates or fisheries monitoring system require to be introduced.

Estimation of Lost and Endangered Hilsa Habitats of Bangladesh

Earlier, hilsa were available in all the major rivers and in their branches and tributaries. Besides the major rivers, hilsa were also abundant in the Karnaphuli, Feni, Surma, Kushiyara, etc. (Ahsanullah, 1964; Quereshi, 1968; Haldar *et al*., 1992). The range of migration of hilsa in the Brahmaputra River stretched up to Tezpur, Assam Province of India, which is about 300 km away from the Bangladesh border (Raja, 1985). The Ganga river hilsa are reported to migrate as far as Agra and Delhi, a distance of about 1,290 km, and in Bangladesh, hilsa ascend the full span of the Gangetic delta system (Pillay and Rosa, 1963). However, due to various factors, a considerable area of hilsa habitats of Bangladesh has been lost. Ahmed (1954) stated that except the districts of Rangpur, Dinajpur, Bogura and Chattogram Hill Tracts, which are not fed by the large rivers, all other districts got a good quantity of hilsa fish during some parts of the year. In addition to the main rivers, he listed the following rivers as hilsa habitats (Table 12).

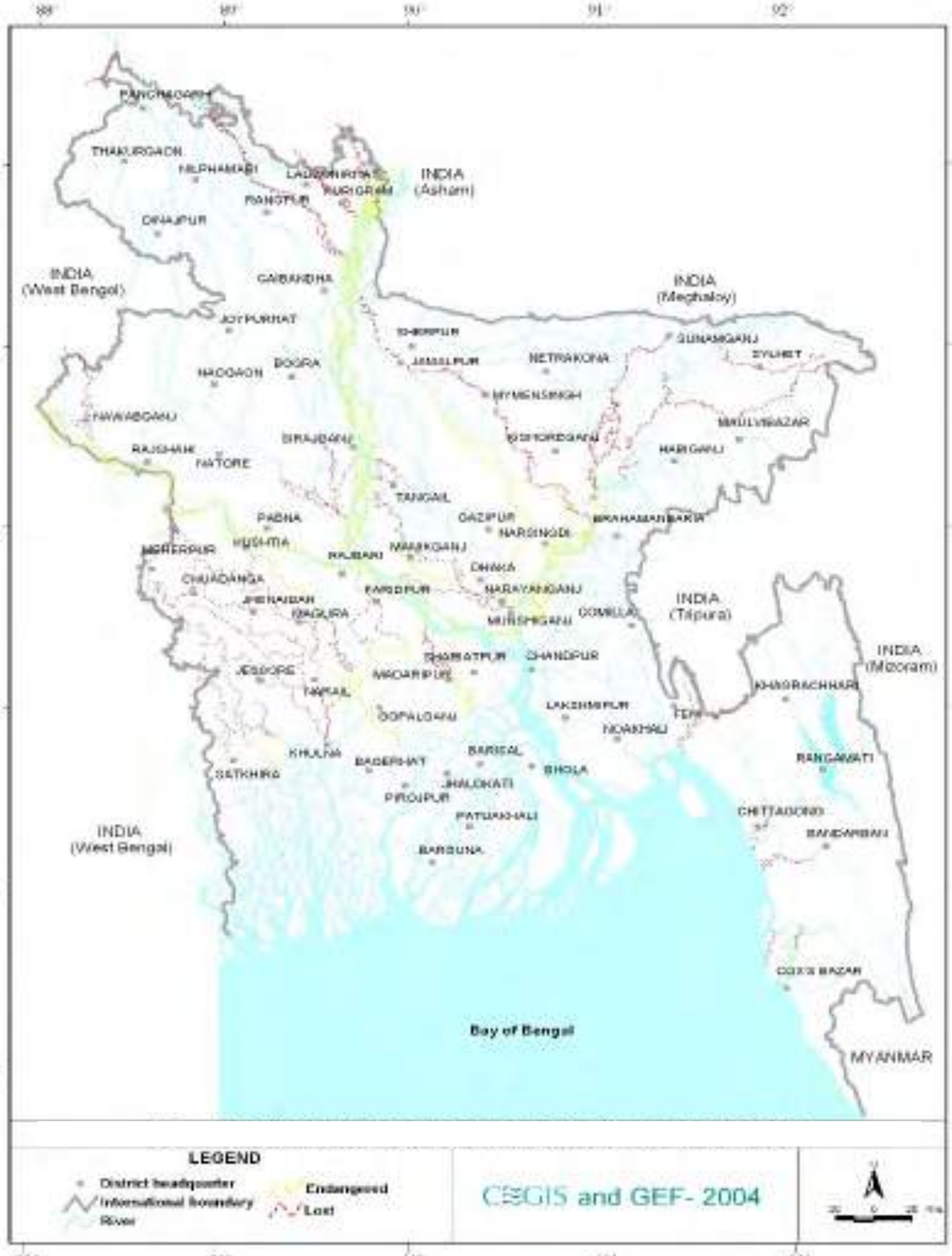

Fig. 22. Lost and endangered hilsa habitat of Bangladesh.

Table 12. Availability of hilsa in different districts and rivers of East Bengal.

Districts	Name of the Rivers
Bakerganj	Tetulia, Kajulia, Joyanti, Kalabadar, Tarki, Andharmanik, Biskhali, Lohalia, Patuakhali, Beglee, Palnakhali, Ilisha, Bering, Arialkhan, Safipur and Nayabhangani
Jessore	Madhumati, Chitra, Nabaganga and Mathabhanga
Mymensingh	Dhanu and Kalinadi
Khulna	Bhairob, Antharohaki, Atrai, Pashur and Baleswar
Sylhet	Kushiyara and Surma
Chattogram	Bettua, Kumirakhal and Karnaphuli
Rajshahi	Mahananda
Pabna	Horasagar
Faridpur	Madhumati
Kustia	Gorai

He also stated that sufficient numbers of hilsa could not ascend to the Brahmaputra and Teesta rivers due to fast currents. Since then, no detailed survey on the abundance and distribution of hilsa has been done except hilsa sample collection for biological works (Shafi and Quddus 1976, 1977 ab).

In the above background, data and information were collected by Focus Group Discussion with the older age group fishers (not below 50 years) those have experience in hilsa fishing from the potential areas. The details of lost and endangered habitats are shown in Fig. 22.

Among the various reasons of habitat degradation, construction of dams, siltation, pollution and blockage of upper mouths are the main factors and due to these reasons, hilsa fishery from about 42 rivers has been lost from Bangladesh. The estimated production loss from these rivers is about 20,000 to 25,000 tonnes per year. Commercial hilsa fishery from the rivers like Garai, Madhumati, Ghorautra, Arialkhan etc. are disappearing rapidly and may be lost completely in near future. Therefore, urgent attention is required to protect and manage the hilsa fishery of these rivers.

Baseline Socioeconomic Studies and Fishing Ban Impact Assessment

Under the Hilsa Fisheries Management and Conservation study, Hilsa Fisheries Management Action Plan and Action Plan Implementation and Mitigation Programs were finalized and approved by the Ministry of Fisheries and Livestock (MoFL) in April 2004. Some of the actions included in the management plan are being implemented. However, there were concerns about the consequences of the enforcement of fishing ban. Considering this concern, a socio-economic survey and impact assessment of fishing ban implementation was initiated by the hilsa research team at the beginning of 2003.

Objective of the Survey

The survey had the following objectives:

- Collection, analysis and interpretation of socio-economic information of hilsa fishers;
- Reporting on the effects of the fishing ban implementation on the livelihood of hilsa fishers and fisher's communities;
- Reporting on the linkages between the impact assessment findings of the Action Plan and Mitigation Program;
- Measure the differences in availability of hilsa and jatka (increase in production, if any) from the people's perception as a result of introducing fishing ban;
- Assess the impact on the livelihood of the Hilsa and jatka fishers during and after the fishing ban implementation period;
- Find out the alternative income generating activities to compensate the loss of hilsa fishers due to ban on fishing activities;
- Obtain people's suggestions to cope with the fishing ban period; and
- Preparing a methodology for further social impact studies.

Socio-economic Survey

Under the study, about 450,000 hilsa fishers were estimated in Bangladesh. Among them 60-70% were jatka fishers. Thus, the total number of jatka fishers was estimated 270,000 - 315,000 belonging to about 110,000 families and socio-economic information was collected from 761 fishers' households from six different districts.

Family Size, Literacy and Living Conditions

The mean family size of the households interviewed was found 6.6, which was above the national average. About 82% of the fishers were illiterate against the national average of 58.9, 42% of the households were single earner, 25% of the families live in Chann hut (straw house), 25% of the households had Katcha (open) toilet and 39.8% of the villages have no electricity.

Land Holdings

Among the hilsa fishers about 88% were landless (below 0.5 acre), 8.5% were marginal and only a small fraction of fishers had (2.5-4.5 acre) land holdings in Patuakhali, Pirojpur, Bhola, Cox's Bazar, Barisal and Chandpur districts.

Income, Expenditure and Debt Situation

The average annual income of the hilsa fishers was found Tk. 76,000 and the fishers were found highly dependent on hilsa fishing. About 70.4% of the respondents' incomes were generated from hilsa fishing (approx. Tk. 53,000/year) except Kalapara and Cox's Bazar, where hilsa fishing generated only 49% and 37% of the incomes. The annual expenditure for livelihood (except capital cost) of the hilsa fishers was found Tk. 52,450 of which Tk. 38,300 was used for food consumption. The mean debt amount of the hilsa fishers of all zones were Tk. 19,000 per household and were a concern to 57% of the respondents. The loan amount was about 24% of their total incomes except Barisal, where the hilsa fishers had no alternate job opportunities.

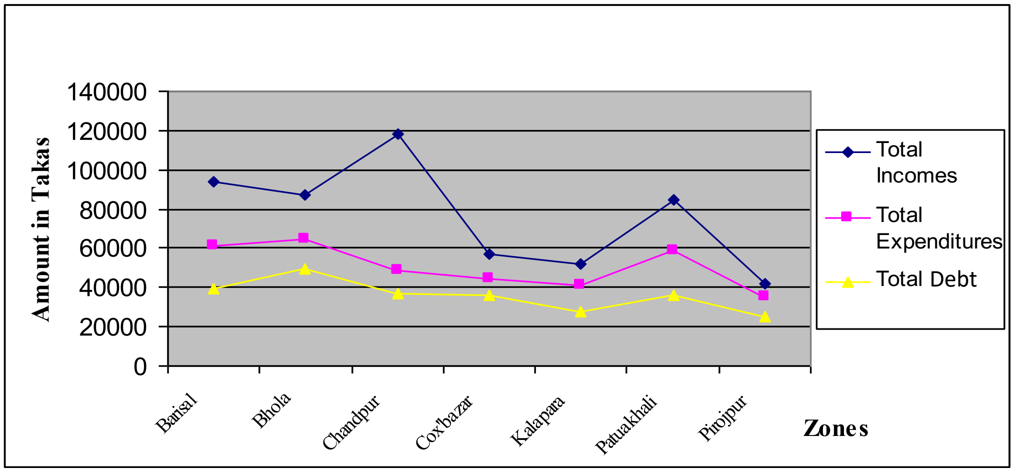

Fig. 23. Annual total income, expenditure and debt by zones.

Food Availability

The poverty situation of hilsa fishers was also reflected in the availability of food. The results indicated an acute food shortage, especially for the poor, landless and marginal groups during the Bengali months of Poush to Baishakh (December to mid-May) in almost all the zones (Fig. 24).

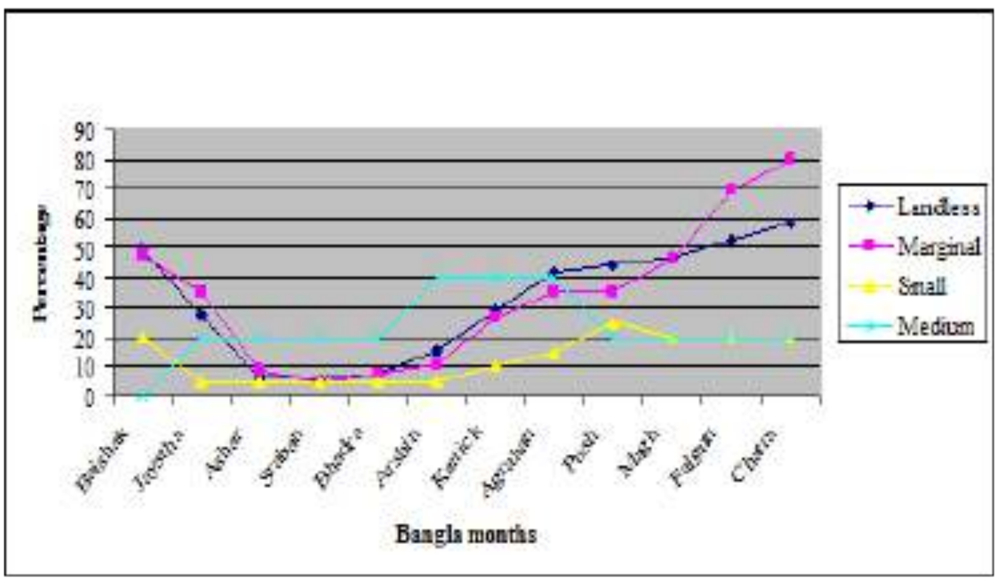

Fig. 24. Food availability (not enough) according to land holdings.

Impact Assessment Survey on Fishing Ban in the Meghna River in Chandpur Region

The impact assessment survey was carried out to assess the potential social impact of hilsa fishing ban on fishers' communities with major focus on poorer groups to identify the possible Alternate Income Generating Activities (AIGA) and realistic compensation measures. About 120 households in three different zones (Barisal, Chandpur and Bhola) were interviewed following a formatted questionnaire. The survey format included specific questions to assess the impact both for 8 months fishing period prior to start fishing ban and during the 8 months fishing ban period and inquired about the AIGA and compensation measures.

Changes in income

A significant change in total income over the 6 months fishing ban period and the 6 months fishing period prior to ban was noticed. During the fishing period, their 8 months total income was Tk. 55,931 of which, hilsa contributed 76%, jatka 23% and other fishing only 1%. During the fishing ban period, their income was 75.8% of the previous 6 months fishing period (24.8% reduction), of which hilsa contributed about 48%, jatka 8% and other activities about 44%.

State of Seized/Submitted Gears

About 68% of the respondent submitted their gears/net or seized by the law enforcing agencies. The average values of seized/submitted gears were Tk. 44,000, 10,000, 37,583, 24,186 and 20,673 for Bhadha jal, Ber jal, Moshari jal, Chandi and Current jal, respectively.

Changes in Expenditure and Consumption of Food Items

Due to the implementation of the fishing ban, the expenditures of the fishers of Chandpur, Bhola and Barisal districts were reduced by 5.2, 31.2 and 23.5%, respectively. Accordingly, consumption of food items also reduced significantly. Except the items of Rice and Ata (wheat flour), the major decrease was noticed for the items like meat, fish and vegetables (10-46%).

Sales of Assets

Due to implementation of fishing ban, about 33% of the fishers have had to sell some of their assets. The main purpose of selling assets was to buy food for consumption (15%), repay loans (45%) and other purposes (40%) such as house repair, clothing's etc. Among the various assets sold by the fishers, boats (30%), cattle (20%), homeland (17%), gold (15%), and trees (10%) are important.

Changes in Occupation

Changes in occupation were significant between the fishing and fishing ban period. Before the fishing ban, all the fishers were involved in fishing but during the fishing ban period, 48% of the fishers were involved in other works to sustain their families. These included daily labor (35%), small business (8%), rickshaw pulling (3%), and agriculture (2%).

Loan Situation of the Hilsa Fishers

The loan situation of the hilsa fishers further deteriorated due to implementation of fishing ban. The previous loan amount was Tk. 48,000 per family and after the fishing ban it has increased to Tk. 76,000 (58% increase). The main purpose of the loan was for fishing (76%), food (11%) and other purposes (13%). Before implementation of fishing ban, the fishers had no loan for food.

Period of Fishing Ban and Food Availability of Hilsa Fishers

The main food shortage of the hilsa fishers was found during mid-December to mid-May. Restrictions were imposed on jatka fishing ban in the selected sanctuary areas during March-April every year. The duration of the fishing ban coincided with the period of food shortage, when not enough food was available to them. Food availability information also suggested the requirements of food subsistence to the hilsa/jatka fishers to strengthen the compensation mechanism under the alternate income generating activities (AIGA).

A management plan was proposed to identify the accurate number of jatka fishers and their rehabilitation through a committee consisting of Local Government representatives and upazila administration. A rehabilitation plan for the loss of their assets and food subsistence including AIGA has also been suggested in the action plan. However, in the lower Meghna River, the hon'be local Minister initiated the complete fishing ban for eight months (November-June 2004) before declaration of sanctuary by DoF and very limited food subsistence was provided to them. The field visit revealed that some of the affected fishers remained unidentified. Food subsistence as provided was also less than the minimum requirement. It appeared that some fishers generated AIGA by their own endeavor but no initiative from the Government sectors was taken.

Organization Involved

In the Action Plan, suggestions provided to engage NGOs to determine the actual number of jatka fishers and their rehabilitation needs. However, no NGO was involved in the program. The Union Parishad (UP) Chairman and members provided substantial assistance to the SUFO/UFO for identification and food assistance to the affected fishers.

Availability of Hilsa after the Fishing Ban

Through focus group discussion with hilsa fishers and stakeholders, information on availability of hilsa was collected. In Chandpur district, the higher availability of hilsa after the fishing ban was not expressed clearly by the fishers because they suffered a lot due to prolonged fishing ban period. In reality, higher catches obtained but not reported loudly. Nevertheless, in few instances, it was reported that some fishers could repay all their loans taken during the ban period within a short time with the higher catches realized after lifting the ban. In Barisal district, the fishers made a clear report about higher hilsa availability. They spontaneously reported an increase in catches of hilsa during June, July and August. The other stakeholders also made a positive report regarding the increase of hilsa following lifting of the fishing ban. Some stakeholders reported availability of bigger sized hilsa with noticeable differences.

Suggestions of the Stakeholders to Cope with the 6 Months Fishing Ban

The implementation of fishing ban to conserve hilsa resources is widely accepted by all kinds of stakeholders. To make the enforcement of the ban endurable and more acceptable to the stakeholders, the fishers made the following suggestions:

- Reduction of duration of the ban to a maximum of 3 months;
- Ban should not be imposed on all kinds of fishing;
- The ban should be made effective in wider area;
- The ban on production of monofilament net needs to be enforced;
- The NGO/UPs should be involved in organizing regular allocation of food if total fishing ban is implemented; and
- The period of ban implementation should be between Poush and Baishakh months (January- May).

Following the suggestions of the fishers and other stakeholders fishing ban in the four-sanctuary areas has been fixed for two months (March-April every year) and presently the government is providing food subsistence @ 40.0 kg/month for the duration of four months along with providing AIGA to a considerable number of fishers.

Marketing and Income

In comparison with the base year (1983-84), hilsa exports increased only by 1,000 tonnes (400 to 1,400 tonnes) by 2001/02. The processing price of hilsa has increased by 7 times (Tk. 20.0/kg in 1985 to Tk. 140 in 2003). The human population increase was about 1.4 times than that of the base year and per capita income increase was US$ 147.0 (equivalent to Tk. 8,000). Total fish availability increased from 7.70 kg/person/year in 1985 to 13.9 kg/person/year in 2003. The increase in exports of hilsa does not support the price rises of hilsa. This may be due to population and per capita income increase and as because hilsa is the preferred fish of the people of Bangladesh.

Preparation and Approval of Hilsa Fisheries Management Action Plan (HFMAP)

Bangladesh Fisheries Research Institute and Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia jointly organized a workshop on ‘Hilsa Fisheries Management Plan for Bangladesh’ on 16 January 2001 at IDB Bhaban, Dhaka to discuss and finalize the Hilsa Fisheries Management Action Plan as formulated by BFRI. The plan was discussed in detail in two technical sessions and 5 issue-based working groups in the workshop and prepared a set of recommendations. The workshop recommended that the formulated HFMAP should be revised incorporating the suggestions of the workshop and submitted to the Ministry for approval and implementation for conservation and management of the hilsa fishery of Bangladesh (Workshop Recommendations, Annexure 1). Following the recommendations of the workshop, a high focused committee was formed by the Ministry of Fisheries and Livestock to finalize the BFRI formulated Hilsa Fisheries

Management Action Plan. The committee finalized the HFMAP incorporating the recommendations of the workshop on 30 December 2001 and submitted to the authority (Fig. 25). However, in a meeting, it further appeared to the HFMAP finalization committee that there are data and information deficiency, especially in respect of specific breeding location, peak breeding period, identified nursery grounds, and statistics of hilsa/jatka fishers in the country. So, the committee felt that information on the above points were necessary to further revise and finalize the action plan. Meanwhile, the Department of Fisheries lunched the Fourth Fisheries Project and one of the main tasks of the FFP/GEF component was to make further study on the present status of the fishery to finalize the HFMAP. In order to conduct this study jointly, DoF signed an MoU with BFRI on 16 September 2002. After the BFRI/FFP/GEF joint study, HFMAP was finalized in 2003 and approved by the Ministry of Fisheries and Livestock on 11 April 2004 for implementation.

Fig. 25. Front page image of initial HFMAP prepared by BFRI.

Studies on Introduction of Selective Fishing

The main objectives of the studies were:

- Analysis of potentials of precluded groups of hilsa to return and harvest;
- Analysis of age and growth rate of hilsa;
- Estimation of length versus weight of hilsa;
- Analysis of the numbers and % contribution of different size groups to total production;
- Estimation of production due to selective fishing introduction;
- Assessment of other benefits and negative impacts of selective fishing;
- Assessment of social reaction and probable impact on market prices of hilsa due to selective fishing; and
- Development of a road map for introduction of selective fishing.

Potential of Precluded Fish to Return and Harvest

The BFRI/CSIRO, Australia studies confirmed that the hilsa move very widely between the sea, estuary and the rivers. Most of hilsa born in the estuary area of the Meghna river and migrate to the sea before maturity and come back. Other studies also confirmed that the increased hilsa production attained due to jatka conservation, and the dominance of smaller size group fish indicated that if smaller size groups of hilsa are precluded from being captured, they would come back and contribute to increase hilsa production.

Relationship between Age and Growth Rate

The hilsa fish attains their maximum length (58.0 to 66.0 cm) within 5-7 years and is a moderately long-life span fish. Their growth rate is faster up to 2.0 year of their age and at this age; they reach to a size of 40-42 cm in length. The absolute growth rate was found 2.6, 2.3 and 2.0 cm at the age of 0.5, 1.0 and 2.0 years, respectively. The relative growth rates over the previous size at these ages were found 2.0, 1.5 and 1.0 cm, respectively and growth rate of hilsa in terms of length almost ceased when they approach to their asymptotic length. Thus, if the smaller size groups of fish are protected in the banning period, an increased production could be obtained from the same numbers of fish.

Relationship between Length and Weight

The length and weight ranges of hilsa caught during 2003-04 were 18.0-45.0 cm and 90-1500 g, respectively. The average weight of the lowest (18.0-19.0 cm) and highest size groups in lengths (44.0-45.0 cm) of fish were 130 and 1,225 g, respectively. Unlike, the increase in length, the increase in weight of hilsa occurs almost throughout their lives. However, the highest rate of weight gain (26-35%) occurs in medium size group (30-37 cm size) than the smaller (18-29 cm) and larger (38-45 cm) size groups fish. The highest, 35% increase in weight observed in the 30-31 cm size group fish followed by 26% weight gain in 36-37 cm size fish. Considering the weight gain, the hilsa up to 36.0-37.0 cm sizes are required to be protected to obtain maximum production.

Relationship between Size Groups and their Contribution to Production

About 762.33 million fish were caught during 2003-04 belonging to 18.0-45.0 cm sizes. The highest contribution (17%) to the total production came from the 28.0-29.0 cm size group followed by (15.8%) 26-27 cm size group fish.

Contribution of Different Age Groups to Total Production

One-year age group fish contributed 29.0% to the total production. On the otherhand, same percent of fish belonging 1-1.5-year age group contributed about 47.0 % of total production (18% higher). Only 9% fish belonging 1.5-2.0-year age group contributed 20%. The above facts indicated that if the smaller age group fish could be saved from being caught, the production of hilsa would increase significantly.

Size Group Selective Fishing and Estimated Production

Age and growth analysis of hilsa caught in Bangladesh indicate that the maximum production could be obtained if fishing ban is implemented for fish up to 36.0-37.0 cm size group. Therefore, if 30, 33 and 35.0 cm size group of hilsa having average individual weight (380, 530 and 580 g) can be protected through imposing fishing ban; it can contribute to raise the overall hilsa production. Here, the plausibility will take an action if the 90% of protected fish are survived and continuous recruitment takes place throughout the year which will allow them time to grow into targeted size groups. The harvest time was calculated based on their relative growth rate (2.0 cm/month). If 30.0 cm size group fish could be protected from being captured, estimated production would be 311,000 tonnes from 256,000 tonnes which is an increase by 55,000 tonnes from the base year production of 2003-04. Furthermore, if 33.0 and 35.0 cm size group fish are protected, the estimated production would be 390,000 and 475,000 tonnes, an increase of 134,000 and 218,000 tonnes, respectively. Considering the livelihood of the hilsa fishers, implementation of fishing bans up to 30.0 cm size group was recommended.

Other Benefits of Selective Fishing

Increase of Hilsa Fishers' Income and Export Earnings

Larger size hilsa are highly priced than the smaller sizes both in the national and international markets. Introduction of selective fishing would allow smaller fish to grow to standard size which would increase incomes of the hilsa fishers and the export earnings as well. During 2003-04 the incomes of fishers from hilsa fishing was about Tk. 56,800 (country wide average) per year and their predicted income increase was TK. 86,400, 130,000 or 211,000 per year at the implementation of 30, 33 or 35 cm size fishing ban, respectively and the net incomes were Tk. 29, 600, 73,200 or 154,000 per year. Thus, no negative impact on the incomes of hilsa fishers due to introduction of selective fishing was foreseen.

The exportable size of hilsa is 1.0 kg and above but this size hilsa were rare in the population (less than 1%). If selective fishing could be introduced, the exportable size hilsa would have increased and more fishers, traders, laborers of hilsa sector could be employed, contributing to increase foreign exchange earnings and reduction of poverty.

Reduction of Fishing Cost and Time

If selective fishing is introduced, the fishers would not require using multiple meshed nets which would increase catch per unit effort of the fishers with reduction of considerable amount of fishing cost and time.

Reduction of Over Exploitation and Increase of First Capture Size

Due to introduction of selective fishing, the smaller size hilsa would be protected which will reduce rate of over exploitation and increase first capture size of hilsa.

Increase of Spawning Success, Egg Production and Jatka Abundance

Due to introduction of selective fishing, the precluded fish will survive and take part in breeding which will increase the spawning success, egg production and consequently jatka abundance.

Reduction of Handling, Transportation and Icing Cost

The smaller fish perish faster than the larger fish. The same number of fishes will contribute to more amount of production. Thus, due to introduction of selective fishing, comparatively handing, transportation and icing cost would be reduced and the quality of hilsa could be maintained better.

Protection of Sex Changing Tenualosa toli (Chandana ilish)

The Chandana ilish are protandrous hermaphrodite and the male fish transformed into females, when they attain the size of 22.0 cm and above. Due to catching of smaller size hilsa, the potential females of Chandana ilish are also being caught together and destroyed and the species is disappearing from Bangladesh. Introduction of selective fishing could protect and re-establish the species in the fishery and thereby increase of production.

Equitable Distribution of Income among the Hilsa Fishers

Due to intensive catching of the smaller fish in the seas and coastal areas, the hilsa could not migrate to the upstream and the fishers of these areas get less fish. So, the fishers of the inland areas are deprived from the benefits of jatka protection program. Introduction of selective fishing will facilitate hilsa migration to the upstream areas, which could lead to an equitable catch and distribution of income to the all fishers.

Increase of Grazing Area and Faster Growth of Hilsa

Introduction of selective fishing will facilitate hilsa migration to the upstream areas and they will get more grazing area and more food. More food and space will ensure faster growth and higher production.

Increase of Riverine Biodiversity and Production

Due to introduction of selective fishing, hilsa production and income of the fishers would be increased leading to improvement of their livelihood condition. As a result, the fishers will motivate themselves towards the conservation of small and gravid fish and to the fish conservation laws which would help conserving riverine biodiversity and increasing riverine fish production.

Probable Negative Impacts of Introduction of Selective Fishing

Some negative impacts may also exert due to introduction of selective fishing which are mentioned below:

Possibility of Over Population

About 566, 648 or 681 million fish would be precluded from being captured for a conservation period of 1 to 9 months. If these fish are not harvested for a long time, and due to breeding of them, there may be over population of hilsa fish in the ecosystem. However, the present plan allows the smaller fish to grow for a certain period and harvest the target size group. Since, the aquatic ecosystem of Bangladesh is highly productive, there might be a chance of over-population if selective fishing is not introduced.

Possibility of Negative Selection and Inbreeding

Due to introduction of selective fishing, the precluded smaller size fish will also breed naturally with other fish of the population. Due to breeding of closed alleys, inbreeds may develop in 10^{th}-15^{th} generations in a natural population. As the hilsa fish do not have any breeding selectively, there is little scope of negative selection or inbreeding.

To augment breeding, government has already declared 10 days (currently it is 22 days) fishing ban in the major spawning grounds during the peak breeding season. Moreover, the fishers have to observe another 10-15 days fishing holidays due to natural causes such as cyclone, gusty wind etc. during the peak breeding season which will promote inter breeding of all the size groups. However, a detailed study is needed to be carried out on the growth rate and breeding performances of hilsa during implementation of selective fishing.

Probable Impact on the Market Price and Consumers

The price of hilsa and other fish depends on their supply. Although hilsa are landed almost throughout the year but the peak season is June to October, which is the lean period for other fish. As such, due to adequate supply of bigger size hilsa, the prices of other fish will not increase; rather the prices of other fish may reduce during the peak hilsa season.

The market price of the smallest sized hilsa is almost equal to the price of smallest sized major carps. However, the prices of hilsa of higher size groups (above 500 g) are always higher than the major carps. Hence, the main consumers of the smallest sized hilsa are the low-income group people. If selective fishing is introduced, the smallest sized hilsa will not be available in the market. As such, the poor income group people will not be able to purchase hilsa unless price of the bigger fish come down due to increased production and adequate supply.

Stakeholders Views on Introduction of Selective Fishing

It was recommended to conserve hilsa up to 30.0 cm size group in different meetings, seminar/workshops held on hilsa. In the sixth meeting of the Parliamentary Standing Committee of MoFL, decision was made to ban hilsa fishing up to 500 g sizes. In a meeting of DoF with the relevant stakeholders, decision was made to forward recommendation to MoFL by further detailing the potential benefits and impacts of introduction of selective fishing. In the BFRI/ACIAR/CSIRO studies on hilsa, recommendation was also made to ban hilsa up to 30.0 cm or 35.0 cm by introducing selective fishing.

In Focus Group Discussion, most fishers (about 90%) feared that they would lose their incomes and increased production might not compensate them. They need food subsistence at least in the 1st year of fishing regulation implementation.

Most of the traders (wholesalers and retailers) supported selective fishing up to 30.0 cm sizes because, due to introduction of the system, production and export potential will increase and icing, handling and transportation cost and harassment will reduce. They also expressed that the quality of hilsa could be maintained better as the small hilsa perishes faster than the bigger fish. However, the poor group of consumers feared that due to introduction of selective fishing, the smaller size fish will not available in the market, prices of hilsa will increase and they will not be able to purchase or eat hilsa.

However, the medium group consumers supported selective fishing as the larger fish are tastier and if production of this group increases, the price of larger size hilsa will come down within their reach.

Strategies for Introducing Selective Fishing

For introduction of selective fishing, modification of certain sections of Marine Fisheries Rules, enacting new rule and regulation of mesh size of hilsa fishing nets are required. Mass awareness campaign, capacity building of DoF officials, registration and licensing of hilsa fishing boats and gears and establishment of Monitoring, Control and Surveillance (MCS) system are also essential. Research and evaluation, especially the potential impacts of introduction of selective fishing on production and livelihood of the hilsa fishers will also be an essential part of the implementation of the system.

Road Map for Introduction of Selective Fishing

The following actions are suggested for introduction and implementation of selecting fishing system:

- Development of consensus and concurrences of relevant authorities for implementing selective fishing;
- Enactment of a new rule for banning catching, trading, transportation, possessing, and handling of hilsa up to 30.0 cm size throughout the year;
- Enactment of a new rule for banning the use of all hilsa catching nets up to 7.5 cm mesh size;
- Modification of Section 10-D of the Marine Fisheries Rule, and enactment of a new rule repealing the present ban on use of 100 mm mesh size floating gillnets to 75 mm;
- Strengthening of mass awareness campaign program and preparation and distribution of awareness building materials among the stakeholders;
- Creation of provision for food subsistence and alternate income generating activities for the hilsa fishers; and
- Establishment of surveillance cheek posts in the main landing centers and recruitment and posting of manpower.

Hilsa Fisheries Management and Development Initiatives

In the history of hilsa fisheries management of Bangladesh, enforcement of conservation of jatka under the Fish Protection and Conservation Rules by deploying Navy and Coast Guards, implementation of gravid hilsa fishing ban during the peak breeding period in the main spawning grounds, declaration of four sanctuaries (now six) in the major jatka abundant areas are the most important. Among the above measures, the most outstanding was introduction of providing food incentives under the umbrella of Vulnerable Group Feeding (VGF) to the fishers. Some of the above activities are discussed briefly below:

Strengthening of Conservation of Jatka

Jatka catching was banned under the Protection and Conservation of Fish Act 1950 and enacted Rule under this Act. However, the rules were not implemented strictly earlier. For more effective protection of jatka, manufacture, marketing and use of monofilament net (popularly known as current jal) were banned by enacting a new government Rule in September 2002. This rule requires surrender of all kinds of monofilament nets to the UFO, UNO or to the nearest police station. About 68% of jatka fishers surrendered their nets or were seized by Naval forces, Coast Guard and law enforcing agencies at the beginning of the jatka season in 2003. During the jatka season of 2004, Navy and Coast Guard were deployed in 17 important points of different rivers for jatka protection. The government also provided additional logistic support to the Navy and Coast Guard. Besides, ban on all kinds of fishing was imposed during January to May in the main jatka catching area of the Meghna River from Shatnol to Alexander in 2004.

Impact of Closed Fishing Season on Abundance of Jatka

To control jatka fishing, a complete fishing ban was imposed in the Meghna River from Shatnol to Alexander section between January and May 2004. This fishing ban provided a chance to assess the impact of such management initiative on jatka abundance. To determine the comparative abundance of jatka, experimental jatka fishing with a standard gillnet was carried out in the Meghna River. The comparative abundance of jatka during 2002-03 and 2003-04 is given in Table 13.

Table 13. Jatka abundance before and during banned fishing season in the Meghna river.

Place of fishing	Year 2003	Year 2004	% Change
	Catch/100 m net/hr (g)	Catch/100 m net/hr (g)	
Mohonpur-Chandpur	40	1289	3230
Ishanbala-Chandpur	400	1135	284
Average	**220**	**1212**	**1756**

Due to implementation of fishing closure, jatka abundance increased about 1,756% in 2004 over the abundance in 2003 and thus, it appears that fishing ban exerted positive impact on the abundance of jatka and thereby recruitment of hilsa, and implementation of sanctuary would be meaningful for sustainable production. However, in the previous years, jatka abundance was decreasing in the Meghna River in the catches of commercial jatka fishers and a decrease of 58% was recorded between 2000 and 2002.

Declaration of Sanctuaries in the Major Jatka Catching Areas

For the declaration of hilsa sanctuaries, 15 different river sections were preliminary screened out. However, considering the vastness of the river sections and logistic support available with the DoF, the most jatka abundant areas were determined by experimental jatka fishing and analysis of catches of set bag nets. Considering the results of the previous studies, the following four river sections were selected for sanctuary declaration following detailed stakeholder's discussion at DoF and later at the Ministry of Fisheries and Livestock (Fig. 25). A complete fishing ban during March-April for the first three sites and during November-January for the Andharmanik River sanctuary was provisionally approved in consultation with the group meetings.

The following four sanctuaries were finally declared by the government, through SRO No. 291/2005, dated 27 October 2005:

- Lower Meghna River from Shatnol, Chandpur to Char Alexzander, Laxmipur (approximately 100 km long river stretch);
- Tetulia River from Bheduria, Bhola to Char Rustom, Patuakhali district (approx. 100 km long river stretch);
- Shahbazpur channel (Meghna) from Madanpur/Char Ilisha, Bhola to Charpial, Monpura, Bhola districts; and
- Andharmanik River, Patuakhali district (Entire river section).

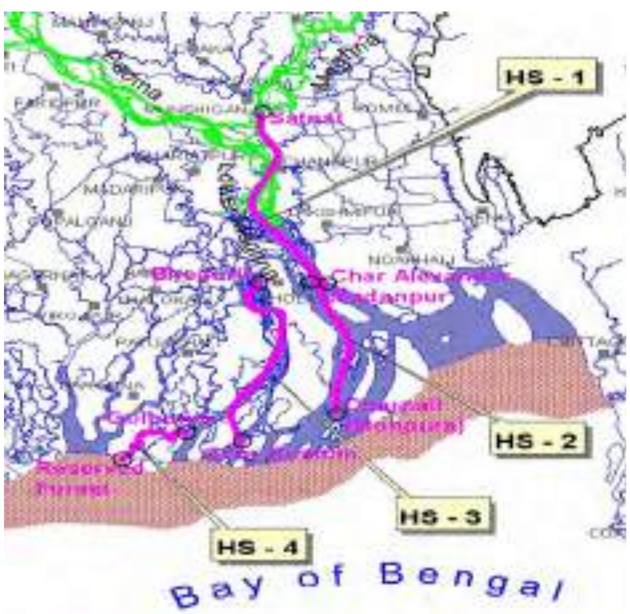

Fig. 26. Hilsa sanctuaries declared under FFP-BFRI.

Declaration of Fishing Ban in the Main Spawning Grounds during Peak Period

The peak breeding season and main breeding grounds of hilsa were delineated by BFRI and GEF through detailed research. During the breeding season, about 60-70% hilsa become sexually mature. Successful spawning and subsequent recruitment of hilsa were hampering due to indiscriminate catching of brood fish from the spawning grounds during peak breeding season. Thus, 10 days fishing ban (five days before and five days after the full moon of Ashwini Purnima) was imposed in an area of about 7,000 sq. km of the main breeding grounds of hilsa (Fig. 27) from 15 to 24 October every year. These 10 days fishing ban was implemented up to 2011. Afterwards, it has been elevated to 22 days and is now being implemented throughout the country.

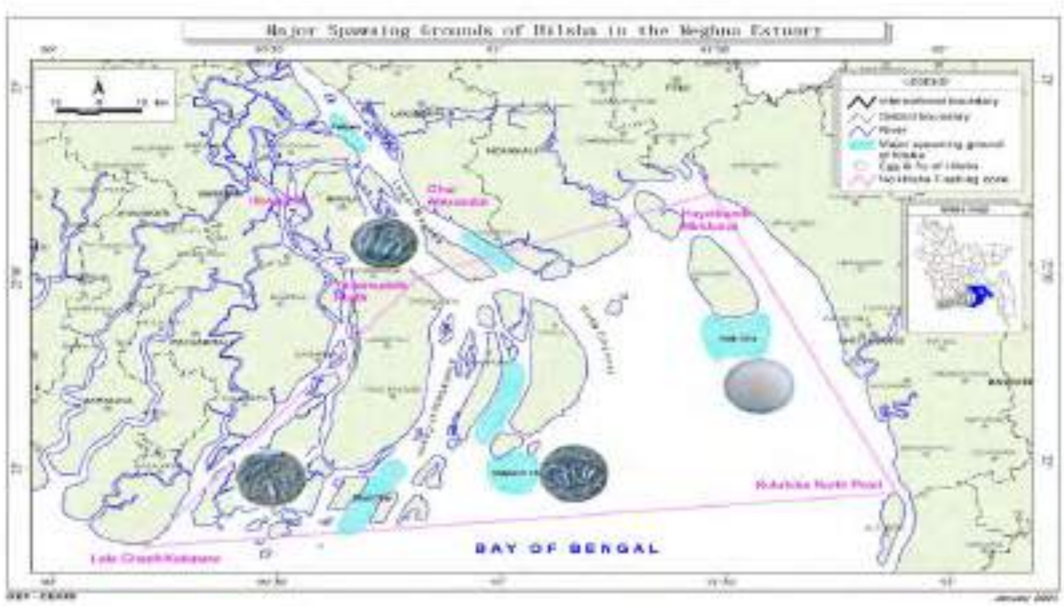

Fig. 27. Area of fishing ban during peak breeding season.

Preparation of Training Module

A detailed training module on "Hilsa Conservation, Development and Management Strategy" was prepared by the senior officials of BFRI for conducting training of different kinds of stakeholders of hilsa fisheries. The module was published by BFRI. In the meantime, a large number of fishermen, aratdar, paikers, traders and social leaders were trained using this module.

Publication of Awareness Building and Mass Communication Materials

Huge number of booklets, leaflets and hand bills were published and distributed among the different kinds of stakeholders by BFRI and DoF. Public awareness was raised through wide publicity in Radio and Television on the importance and benefits of jatka conservation and published advertisements, writing columns and editorials in the national and local newspapers. Due to these wide range awareness activities, jatka catching and selling decreased considerably.

Introducing Jatka Conservation Week and River Rally

Jatka Conservation Week was introduced in the month of March and observed for 2 months, March-April for mass awareness building. In the inauguration day, usually the Minister of Fisheries and Livestock along with the local public representatives and administrative officials address the participants about the importance of jatka conservation after a River rally. Besides, a press briefing is also organized before the commencement of jatka conservation week and special supplement published in some most circulated national dailies highlighting the programs and activities of the government on jatka conservation. This created a good impact on the fishers, traders, consumers and other stakeholders.

Introduction of Food Incentive for the Fishers

The jatka fishers are one of the poorest groups of people in Bangladesh**.** Before introduction of HFMAP, incomes of the crew hilsa fishers were only Tk. 14,397 per year per household, which was 37.15% lower than the poor household groups of Bangladesh and most of them live in the lower stages of poverty level. These crew fishers usually catch jatka. Due to imposing fishing ban in the nursery grounds for two months, they have lost about 25% of their annual incomes. Thus, to reduce the poverty level of the fishers, food incentives was provided since 2004 under the umbrella of Vulnerable Group Feeding (VGF). Although in the initial year, the amount of food incentive and coverage of household was very low, presently the coverage of household, amount of food incentive and duration has been increased considerably.

Upgradation of Hilsa Zones

For effective management and conservation of hilsa, the Government of Bangladesh has formed two hilsa zones including 10 districts by gazette notification of 20 July 1995. In the selected hilsa zones some of districts such as Rajshahi, Gaibandha, Serajganj, Pabna, Jhalkathi, Khulna, Dhaka, Faridpur, Shariatpur, Noakhali and Bagerhat are not included but these districts are also important in respect of jatka fishing, selling and spawning and for existence of nursery areas there. Thus, instead of two hilsa zones, four hilsa zones were proposed with the inclusion of the above districts which was agreed in a consultation meeting at DoF on 26 January 2003 and necessary administrative action was taken by DoF.

Task Force for Monitoring and Evaluation of Jatka Conservation

To implement the HFMAP, it was proposed to form different committees from the Ministry level to the village/Maholla level delineating their duties and responsibilities. However, DoF formed committees up to the upazila level.

Introduction of National Awards to the Best Jatka Conservator

Proposal was made for National Awards for the best jatka conservator. This National Awards are now being awarded to the best jatka conservator during celebration of National Fish Week.

Posting of DoF Officials on Deputation in the Jatka Zones

Earlier, some post of Upazila Fisheries Officers of DoF would remain vacant during the peak jatka season. Thus, provision was made to fill up these positions by deputation of officers from other districts during the peak jatka season to strengthen jatka conservation activities. Meanwhile, DoF has created some new posts and also filled up some of the vacant posts. However, the system of deputation is still followed for strengthening of jatka conservation activities.

Chapter VIII

Conservation of Hilsa in the Meghna River Estuary and its Breeding Potential

Introduction

Hilsa (*Tenualosa ilisha*) is the most important single species fishery and national fish of Bangladesh. It accounts for nearly half of the total marine catches, and 12% of total fish production of the country (DoF, 2017). About 75% of the global hilsa is landed from Bangladesh waters, 15% from Myanmar, 5% from India, and 5% from other countries (Miah, *et al*., 2015). For the judicial management of hilsa fishery resources in Bangladesh, different management interventions were adopted under the Hilsa Fisheries Management Action Plan (HFMAP). Despite these interventions, hilsa are being caught indiscriminately using gillnet of different meshes during up and downstream migration. This widespread unregulated fishing may exert negative impact on hilsa production. So, determining the optimum mesh size of gillnet for catching hilsa can be an appropriate step to halt the indiscriminate exploitation of hilsa juvenile (jatka) and matured hilsa.

The growth performance and other biological phenomena like sexual maturity, feeding habit of hilsa in open water habitats is already known. But, studies on growth performance and its maturity status in confined water bodies is still scanty. Therefore, it is imperative to carry out research on the culture of hilsa in captive condition to fulfill the greater demand as well as to minimize the impact of anthropogenic interventions and climate change driven anomalies. Additionally, cage culture of hilsa in confined brackishwater habitat can be instrumental to encounter any adverse impact if arises in near future.

Albeit, hilsa production has increased manifold, yet unable to meet the high demand of fast-growing population of the country. Aquaculture of hilsa using hatchery seed could be an important innovation to increase hilsa production. Typical life cycle of hilsa is a major obstacle for artificial propagation. To combat this challenge, on board breeding trial of hilsa was attempted to develop seed production technology to enhance the hilsa fishery resources of the country.

In order to address the aforesaid exclusive issues, the present research was executed in collaboration with the WorldFish ECOFISH^{BD} Program during 2015 to 2017 with the following broad objectives.

Objectives

- To determine gillnet selectivity of hilsa in the Meghna river estuary.
- To assess the impacts of sanctuary on the abundance and biodiversity of fishes.
- On-board breeding trial of hilsa and testing of larval rearing.

- To determine growth and survival of juvenile hilsa at the nursery phase in brackishwater ponds to evaluate potential for aquaculture.

Gillnet Selectivity Study

Material and Methods

The study was conducted in different selected hilsa fishing grounds in Ramgoti, Hatia and Monpura area of the Meghna river. Approximately 660 adult hilsa were randomly selected from commercial gillnet catches with speedboat and research vessel 'MV Rupali Ilish'of the Riverine Station, Chandpur. The gillnet with 55 mm, 65 mm and 75 mm mesh sizes were used for the experimental fishing. These three mesh sizes were selected as these are widely used in commercial fishing in Bangladesh.

Collected data were analyzed by measuring the optimum length (L_m) and other selectivity parameters using Holt's model (Sparee and Venema, 1998) following the formula $S_L = exp[-(L-L_m)^2/2*s^2]$ where, L_m *is* optimum length for being caught, SL, fraction (ranged 0 to 10), and s, the common standard deviation. Input data for this model were the numbers of caught fish by length group for each gear, i.e. *Ca, Cb* and the two used mesh sizes, including *ma* and *mb*. In order to compare and estimate the result, linear regression method was applied. Prior to statistical comparison, all data were first tested for normality and unequal variance.

Results

The catch percentage of hilsa by 5.5 cm, 6.5 cm and 7.5 cm mesh size gillnet were 38.78% (256 fish), 39.10% (258 fish), and 22.12% (146 fish), respectively. The majority of fish caught by gillnet with three mesh sizes were found to be matured. Total length of the fish ranged from 20.0 to 36.0 cm for 5.5 cm mesh size, 24.0 to 38.0 cm for 6.5 cm mesh size and 28.0 to 44.0 cm for 7.5 cm mesh size gillnet. Mean total lengths were calculated as 24.7±2.7 cm, 31.2±2.78 cm and 34.33±4.69 cm for 5.5 cm, 6.5 cm and 7.5 cm mesh sizes gillnet, respectively (Table 1).

Table 1. Catch percentage and mean total lengths of hilsa by the gillnet with different mesh sizes in the River Meghna of Bangladesh during 2016.

Sl. No.	Mesh Size (mm)	Fish No.	Catch Percentage (%)	Total Length Range (mm)	Mean Total Length (cm)
1	55	256	38.78	200-360	24.7 ± 2.70
2	65	258	39.10	240-380	31.2 ± 2.78
3	75	146	22.12	280-440	34.33 ± 4.69

The distribution of length frequency at the points designated by ln Ca(L)/Cb(L) for three successive pairs of gillnets are presented in Fig. 1. The regression constants *a* and *b* were also estimated. The values of the Selectivity Factor *(SF)* and Standard Deviation *(S)* were calculated.

The probability of capture against lengths for all mesh sizes showed three different selection ranges and formed a selectivity curve (Fig. 2). The optimum catch lengths of the gillnets with

55, 65 and 75 mm mesh sizes were calculated as 260.50 cm (L_m), 328.36 cm (L_m), and 370.99 cm (L_m), respectively (Table 2).

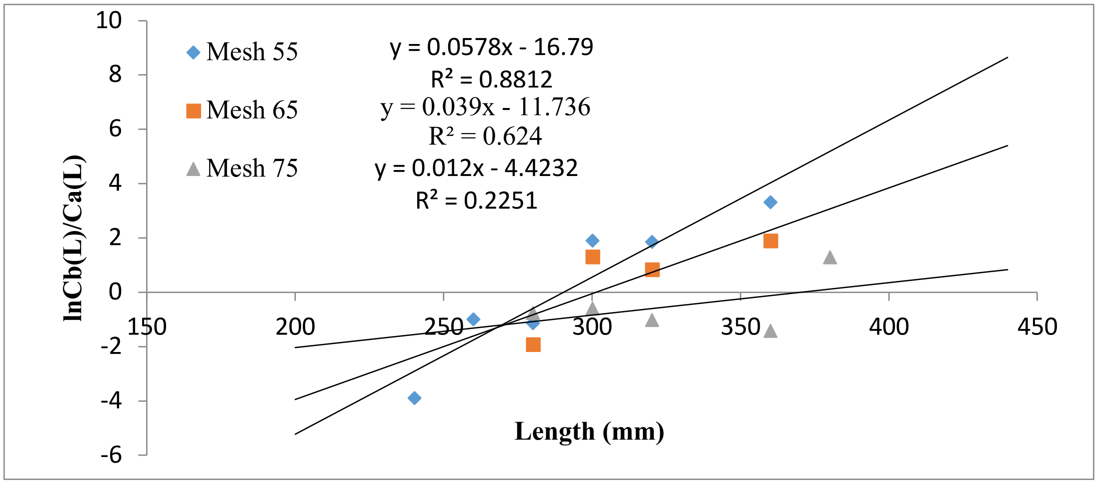

Fig. 1. The regression of ln (Cb/Cα) on fish length for *T. ilisha* for gillnets of 5.5cm (55 mm), 6.5 cm (65 mm) and 7.5 cm (75 mm) mesh size from the River Meghna in Bangladesh.

Table 2. Regression constants (a & b), Standard deviation (s), Selectivity factor (SF) and Optimum length (L_m) estimated from the gill-net selectivity studies of *Tenualosa ilisha*.

Mesh Size	a	b	SF	s	Selection Range	Optimum Length (L_m)
5.5 cm	-16.79	0.0578	4.84	38.84	254.71-266.28	26 cm (260.50 mm)
6.5 cm	-11.73	0.039	4.63	47.58	314.69-342.02	32.8cm (328.36 mm)
7.5 cm	-4.42	0.012	5.26	57.48	347.34-394.64	37cm (370.99 mm)

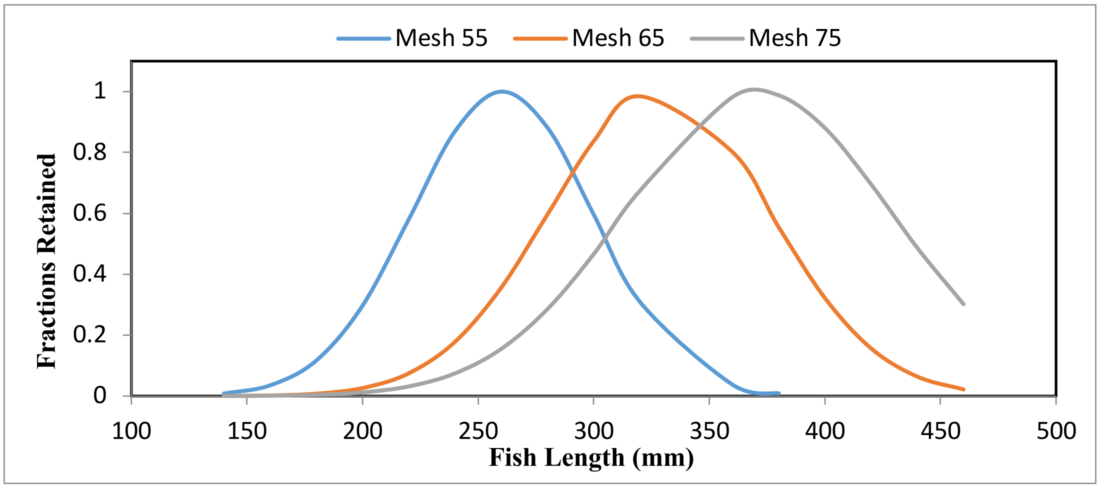

Fig. 2. Selectivity curves for *T. ilisha* for gillnets of 5.5cm (55 mm), 6.5 cm (65 mm) and 7.5 cm (75 mm) mesh size from River Meghna in Bangladesh.

Discussion

National Hilsa Fisheries Management Action Plan (HFMAP) fosters the importance of hilsa resources conservation for its long-term sustainability. In addition to the existing management interventions included in the HFMAP, regulation of the mesh size of gillnet to estimate the approximate minimum catch sizes of the target species, fishing gear selectivity studies are very important (Sparre *et al*., 1989) and this can exert myriad impact on the overall hilsa production.

The reported size at first capture of hilsa from 1995 to 2003 ranged from 13.12 cm to 35 cm (BOBLME, 2011). Rahman and Cowx (2008) also reported that optimum mean length of hilsa (L_m) at first capture was 32.9 cm and suggested that less than 32.9 cm hilsa must not be captured. In some other research works (gillnet selectivity) on *T. ilisha*, the mesh size wise optimum length was calculated as 29.05 cm for mesh size 7.6 cm, 39.92 cm for mesh size 10.2 cm, 42.16 cm for mesh size 11.4 cm and 53.62 cm for mesh size 12.7 cm (BoBLME, 2014). As *jatka* below 25 cm length size are not allowed for catching (MoFL, 2013; SRO No. 92-law/2013), hilsa above 29.05 cm sizes can be excluded and at least 7.6 cm mesh size of gillnet should be maintained to carry on fishing operation. But, most of the hilsa gets sexual maturity while reaching in 30-32 cm size and become ready to shed their eggs for the first time. Therefore, for better sustainability of the hilsa resources, each hilsa should be allowed to shed eggs at least once in their lifetime and shouldn't be captured below the size of 32 cm for which minimum recommended mesh for gillnet should be 8.0 cm.

Impact of Sanctuary on Abundance and Biodiversity of Fish

Introduction

Bangladesh is endowed with one of the richest open water fisheries resource in the world just after China and India that contributed more than 90% of the country's fish production in the past (Ali *et al*., 2009). But unfortunately, this rich aquatic diversity has experienced a substantial decline during last four decades due to various manmade and natural interventions that have caused irreversible damages. Therefore, to protect, conserve and manage the fisheries resources for sustainable production, government has taken different initiative of which fish sanctuary has been considered as an important tool with a policy shift towards community participation (*Ali et al*., 2009).

Fish sanctuary is a delineated protected area declared under the "Protection and conservation of Fish Act (1950)" where targeted fish species alongside with other species gets peaceful shelter for their independent movement, feeding and natural propagation. In another word, establishment of aquatic sanctuary is one of the effective tools for conserving fish stock, preserving biodiversity and increasing fish production. In some instances, restoration as well as conservation of habitat may be possible by establishing aquatic sanctuary. Impact of fish sanctuaries has been reported positive in almost all cases on fish production, biodiversity and socioeconomic condition of the fishing community. In addition to conserving biodiversity, sanctuary has myriad impacts on aquatic environment (Ali *et al*., 2009).

The general importance of fish sanctuary is outlined below:

- Conserving aquatic biodiversity and increased fish production.
- Ensuring safe breeding and feeding ground.
- Ecological restoration.
- Increasing the abundance of threatened fish species.
- Improved the livelihood conditions of fishing community.
- Protect many other aquatic fauna and flora etc.

Hilsa is the most important single species fisheries in Bangladesh. About 12% of the countries fish production comes from hilsa. More than 2% people of our country directly or indirectly are related with the hilsa fishery and it is the main source of their livelihood (DoF, 2016). Economic contribution of this single species is very high in an agriculture-based country like Bangladesh. The hilsa fishery in Bangladesh has been suffered by a combination of factors *viz.* recruitment over-fishing (indiscriminate harvest of gravid fishes) and growth over-fishing (indiscriminate catching of jatka). Therefore, considering the importance of hilsa in nutrition, employment and economy, government has declared sanctuaries in the major nursery grounds of hilsa under the Protection and Conservation of Fish Act, 1950. As a result, overall hilsa production of the country has increased manifold. However, no comprehensive studies were conducted to assess the impact of sanctuary. Hence, assessing the impact of sanctuary on the fish species diversity as well as on the ecosystem, deserve comprehensive attention.

The effectiveness of sanctuaries depends on several key factors such as identification of the type of sanctuary needed, selection of water body based on technical and social issues, appropriateness and compliance with the rules introduced. Depending on the purpose, the sanctuary may be seasonal/temporary or permanent. One factor is the lifecycle of the main species being protected, fish species that attain maturity within a year or even spawn twice a year need only few months refuge to ensure that they survive to reproduce which is mainly the case for small floodplain resident species. On the other hand, fish species such as major carps that require several years to mature to breeding age need a permanent refuge so that enough fish can live and grow there until they reach breeding age/size and can then spawn either within the same sanctuary or in a seasonal sanctuary area in suitable habitat (Ali *et al*., 2009).

Materials and Methods

The Hilsa investigation team of the Riverine Station, Chandpur carried out the investigation inside and outside of the sanctuary using the BFRI Research Vessel MV Rupali Ilish and other mechanized and non-mechanized boats. Major spawning grounds of hilsa declared as sanctuary and the adjacent areas were covered for comprehensive impact study. The categories and numbers of fishing gears and their CPUE were assessed in both sanctuary and non-sanctuary areas and by this the prevalent trend and overall impact of sanctuary was determined. Fish species diversity of the sanctuary and non-sanctuary areas was determined by studying catch composition of different fishing methods and gears. Water quality parameters of sanctuary and non-sanctuary areas *viz.* air temperature, water temperature, free carbon dioxide (CO_2), dissolved oxygen (DO), pH, total hardness and total alkalinity were studied using HACH water test kit (Model FF2) and APHA (1995) method.

Monthly sampling of plankton assemblage from sub-surface water (four times in a day at 6, 12, 18 and 24 hrs. to know the diurnal variation) were done by filtering 50 L river water through a 25 µ and 50 µ plankton net for qualitative (preferably up to species level) and quantitative analyses. For plankton counting, the S-R (Sedgwick Rafter) cell was used which is 50 mm long, 20 mm wide and 1 mm deep. The number of plankton in the S-R cell was derived from the following formula (Willen, 1976):

$$\text{Number of species/Liter} = \frac{C \times 1000\ \text{mm3}}{L \times D \times W \times S}$$

Where,

C = Number of organisms counted

L= Length of each stripe (S-R cell length) in mm

D = Depth of each stripe in mm

W = Width of each stripe in mm

S = Number of strips

Data analysis

The relevant data were processed and analyzed manually and for computer-based analysis. MS Excel of Office 2007 version was used.

Results and Discussion

Catch Per Unit Effort (CPUE) of Sanctuary and Non-Sanctuary Area

The average CPUE of the different fishing gears operated in the sanctuary and non-sanctuary areas of the Meghna river have been determined and the trend was found to be increasing in the sanctuary areas compared to the non-sanctuary areas (Fig 1). The CPUE of Chandi jal ranged from 3.5 kg/haul in non-sanctuary areas to 8 kg/haul in sanctuary areas. Inside the sanctuary areas, the highest CPUE of Chandi jal was found 8 kg/haul in Char Bhoirobi and the lowest in Kaliganj region 6 kg/haul. On the other hand, inside the non-sanctuary areas, the highest CPUE of Chandi jal was 5 kg/haul found in Gazaria and the lowest CPUE was 3.5 kg/haul found in Upper Tarabunia region. The CPUE of Gulti jal ranged from 3 kg/haul in non-sanctuary areas to 6 kg/haul in sanctuary areas. Inside the sanctuary areas, the highest CPUE of Gulti jal was found 6 kg/haul in Kaliganj and the lowest in Char Bhoirobi region 5 kg/haul. On the contrary, inside the non-sanctuary areas, the highest CPUE of Gulti jal was 4 kg/haul found in Gazaria and the lowest CPUE was 3 kg/haul found in Sureswar region. The CPUE of Current jal also exhibited an inconsistent tendency in different regions of sanctuary and non-sanctuary areas. The CPUE of Current jal ranged from 3 kg/haul in non-sanctuary areas to 5 kg/haul in sanctuary areas. Inside the sanctuary areas, the highest CPUE of Current jal was found 5 kg/haul in Kaliganj and the lowest in Ramgoti region 3 kg/haul. On the other hand, inside the non-sanctuary areas, the highest CPUE of Current jal was 3.5 kg/haul found in Gazaria and the lowest CPUE was 3 kg/haul found in Sureswar region.

The gears used for capturing hilsa are mainly set gillnet (Chandi jal) and drift gillnets (Gulti, Kona jal, Current jal). Fishers also use some seine nets (Jagatber jal, Purse seine net, Network jal) but recently operation of Jagatber jal is gradually reducing due to Govt. ban on the use of this gear. Fishing gears such as small mesh current jal, Behundi jal (Set bag net), Moshari ber jal and Charghera jal are detrimental and thereby excluded from the study.

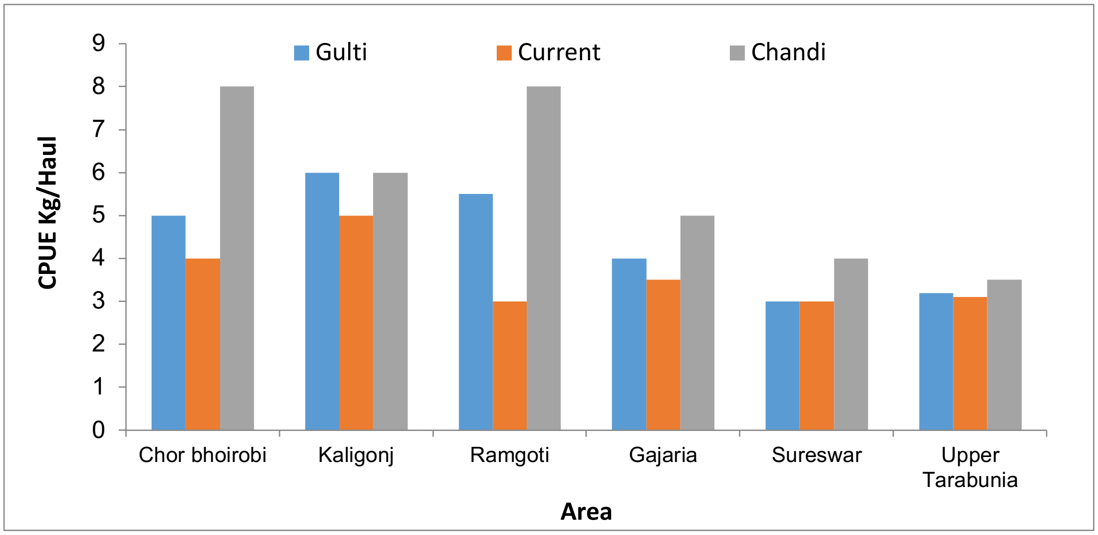

Fig. 1. CPUE of different fishing gears operated in sanctuary and non-sanctuary areas.

Impact of Sanctuary on Hilsa and Other Fish Production

Under the Fish Protection and Conservation Act 1950, the government has enforced different management interventions for the sustainable exploitation of hilsa fisheries. Among these management interventions, declaration of sanctuary is the most important ones that has been maintaining since 2005-06 (Table 1). The establishment of sanctuaries is showing a tremendous positive impact on overall hilsa production in Bangladesh (Fig. 2). Hilsa production statistics of the Meghna river, the major river system of Bangladesh from Fisheries Resource Survey System (FRSS) (DoF, 2017) showed that hilsa production has increased by 220% in 2017-18 in comparison to the base year 2005-06. During this time, hilsa production has increased from 55,000 tonnes to 176,399 tonnes (Fig. 2). Average annual percent change of production was 25.3% at this time.

Table 1. Different management interventions for hilsa resource conservation.

Year	Management system	Management type
2001-02	Conventional	Without any management
2002-03	Conventional	Traditional (improved) management
2003-04	Jatka conservation	Protection system
2004-05	Jatka conservation	Protection system
2005-06	Jatka conservation + sanctuary	Full Moon basis
2006-12	Jatka conservation + sanctuary +10 days Hilsa fishing ban	Full Moon basis
2012-15	Jatka conservation + sanctuary + 11 days Hilsa fishing ban	Full Moon basis
2015-16	Jatka conservation + sanctuary + 15 days Hilsa fishing ban	Full Moon basis
2016-18	Jatka conservation + sanctuary + 22 days Hilsa fishing ban	Full Moon basis (with new Moon)

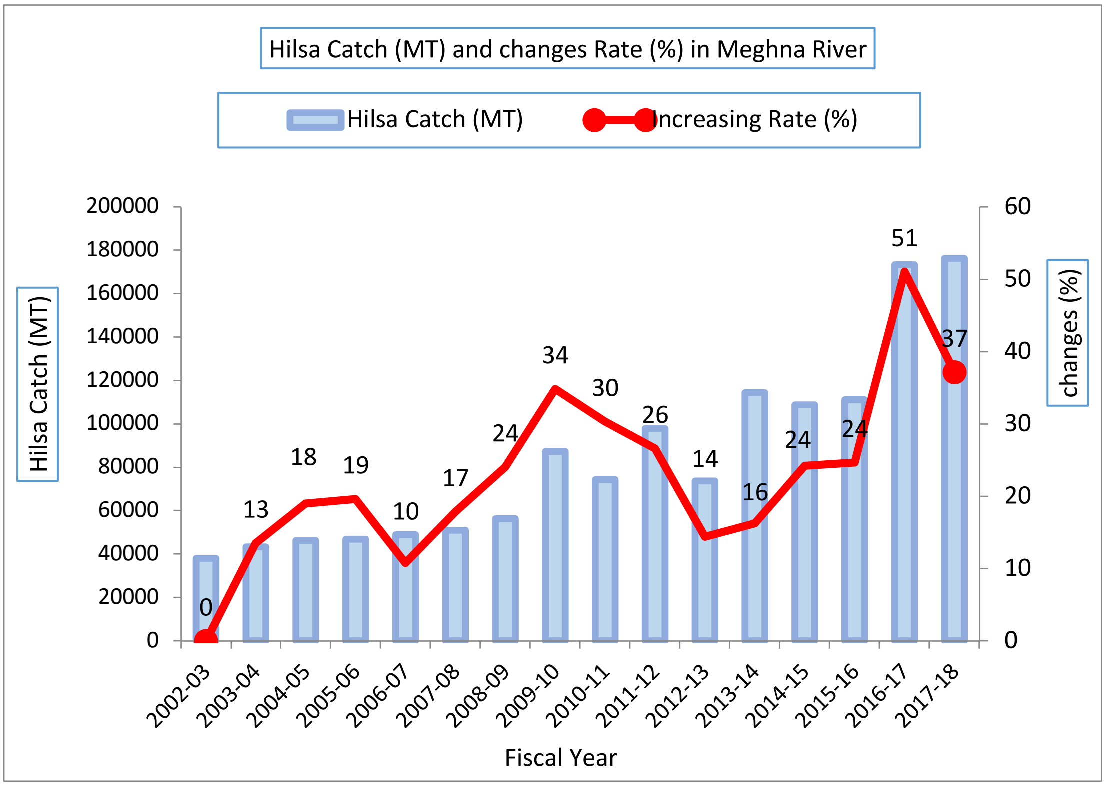

Fig. 2. Hilsa production trends after the establishment of sanctuary in the river Meghna.

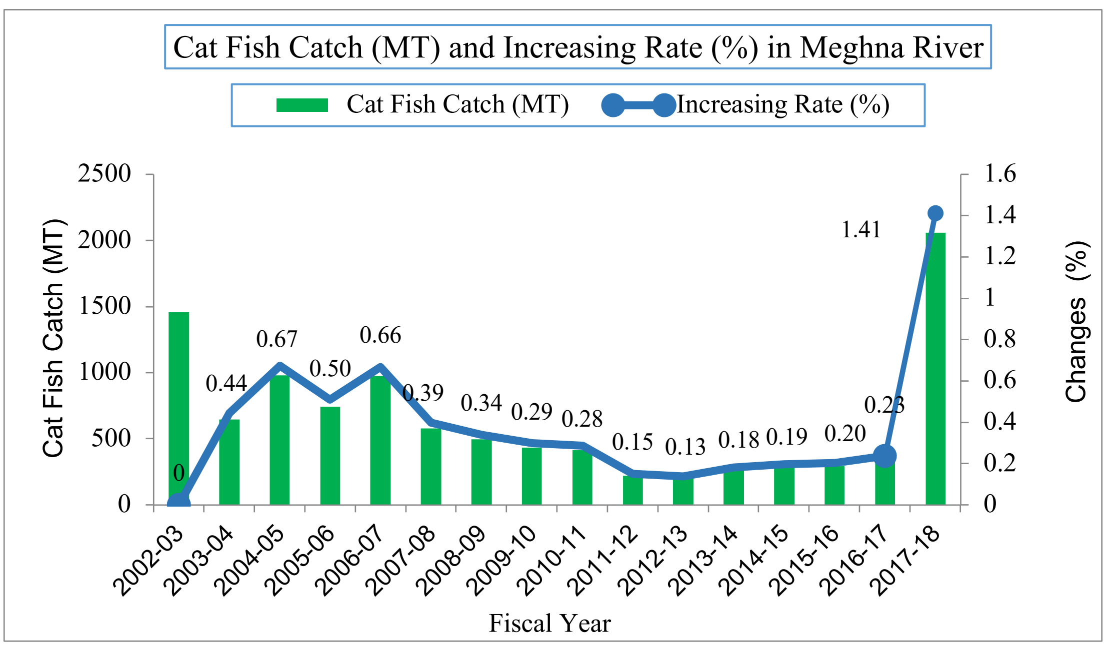

Fig. 3. Catfish production trends of the river Meghna after the establishment of sanctuary.

The production of catfish showed a fluctuating trend after the establishment of sanctuary. However, last year, a huge upsurge was observed in the production compared to the previous years (Fig. 3).

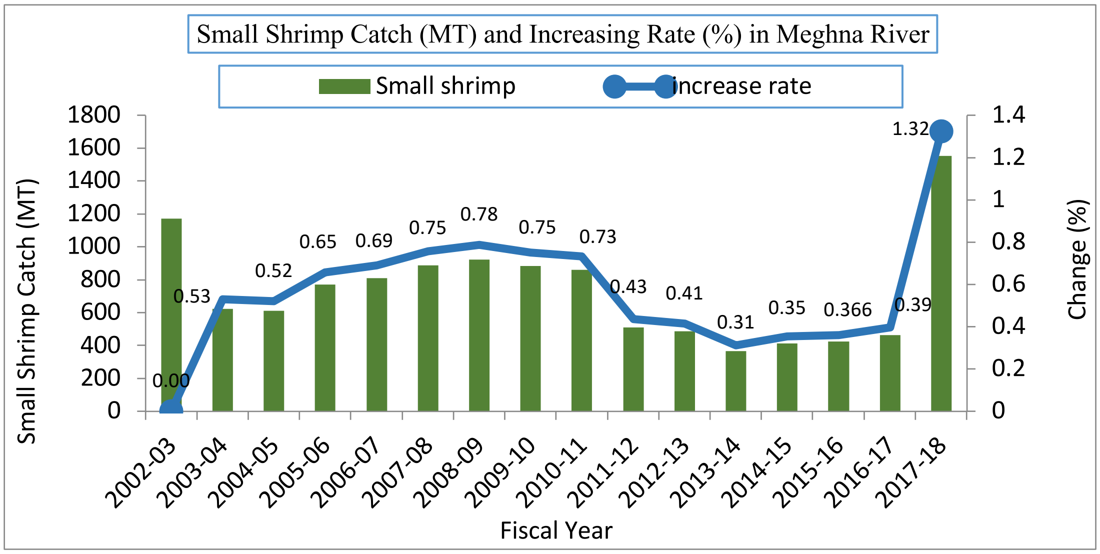

Fig. 4. Production trends of small shrimp in the river Meghna after the establishment of sanctuary.

The production of major crustacean, shrimp (both small and big) also exhibited a fluctuating tendency. But last year, a massive rise was observed in shrimp production than the previous years like the catfish production (Figs. 4 and 5). Similar phenomenon was observed in case of commercial landing of some important species found in the Meghna river. The up and rise of the production may be associated with the resilience of the implementation of management interventions.

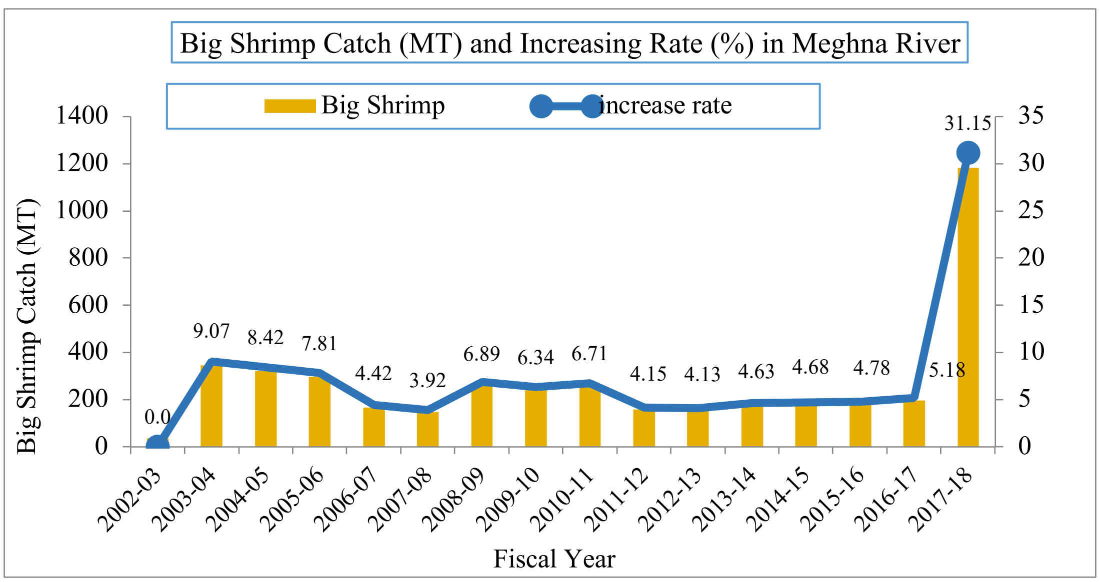

Fig. 5. Production trends of big shrimp in the river Meghna after the establishment of sanctuary.

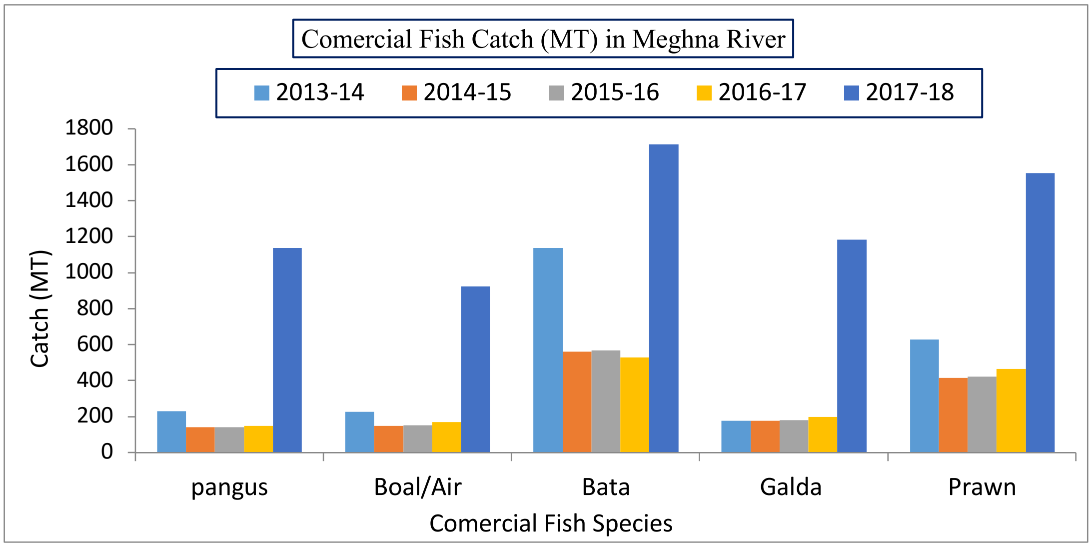

Fig. 6. Commercial catch of some important riverine species found in the sanctuary areas of Meghna river.

Fish Species Composition of Sanctuary Area

The fish species diversity of the sanctuary areas virtually became enriched along with the presence of large number of indigenous species viz. Chapila, Puti, Mola, Dhela, Air, Shol, Taki, Gojar, Poa, Shilong etc. (Figs. 7, 8 and 9). Albeit, no published data were available about the intensity of different species, but the fisher's perception as well as experimental fishing of BFRI revealed that intensity has been increased many folds after the establishment of the sanctuary in the Meghna River.

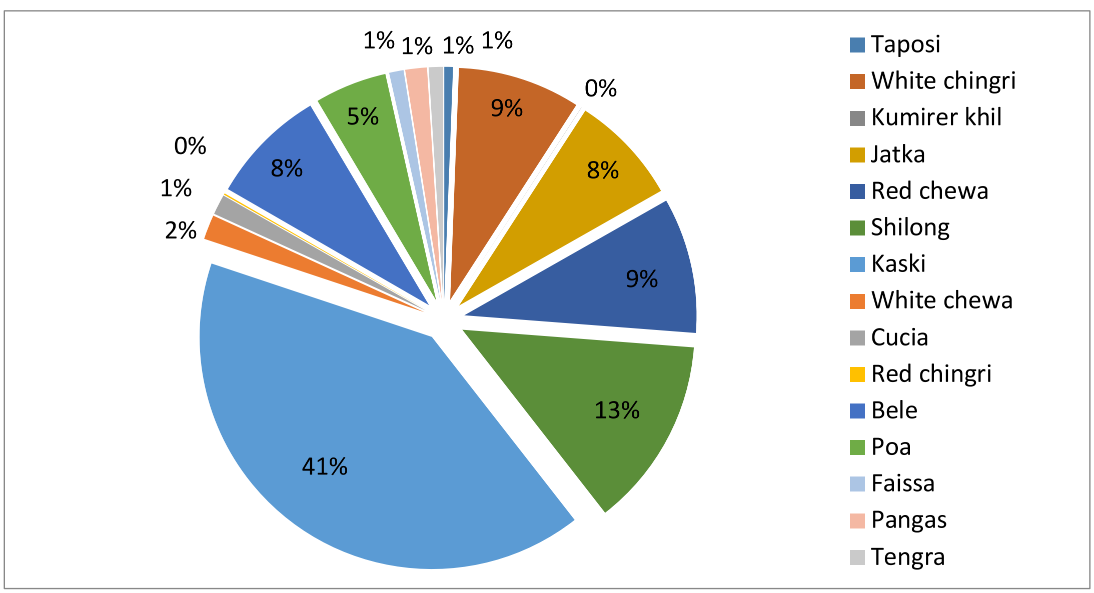

Fig. 7. Species composition of Behundi jal catch.

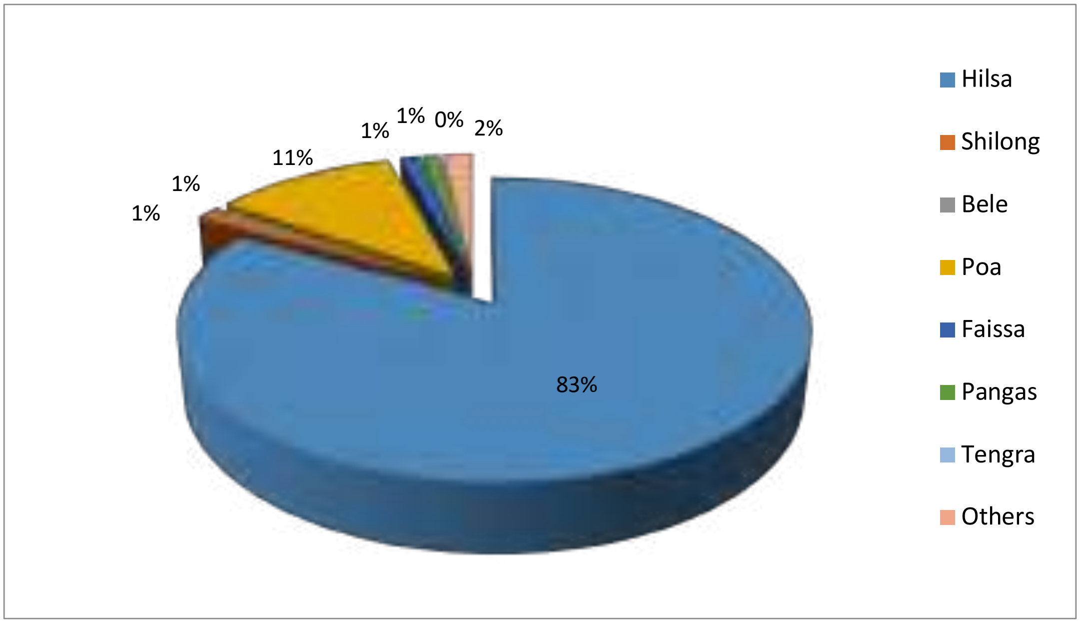

Fig. 8. Species composition of Gulti jal and Chandi jal catch after the establishment of sanctuary.

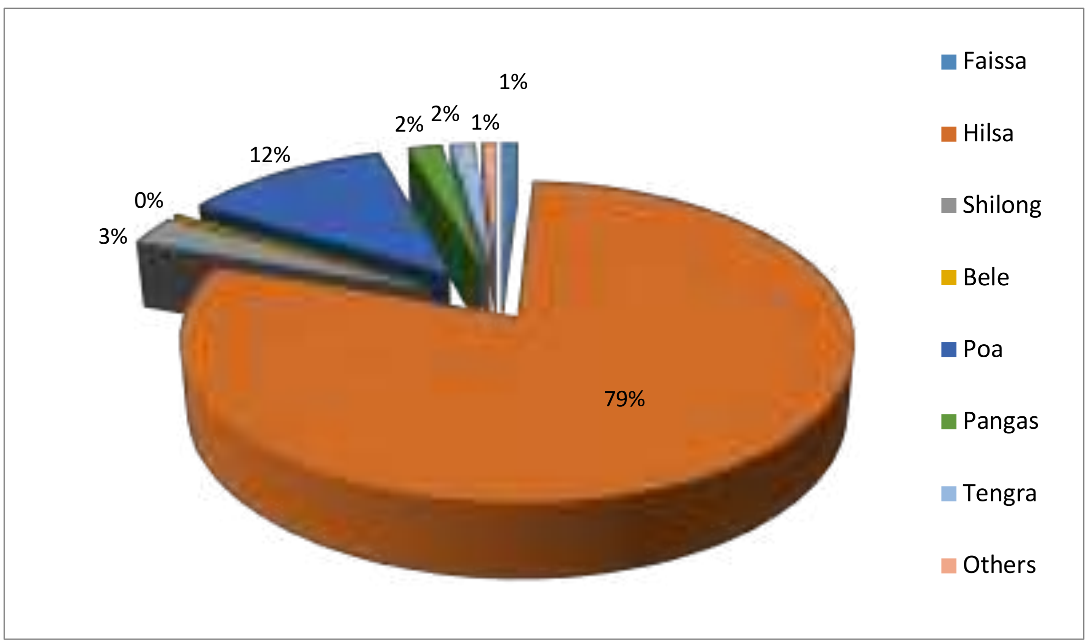

Fig. 9. Species composition of Current jal catch after the establishment of sanctuary.

Impact of Sanctuary on the Ecology of the River

Physico-chemical Parameters

The physico-chemical parameters exert important roles on the growth and production of fish and other aquatic organisms. Suitable water quality parameters are prerequisites for a healthy aquatic environment and to produce enough food organisms. The primary productivity of water body is dependent on physical and chemical factors of water in relation to the environmental factors. So, all the parameters *viz.* Air temperature (°C), water temperature (°C), free carbon dioxide (CO_2), dissolved oxygen (DO), pH, total alkalinity and total hardness were carefully measured and fluctuations among them were observed inside and outside the sanctuary areas during the study period (Table 1 and 2). Physico-chemical parameters were studied for all sampling locations of the Meghna river system inside and outside the sanctuary were found in suitable range and no remarkable deviations were observed (Tables 1 and 2).

Table 1. Water quality parameters of sanctuary areas.

Sampling spots	Month	Parameters (Mean±SD)						
		Air temp (°C)	**Water temp (°C)**	**DO (mg/l)**	**Free CO_2 (mg/l)**	**p^H**	**Total alkalinity (mg/l)**	**Total hardness (mg/l)**
Char Bhoirobi	Sep	33.5±0.5	31.5±1.3	5.6±0.2	15.5±0.6	7.7±0.3	72.7±4.7	96.0±17.2
	Oct	33.3±0.7	30.7±1.1	6±0.2	13.4±0.5	7.3±1.2	78±5.3	90.0±8.9
	Nov	29.8±1.1	28.2±1.3	5.5±0.5	14.3±1.2	7.9±0.2	79.7±5.0	70.3±1.5
Kaliganj	Sep	31.8±0.2	29.9±1.1	5.0±0.1	18.5±0.5	7.2±0.6	78.2±18.3	52.0±12.7
	Oct	33.0±0.7	32.5±0.2	5.6±0.2	17.4±1.1	7.5±0.3	73.6±12.2	61.0±11.2
	Nov	30.5±0.5	29.0±1.0	5.6±0.1	17.2±0.8	7.6±0.2	80.0±7.9	72.0±18.2
Ramgoti	Sep	32.0±0.4	31.3±0.3	5.1±0.3	18.1±2.1	7.8±0.8	73.1±13.5	95.0±17.2
	Oct	33.4±0.5	32.2±0.2	5.5±0.2	17.4±1.4	7.6±0.5	85.0±11.2	70.0±27.4
	Nov	30.8±0.3	29.0±0.9	4.9±0.1	19.0±0.8	7.3±0.2	75.0±7.8	105.0±55

Table 2. Water quality parameters of non-sanctuary areas.

Sampling spots	Months	Parameters (Mean±SD)						
		\Air temp (°C)	**Water temp (°C)**	**DO (mg/l)**	**Free CO_2 (mg/l)**	**p^H**	**Total alkalinity (mg/l)**	**Total hardness (mg/l)**
Gazaria	Sep	32.4±0.3	30.2±0.8	5.0±0.3	19.7±1.5	7.9±0.2	77±5.3	73.7±16.3
	Oct	33.2±0.8	31.2±1.0	5.7±0.4	17.7±3.8	7.7±0.3	83.7±14.0	89.2±14.9
	Nov	30.7±0.6	29.8±0.3	5.6±0.3	16.8±2.4	7.5±0.5	74.0±5.3	82.0±16.7
Sureswar	Sep	30.8±0.6	29.9±1.1	5.5±0.6	18.5±0.4	7.3±0.6	76.3±16.3	58.0±27.2
	Oct	32.0±0.6	31.5±0.9	5.8±0.4	17.4±1.2	7.6±0.2	72.5±11.5	62.0±26.3
	Nov	29.5±0.7	28.9±1.2	5.7±0.1	16.2±0.7	7.7±0.3	82.2±17.9	70.0±19.5
Upper Tarabunia	Sep	32.5±0.6	31.2±0.6	5.1±0.5	18.4±2.0	7.7±0.9	76.1±23.4	60.0±17.4
	Oct	32.4±0.9	31.1±0.6	5.2±0.3	17.3±1.6	7.8±0.1	84.0±31.4	66.0±18.0
	Nov	29.8±0.3	28.0±0.9	5.9±0.1	18.1±0.7	7.4±0.4	80.2±21.8	72.0±26.1

Planktonic biomass of sanctuary and non-sanctuary area

Abundance of plankton in sanctuary and non-sanctuary areas showed a wide range of variation (Tables 3 & 4). Average total phytoplankton density (no./l) inside the sanctuary areas of the Meghna river was higher than the non-sanctuary areas. Phytoplankton largely dominated over zooplankton throughout the study period. The mean contribution of phytoplankton was more than 96% in both the areas and zooplankton contributed the rest. Among the planktonic algae 38 genera of phytoplankton under 6 families and 12 genera of zooplankton under 8families were recorded inside the sanctuary areas whereas, 34 genera of phytoplankton under 5 families and 10 genera of zooplankton under 8 families were found outside the sanctuary areas of the Meghna river.

Table 3. Plankton composition of sanctuary areas.

Stations	Months	No. of plankton (Mean±SD)	
		Phytoplankton (no./l)	Zooplankton (no./l)
Char Bhoirobi	September	37900±6854.0	2166±757.2
	October	35366±7071.3	5656±5729.3
	November	37166±5378.1	2100±608.3
Kaliganj	September	36500±8560.0	2150±850.2
	October	33150±7500.5	2770±640.6
	November	35000±6634.1	2110±588.5
Ramgoti	September	28200±4509.6	1920±530.2
	October	25100±3600.4	1520±220.8
	November	28700±4800.0	1970±689.6

Table 4. Plankton composition of non-sanctuary area.

Stations	Months	No. of plankton (Mean±SD)	
		Phytoplankton (no./l)	Zooplankton (no./l)
Gozaria	September	23033±1950.2	1333±152.8
	October	19700±1571.6	1316±76.4
	November	27000±2000.0	1500±180.3
Sureswar	September	33300±4400.5	2160±350.0
	October	29900±2300.4	2050±430.3
	November	31000±7500.0	1970±279.0
Upper Tarabunia	September	34100±6500.0	2210±587.0
	October	31700±6890.0	2160±600.0
	November	30500±5500.2	2110±460.2

Discussion

A number of sanctuaries have been established in haor, baor, beels (natural depressions), seasonal floodplains, rivers and in marine areas in Bangladesh in order to protect and conserve the targeted species. The studies on the impact of sanctuaries have been done by some previous investigators some of which might not have direct implications to the present studies due to geo-morphic differences in water bodies. However, the outputs of these sanctuaries were found positive in all instances.

In the present study, increased CPUE of different fishing gears operated in the river Meghna were found after the establishment of sanctuary. No baseline study on the CPUE of different fishing gears were conducted that could give access to compare the results directly; however, in some of the previous investigations operated in different water bodies reflected the positive impact of sanctuaries. According to MACH project report (2002), catch per unit area (kg/ha) in different locations of 'Hail haor' (April 1999-March 2000) was recorded 112.8 kg, 393.64 kg, 69.82 kg, 278.21 kg, 248.12 kg, 158.87 kg and 35.57 kg in baseline catches but after the establishment of the sanctuary, the impact study (April2000-March 2001) revealed that catches were 190.55 kg, 465.73 kg, 78.01 kg, 322.9 kg 7,442.58 kg, 176.04 kg and 87.15 kg, respectively in the above mentioned area. The results of the present study match with the findings of Haldar (2006), reported that the CPUE of jatka (hilsa juvenile) in different places of the Meghna river has increased after the establishment of sanctuaries.

The biodiversity of different resident riverine species has been increased with the re-appearance of some IUCN listed threatened species as stated in the present study. If the geo-morphic differences of the water bodies are disregarded, similar results were found by Azher *et al*. (2007) who studied the impact of sanctuary on fish production and fish biodiversity of Dopi beel (sanctuary site) and Chotadigha-boradigha beel (non-sanctuary site) in Joanshahi haor over a period of two years from January 2004 to December 2005. The total production obtained from the Dopi beel was much higher than from the Chotadigha-boradigha beel. The fish species seemed as threatened were found to reappear in Dopi beel, while in Chotadigha-boradigha beel, the number of threatened species had been decreased. Thompson (2003) reported that establishment of sanctuary in 26 water bodies with support from WorldFish Center, NGO and DoF in Bangladesh changed the composition of small fishes as well as overall biodiversity. Kadir *et al*. (1999) reported that evidence of increasing fish diversity and catches in open floodplain beels as a result of establishment of fish sanctuaries. Haldar (2006) studied the impact of sanctuary on the biodiversity of the river Meghna that confers with the present study also reported that the number of resident riverine species and different shrimp and prawn has increased after the establishment of sanctuaries.

The impact of the establishment of sanctuary was also found positive on the ecology and plankton assemblage of the river Meghna according to the present study. Azhar *et al*. (2006) carried out the study on the impacts of fish sanctuaries on the production and diversity of plankton in beels of haor region at Mithamain Upazila of Kishoreganj district in Bangladesh during July 2004 to June 2005. He reported a total of 75 (60 phyto and 15 zooplankton) and 74 (59 phyto and 15 zooplankton) genera of plankton in two areas of sanctuary whereas, only 50 (39 phyto and 11 zooplankton) genera were obtained in non-sanctuary area. The physico-chemical factors did not show any significant difference among the treatments except water depth and they were within productive levels. Flura *et al*. (2018) studied the Physico-chemical properties and plankton abundance in sanctuary and non-sanctuary areas in the river Meghna, Bangladesh and found positive impact of sanctuary, however; no significant differences were reported. The river Meghna is a very vast and dynamic fluvial aquatic habitat. The variation that exists may be for river water discharge rate, water depth, local influx, temperature, and rainfall pattern. There is no physical demarcation between sanctuary and non-sanctuary areas in the river Meghna, therefore, substantial variations might not observe between the water quality of sanctuary and non-sanctuary areas as down stretches always receives the influx of upper stretches. Similar to the physico-chemical parameters, deviations were observed in terms of plankton composition inside (comparatively higher) and outside (comparatively lower) the sanctuary, however, this was not substantial. As there were no physical demarcation, the inhibition of the movement or migration of planktons are virtually impossible. Inside the sanctuary areas, there was less interruption on the ecology at least during the banning period due to prohibition of fishing operation that might attributable to these deviations.

The conservation of freshwater fisheries has been recognized as an important action throughout the world (Cowx, 2002) for fisheries management. Saunders *et al*. (2002) reported that, freshwater protected areas as a living resources management tool might play a vital role to protect freshwater biodiversity. Now a days the use of protected areas as a tool for conserving biodiversity is receiving wide attention. Moyle and Sato (1991) stated that the world urgently needs protected areas that specifically target freshwater habitats and protect biodiversity, representative habitats, rare or endangered species and remnants of intact habitats. Therefore, in compliance with above recommendations, urgent steps should be taken to enhance the management of existing sanctuaries and declare more new sanctuaries where biodiversity and habitat conservation are needed. As the most important river system of Bangladesh, the river Meghna deserves special attention in this regard.

Growth and Survival of Hilsa Juveniles (Jatka) in Brackishwater Nursery Pond

Introduction

Hilsa (*Tenualosa ilisha*) is a euryhaline species and has a wide range of salinity tolerance. It inhabits in the sea a part of its life and then migrate upward towards estuaries and river for spawning. As a popular fish, hilsa has very high demand in Bangladesh but its availability is only seasonal and also not enough. If culture of hilsa in confined waters could be established, it could be possible to increase both production and supply round the year. With this in view, culture of hilsa in freshwater ponds was first tried in the Riverine Station of BFRI in Chandpur and continued for quite long time. However, its growth, taste, maturity and gonadal development were not satisfactory. In this context, brackishwater pond culture of hilsa has been initiated in Khepupara Sub-Station of BFRI in Patuakhali.

Materials and Methods

This experiment was conducted in a brackishwater pond of Bangladesh Fisheries Research Institute, Riverine Sub-station, Khepupara, Patuakhali (Latitude 21°58′9"N and Longitude 90°14′25"E) from January 2016 to September 2016. The study was mainly focused on growth and survival of hilsa juvenile (jatka) in brackishwater pond.

Pond preparation

Experiment was carried out in a brackishwater pond with an area of 45 decimals that was sub-divided into 9 equal compartments (5 decimal each) by fine mesh filter net. The pond firstly was completely dewatered and exposed to the sunlight for one month to be fully dried up. After drying up, agricultural lime was thoroughly spread over the brackishwater pond area @ 1 kg/decimal. The pond was refilled with water (7ppt) after 5 days of liming.

Treatments and replication

A complete randomized design (CRD) was used to allocate three treatments replicated three times at three levels of stocking density (1, 2 and 3 hilsa juvenile (jatka)/m^2).

Treatment-1: 40 jatka per decimal or 1 jatka/m^2 and total number of 200 jatka/compartment.

Treatment-2: 80 jatka per decimal or 2 jatka/m^2 and total number of 400 jatka/compartment.

Treatment-3: 120 jatka per decimal or 3 jatka/m^2 and total number of 600 jatka/compartment.

Collection and stocking hilsa juveniles

Juveniles of hilsa (Jatka, 10-12 cm) were collected from seine net catch at Andharmanik river estuary. Seine netting was done very smoothly to avoid any extra pressure and injury. Jatka were kept in oxygenated polyethylene and placed in a jute bag covered with wet-jute mat to protect high temperature and sunlight. Then live jatka were transported to the Riverine sub-station, Khepupara with a speed boat. Collected jatka were first acclimatized with the pond water before releasing in the experimental ponds.

Fertilization

Preliminary fertilization was done with urea 240 g/dec and triple super phosphate TSP, 116 g/dec.

Water quality monitoring

Important physico-chemical parameters viz. salinity, water depth, transparency, water temperature, ammonia, pH, dissolved oxygen and free carbon dioxide of pond water were monitored fortnightly and were found to be at accepted level. Water exchange was done from adjacent canal by submersible pump. Two air blowers were used for aeration.

Feed management

Nursery powder feed (protein 36%, fat 7%) at 1% fish biomass was applied daily at the pond for rearing jatka. Gut contents of reared jatka were analyzed. Jatka did not respond to pelleted floating feed when applied.

Fig. 1. Newly prepared pond and jatka sampling.

Results

Growth rate of hilsa juvenile under different stocking densities were recorded at 15 days interval and the results have been presented in the Table 1. The result indicated higher growth in weight (g) at lower stocking densities and the growth rate gradually decreased with increasing densities. There was no significant ($p \leq 0.05$) difference in initial weight of fish under different treatments. In the study period the significantly higher mean weight gained by hilsa juvenile was 175.33±12.83 g in Treatment T_1 and lowest in T_3 was 134.67±31.57 g. The weight gain was significantly different ($p > 0.05$) between T_1 and T_3 but no significant difference ($p > 0.05$) between T_2 and other two replications.

The length gain was significantly different ($p > 0.05$) between T_1 and T_3 but no significant difference ($p > 0.05$) between T_2 and other two. Highest length gain in T_1 was 18.41±0.96 cm and lowest in T_3 was 16.77±0.43 cm. The mean specific growth rate of hilsa juvenile in different treatments ranged between 1.11 and 1.20. The significantly ($p \leq 0.05$) higher SGR values (1.20) was recorded in treatment T_1 while the lowest (1.11) was obtained also in treatment T_3. Significant differences were found between T_1 and T_3 but no significant difference ($p>0.05$) between T_2 and other two treatments when compared using ANOVA ($p\leq0.05$).

The survival rate in different treatments was comparatively low. The survival ranged between 34.73 to 45.58 %. Treatment T_1 and treatment T_2 showed significantly higher survival than Treatment T_3. The mean values of survival (%) were 45.58±4.46, 40.15±4.77and 34.73±2.25for treatments T_1, T_2 and T_3, respectively. There were significant differences between T_1 and T_3 but no significant difference ($p>0.05$) between T_2 and other two sites when compared using ANOVA ($p\leq0.05$).After 274 days of rearing, average daily length gain in cm of reared hilsa juvenile (jatka) was highest in T_1, value 0.067 cm/day and lowest in T_3 value, 0.061 cm/day. Average daily weight gain of reared hilsa juvenile (jatka) was highest in T_1 was 0.616 g/day and lowest in T_3 was 0.47 g/day. In monthly mean length and weight increment, T_1 showed better performance compared to others in brackishwater pond. The results show that the lower is the stocking density, better is the growth performance.

Table 1. Growth performance and survival of hilsa juvenile (jatka) after 274 days rearing in brackishwater pond.

Parameter	**Treatment 1(T_1)** **200 Jatka/ compartment**	**Treatment 2 (T_2)** **400 Jatka/ compartment**	**Treatment 3 (T_3)** **600 Jatka/ compartment**	**P-value**
Initial length (cm)	7.3±1.02	7.3±1.04	7.3±1.30	0.68
Final length (cm)	25.71± 0.96^{a}	24.7±0.83^{ab}	24.07±0.43^{b}	0.18
Net length gain (cm)	18.41± 0.96^{a}	17.40±0.83^{ab}	16.77±0.43^{b}	0.18
Initial weight (g)	6.5±1.25	6.5±1.27	6.5±1.26	0.841
Final weight (g)	175.33±12.83^{a}	159.41±15.19^{ab}	134.67±31.57^{b}	0.035
Net weight gain(g)	168.83±12.83^{a}	152.91±15.19^{ab}	128.17±31.57^{b}	0.035
Specific growth rate SGR (% g/day)	1.20± 0.05^{a}	1.17±0.03^{ab}	1.11±0.02^{b}	0.036
Average daily length gain (cm)	0.067	0.064	0.061	
Average daily weight gain (g)	0.616	0.56	0.47	
Survival rate (%)	45.58±4.46^{a}	40.15±4.77^{ab}	34.73±2.25^{b}	0.043

*Value in the same raw having the same superscript are not significantly different ($p<0.05$).

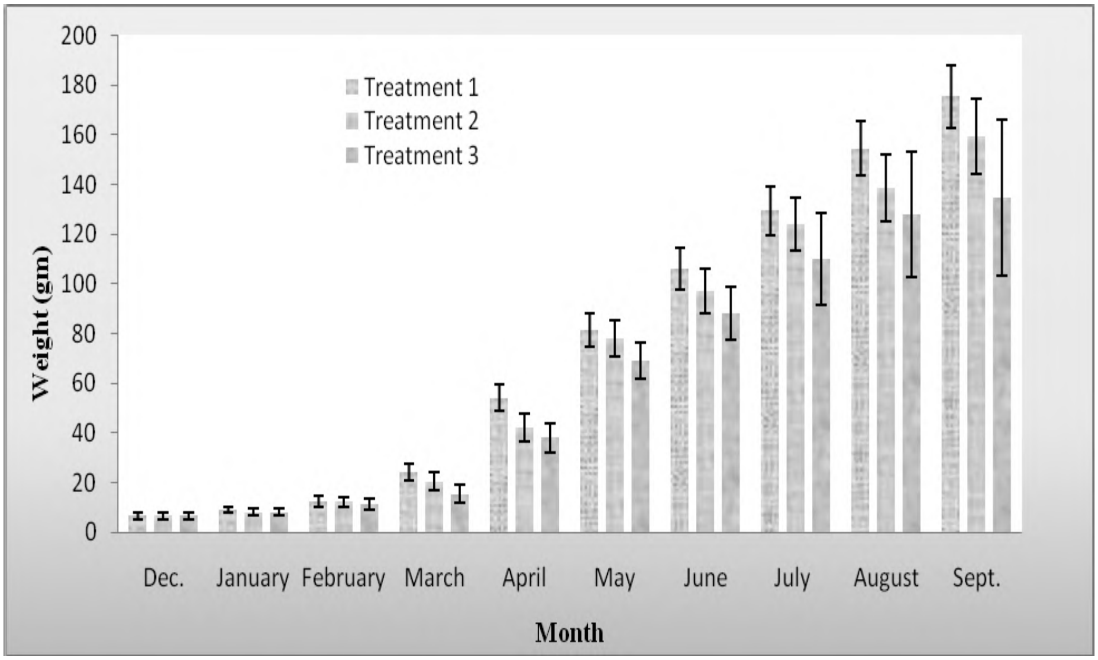

Fig. 2. Monthly mean growth increment of *T. ilisha* at different stocking density in brackishwater pond.

Physico-chemical assessment

Physico-chemical parameters of brackishwater pond were found to be within acceptable limit throughout the study period as showed in Table-2.

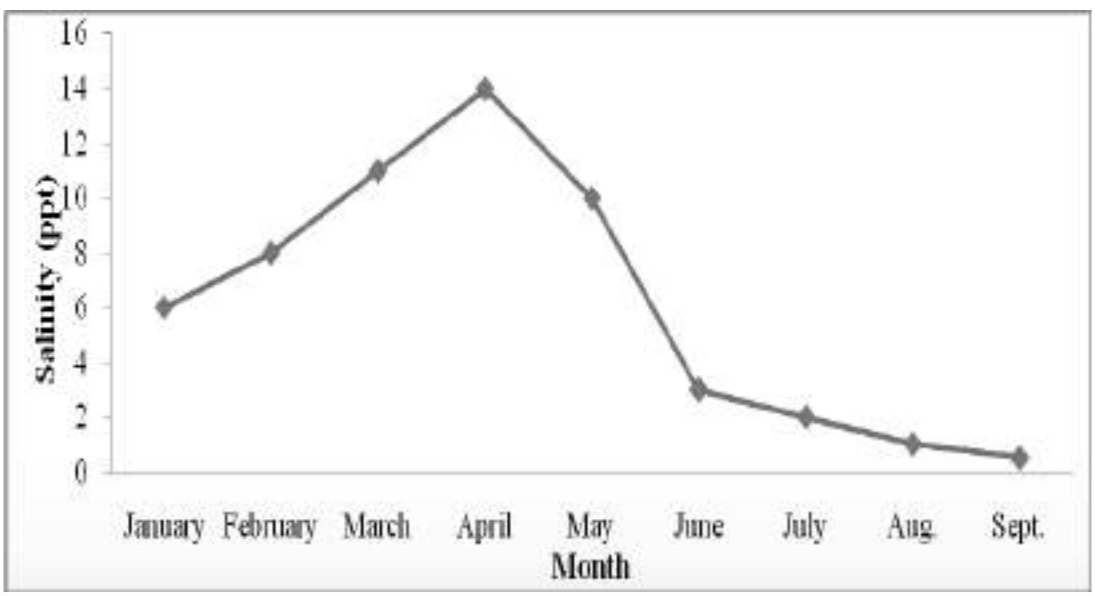

Fig. 3. Monthly Salinity variation in brackishwater pond.

Salinity of the pond fluctuated greatly from one month to another (Fig.2) which is very normal phenomena in case of brackishwater pond that are interconnected to estuarine river. Salinity was highest in April and lowest in September and ranged from 0.5 to 13 ppt in brackishwater pond.

Table 2. The Physico-chemical parameters of brackishwater pond prepared for the rearing of hilsa juveniles (jatka).

Parameters	Hilsa juvenile (jatka) rearing in brackishwater pond
Water temperature (°C)	24.978±2.205(22.6-28.10)
p^H	7.77±0.11(7.62-7.90)
DO (mgL^{-1})	6.14±0.512(5.2-6.7)
Alkalinity(mgL^{-1})	60.82±12.44(51.3-85.5)
Transparency (cm)	28.28±1.143(26.8-30)
Water Depth (m)	2.302 ±0.037(2.25-2.36)
Ammonia (ppm)	0.063 ± 0.078(0.017-0.2)
Free CO_2 (mgL^{-1})	8.444±3.283(5-15)

* All the values were reported as mean with standard deviation. Values in parentheses indicate the range of parameter.

Plankton enumeration

The plankton populations were monitored in brackishwater pond over the 274 days of experiment which are summarized in Table 3. Among the available phytoplankton Bacillariophyceae group found to be dominated while in case of zooplankton dominant group was Rotifera.

Table 3. Availability of plankton in juvenile (jatka) reared brackishwater pond and in the River Andhermanik (February - September).

Site	Hilsa juvenile (jatka) in brackishwater pond	
Plankton group	Mean±SD	Range
Phytoplankton (cells L^{-1})		
Euglanophyceae	172±55	100 - 250
Bacillariophyceae	2513±221	2120-2750
Cyanophyceae	154±21	120-180
Cholrophyceae	596±91	480-700
Zooplankton (Individual L^{-1})		
Copepoda	541±71	450-650
Rotifera	977±176	850-1250
Protozoa & others	126±43	50-175

* All the values were reported as mean with standard deviation. Values in parentheses indicate the range of parameter.

Discussion

It is widely believed that hilsa could be cultured in brackishwater pond, lagoons and enclosed water areas of the large barrages, where this fish has been to adopt in freshwater (Haldar, 2012). However, few studies have been conducted so far to examine the growth of *Tenualosa ilisha* under captive condition. Present study might be the first attempt to reveal the growth performance of *Tenualosa ilisha* in brackishwater habitat.

Growth performance of jatka varied in different stocking densities. The highest growth rate was found in treatment T_1 which was stocked with lower densities of 200 jatka/compartment although same food was supplied in all treatments at an equal rate. The lowest growth rate was obtained in the present experiment under the highest stocking rate. Fish stocking density is one of the most important parameters affecting fish growth and health in a number of ways (Mazlum, 2007; Zhu *et al*., 2011). Rahman *et al.* (2012a) conducted an experiment on growth rate of hilsa juvenile reared in two ponds and found 1.44 cm/month, 1.97 cm/month increment in length and 9.83 g/month, 22.17 g/month increment in weight, respectively in Chandpur during 1988-89. In another study Rahman *et al*. (2012b) tried to culture jatka collected from the Meghna River, in freshwater ponds for a period of 15 months, and recorded an average length and weight were 29.24±5.0 cm and 274.38±55.0 g respectively, with 40% survival rate. According to Rahman *et al.* (2012a), the probable reason behind the low survival of hilsa in pond habitat is the lack of migration facilities from freshwater to sea. Findings of the present study is indicating relatively better growth performance of hilsa juvenile (jatka) in brackishwater pond compared to previous studies which were undertaken in freshwater pond.

On-Board Breeding Trial and Larval Rearing of Hilsa

Materials and Methods

Time frame selection

Breeding trial activities were carried out from 10 October to 2 November 2016 in the River Meghna of Bangladesh. A total of six breeding trials were completed using speed boat and research vessel M. V. Rupali Ilish of the Riverine Station, Chandpur.

Site selection for artificial breeding

Based on availability of matured hilsa, three sampling spots were selected as follows:

- Chairman Ghat, Hatia (Noakhali)
- Ramgoti (Laxmipur)
- Katakhal and Charboirobi (Chandpur)

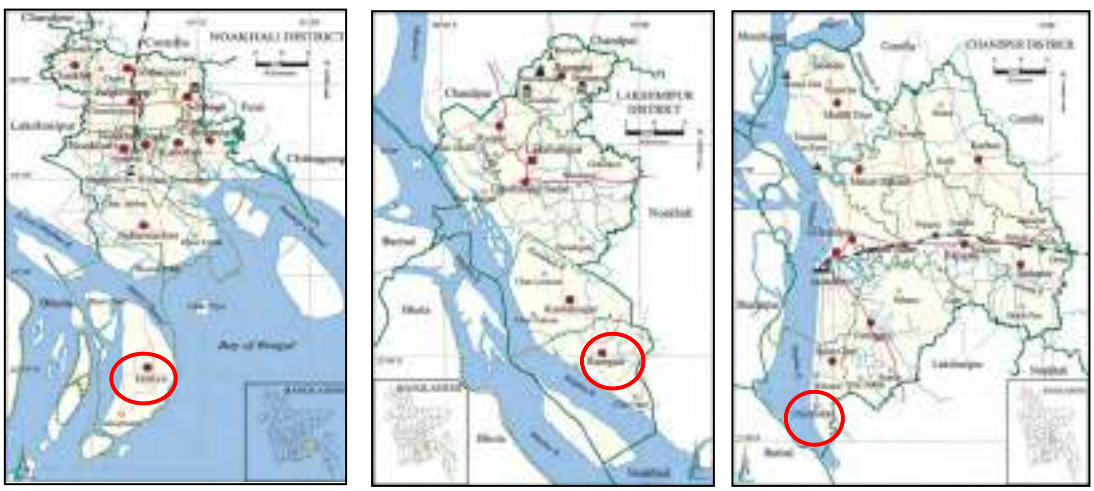

Fig. 1. Map showing sampling spots in the Meghna river for collecting matured gravid hilsa.

Preparation of breeding equipment

A portable model hatchery was established on the research vessel (M.V. Rupali Ilish) to provide the breeders a semi-natural condition as in the hilsa breeding ground. The portable hatchery that was set up on the research vessel for onboard breeding trial consists of an overhead tank, circular tank, bottle hatchery and a hatching jar. A plastic overhead tank of 1000 L capacity was placed on the vessel at 3.5 meter above the hatchery unit. River water from the spawning ground was stored in the overhead tank for hatchery operation. A circular tank of 500 L capacity was used to stock collected gravid hilsa with water supply, oxygenation, and proper disinfection. A 100-liter capacity incubation bottle covered by zero mesh net was used for incubation of fertilized eggs.

Fig. 2. Reserve tank, bottle hatchery and circular tank setup on research vessel (M.V. Rupali Ilish) for on-board breeding trial of hilsa.

Hatchling jar

A 3 L capacity plastic jar with air stone was also used for hatching of eggs. A 15 L capacity plastic bowl was used for the collection of spawn/fry provided with aeration when needed.

Collection of gravid hilsa by experimental fishing for artificial breeding

Gravid hilsa were obtained from experimental fishing by BFRI research vessel using 6.5-7.5 cm mesh sized gillnet (multi-dimensional net). Collected gravid hilsa were conditioned in a bowl containing river water maintaining natural environmental condition by providing water circulation and oxygenation to help release eggs.

Fig. 3. Collection of suitable gravid hilsa.

Live fish stripping

A total of 13 pairs of gravid hilsa were tried for breeding onboard at the major spawning grounds of hilsa during the ban period. Eggs from the matured female and milt from the male were collected through stripping and then mixed with the caudal fin of hilsa for fertilization**.** The fertilized eggs were then transferred to a hatching jar for incubation providing mild water circulation, aeration and shade to protect penetration of direct sunlight as the species is light sensitive. The various stages of embryonic development of fertilized eggs were continuously examined under compound microscope until the dead cell was found. Hatching commenced on 15 to 18 hrs. and completed in 20 to 21 hrs. at temperature 24-29°C, dissolved oxygen 6.5 to 8.5 and pH 7.6 to 7.8.

Results

A standard breeding protocol was followed for onboard breeding trial of hilsa. The breeding protocol was modified and finalized following De and Sen (1988). A total of 259 gravid hilsa were collected during the whole breeding operation. Most of the female broods were found to be at the maturity stages between V to VI$^+$. Female fishes in which large transparent ova seen oozed out at the slightest pressure were marked as maturity stage VI$^+$. Male hilsa having vas deferens full of milt which oozed out freely with little pressure were marked as maturity stage VI$^+$.


Fig. 4. Sorting of matured female and male hilsa suitable for breeding trial.

Breeding Trial

Breeding trials were completed when hilsa fishing ban was progressing. Immediately after getting the oozing female, eggs were stripped into a bowl by wet method and the milt from the males stripped over the eggs for fertilization. Eggs and milt were mixed gently with the help of bird's feather and caudal fin of hilsa.

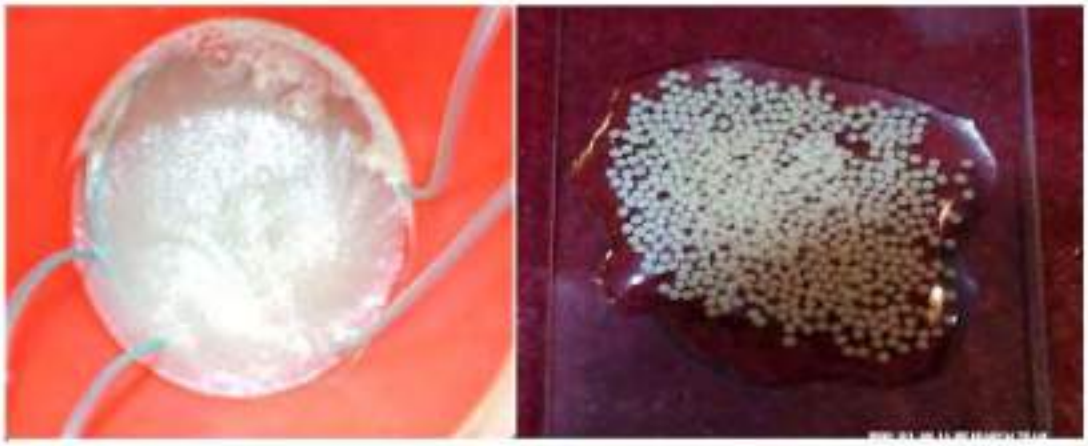

Fig. 5. Pictorial view of fertilized hilsa eggs and aeration process.

A total of 6 breeding trials were conducted at different locations of the hilsa spawning grounds. After failing to hatch out spawn in five subsequent breeding trials, the final breeding trial was conducted at Katakhal, Chandpur on 01 November 2016 using 2 males and 1 female. Eggs and milt were collected through stripping were mixed and placed in the incubation jar provided with good water circulation and oxygenation. The eggs were fertilized; vitelline membrane and cytoplasmic membrane formed around the egg yolk. Immediately after the fertilization of eggs, they started swell up. The eggs were found very soft, smooth, non-adhesive and almost spherical in shape. The vitelline membrane was found to be separated from the egg yolk 1.4 hours after fertilization (haf) and cleavage found to be formed under the microscope. This stage was identified as 2-cell stage of embryonic development that continued subsequently for few more hours. At 2.5 haf 8-cell stage and at 3.5 haf 16-cell of embryonic development was observed. The morula stage of embryonic development was observed at 4.5 haf. This development phase continued upto18-myotome stage that was identified after 8.5 haf. Thereafter, embryonic development stage ceased abruptly and of no further development was observed up to 12 haf and all eggs were either dead or arrested.

Discussion

The possibilities of hilsa aquaculture in confined water bodies have been reflected in some previous investigations (Pillay, 1958; Hora, 1940) that further stressed the need for development of artificial breeding and grow out technology of hilsa because of its greater nutritional and commercial interest (Sahoo and Puvanendran, 2012). Successful reproduction of hilsa depends on proper maturity of male and female that varies considerably in hilsa. Sahoo and Puvanendran, (2012) reported that the size at sexual maturity vary from 16.0 cm to 40.0 cm and 19.0 cm to 43 cm, for male and female hilsa, respectively. Stages of maturity of female gonads have been studied by few workers (Pillay and Rao, 1962; Mathur, 1964; De, 1986) revealed that female below 30 cm size group hardly take part in spawning activity.

Since 1908, several attempts towards artificial breeding of hilsa have been made (Wilson, 1909; Raj, 1917; Southwell and Prashad, 1918) but the major breakthrough came during late 70s (Malhotra *et al*., 1969). The breeding trials were mostly conducted either in the afternoon or in the late evening as described by (De, 1986; Sen *et al*., 1990). Immediately after fertilization of the eggs, this started swelling and the color of the yolk turned to light greenish yellow from its original light yellow colour which was also observed by Hora (1940). About 15-20 min, after fertilization, the eggs became almost colorless and attained a size of 1.95 mm to 2.10 mm diameter, the average being 2.02 mm. The eggs were very soft, smooth, non-adhesive and almost spherical in shape. The eggs were almost demersal in nature in still water and easily buoyed up and drifted by slight currents (Hora, 1940). Hilsa spawn in freshwater and deposited eggs hatch after 23-26 haf at an average temperature of 23°C (Jones and Menon, 1951). Embryonic development of the species was monitored closely in the present study and a pivotal role of water temperature was identified like many previous workers (De, 1986; Kulkaran, 1950). Kulkarani, (1950) reported that the incubation period varies between 18-20 hrs. at 28.5°C; 18-20 hrs. at 23.5°C to 30.0°C (Malhotra *et al*., 1970) and 18-21 hrs. at 24°C to 29°C (De, 1986). In the present study, morula stage was found about 3 haf followed by blastula and then gastrula that appeared 5 haf. Similar results were found by De and Sen, (1988) and De (1986).

River is a unique habitat where temperature and other physico-chemical parameters changes slowly. Therefore, chances of sudden stroke or abrupt impact on the embryonic development might not happen. On the contrary, this condition is very difficult to maintain in a portable hatchery that was set on the M.V. Rupali Ilish for which success in this regard might be compromised. Detailed further investigation may address the reasons behind the failure of the present breeding attempt.

Acknowledgements

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Chapter IX

Research on Jatka Conservation and Alternate Income Generation

Introduction

The production of hilsa, the largest single fishery of Bangladesh contributing about 12% of total fish production showed a declining trend from 1989-90 to 2002-03 due to lack of conservation and management. Catching of mother hilsa during spawning season and reduction of recruitment due to indiscriminate catching of hilsa juveniles (jatka) were the main reasons for this decline. Therefore, to prevent this declining trend, uninterrupted breeding of hilsa to augment recruitment, control of jataka catching and improvement of hilsa fisher's livelihood were taken into consideration under Hilsa Fisheries Management Action Plan (HFMAP) to obtain an increased and sustainable production of hilsa. As part of the management measures, several sanctuaries were established, fishing ban in the main spawning grounds imposed, jatka protection program launched and food assistance to the hilsa fishers (Vulnerable Group Feeding, VGF and Alternate Income Generating Activities, AIGA) provided. The above measures made a positive impact and there has been an upward trend in hilsa production. Therefore, in order to strengthen and continue implementation of the above management measures and to assess their impacts on the fishery, the present research and development (R & D) program was undertaken jointly by DoF and BFRI and implemented for seven years from July 2008 to June 2015 to address various issues related to hilsa research and development.

Objectives

The main objective of the program was to conduct broad based research on hilsa biology and environmental issues of the riverine and coastal ecosystem including capacity building of the research station and the scientists and preparation of awareness building materials. The achievement of research on various issues is briefly presented below:

Research Achievements

Confirmation of Breeding Grounds

In experimental fishing and catch assessment from the landing centers, large size hilsa were found in the lower Meghna River and coastal areas during 2008-2015. However, small size hilsa lower than 30.0 cm were available in the upper part of the Meghna River. The male and female sex ratio of hilsa at the lower Meghna River adjacent to the main spawning grounds was 35% and 65%, respectively. Almost 100% of fish of Monpura and Hatia region was above 32.0 cm size and most fishes of this size were ready for breeding. Based on the above findings, this area has been further confirmed as the breeding grounds of hilsa.

Natural Breeding Success

Natural breeding success was determined by observing the number of spent hilsa in the main spawning ground under different management system. The comparative results since 2002 are given in Fig. 1.

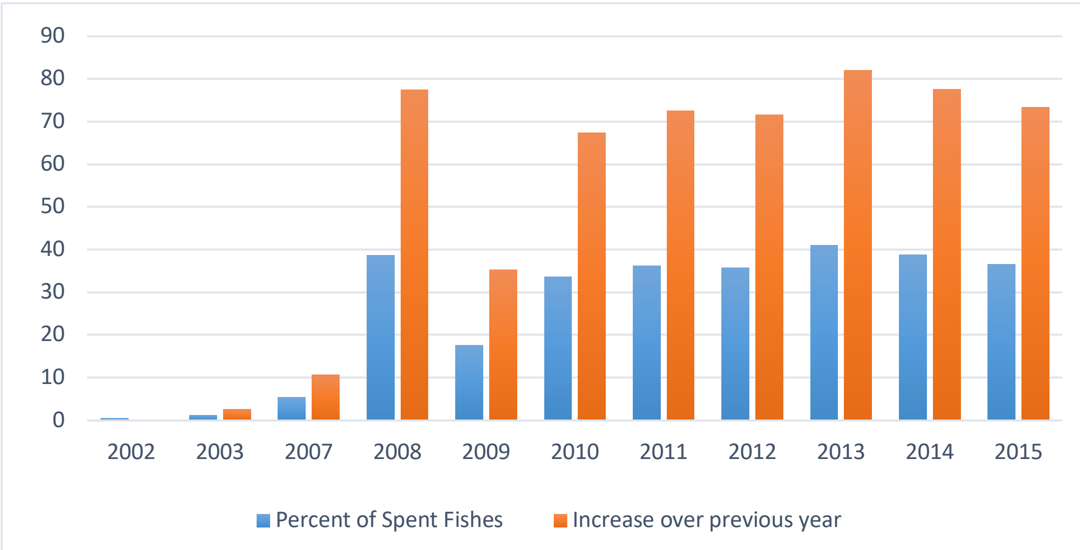

Fig. 1. Comparative breeding success of hilsa under different management options.

From the figure, it is seen that natural breeding of hilsa has increased almost continuously during the study period (2008-2015) compared to 2002 due to implementation of fishing ban for the duration of 11 to 22 days in different years during the peak breeding season and this management measure proved to be very effective to augment natural breeding of the hilsa fish.

Impact on Abundance of Jatka

The abundance of jatka was determined during the period from 2008-09 to 2014-15 by experimental fishing in the lower Meghna River to assess the impact of conservation measures on the abundance of jatka. The CPUE of jatka by 100-meter long monofilament gill net under different management measures in different years is shown in Table 1. In 2005, hilsa sanctuaries were established and hilsa conservation rules enforced by deploying Bangladesh Navy, Coast Guard along with mass awareness building activities. From 2007 to 2015, management measures were further strengthened by elevating fishing ban from 10 days to 15 days in the main spawning grounds, strengthening jatka protection program, expanding social safety-net program by VGF and AIGA for the fishers and strengthening of institutional capacity of Community based Organizations (CBOs). Because of the positive impact of the above management interventions, fishing ban was further extended to 22 days throughout the country from 2016. Because of vigorous implementation of the above management programs, the abundance of jatka has increased by 327% in 2015 over the base year 2005 (Table 1).

Table 1. Abundance of jakta under different management measures.

Year	Jatka Catch/100 M net/hour/day (kg)	Decrease (%)	Increase (%)	Management measures implemented
2005	0.94	-	-	Hilsa sanctuary and enforcement of jatka conservation
2006	0.61	35.10	-	Do
2007	0.72	-	18.03	Do + 10 days brood hilsa fishing ban + food assistance
2008	1.89	-	163	As above + AIGA
2009	2.31	-	145	As above
2010	2.44	-	160	As above
2011	2.72	-	189	As above + 11 days hilsa fishing ban
2012	2.74	-	191	As above
2013	2.78	-	196	As above
2014	3.04	-	323	As above
2015	3.07	-	327	As above + 15 days brood hilsa fishing ban

Protection of Brood Fish, Egg and Hatchlings

The breeding success of hilsa mainly depends on the number of brood fish protected from not being captured immediately before the peak breeding season. Thus, to protect brood hilsa, fishing ban was implemented in the main breeding season from 11 to 15 days in different years as mentioned above (Table 1). The impact of implementation of fishing ban in the main spawning grounds on the amount of eggs and number of jatka produced is given in Table 2.

Table 2. Impact of fishing ban on the increase of egg, hatchlings and fry production.

Years	Number of hilsa protected (million)	Estimated egg production (kg)	Hatching production at 50% hatching rate (million)	Jatka production at 10% survival (million)
2007	144	46,800	29,300	2,930
2008	156	3,92,620	245,385	24,538
2009	149	170,420,	85,210	8,521
2010	151	336,199	210,120	21,012
2011	161	385,500	240,937	24,098
2012	-	380,400	237,750	23,775
2013	165	447,100	278,437	27,943
2014	163	417,765	261,103	26,110
2015	166	599,720	299,860	29,986

*Average gonad weight 100 g/fish, ** Average number of egg/g of gonad 12,500.

Due to implementation of fishing ban from 11 to 22 days during different years, the number of brood hilsa protected from not being captured has increased from 144.0 million in 2007 to 166.0 million in 2015 (15.3% increase). Similarly, the egg production has increased from 46,800 kg in 2007 to 599,720 kg in 2015 and hatchling and jatka production also increased from 29,300 million to 299,860 million and 2,930 to 29,985 million, respectively.

During 2009 to 2011, fishing ban for brood hilsa was implemented for 10 days in the breeding grounds and from 2012 to 2014, ban period was enhanced to 11 days and implemented throughout the country. However, in 2015, hilsa fishing ban period was increased up to 15 days and from 2016 onward, ban period was further increased for 22 days and being implemented throughout the country. Increased duration of brood hilsa fishing ban appeared to be very effective towards natural breeding success of hilsa that has significantly increased the production of hatchling and jatka.

Delineation of two New Sanctuaries in Shariatpur and Barisal Districts

Based on findings of the in-depth research of BFRI in the lower Padma River of Shariatpur district, and Nayabhangani, Lata and Dharmaganj River of Hijla and Mehendiganj upazila of Barisal district, two new sanctuaries each having about 20 km and 82 km long River stretches have been delineated (Fig. 2). Meanwhile, the Government has declared these two new sanctuaries by gazette notifications under the relevant acts and rules (Anneures 2, 3; S.R.O. No. 83-Law/2014, dated, 22 May 2014, and S.R.O. No. 107-Law/2018, dated 12 April 2018). The area of the sanctuaries and fishing ban period is mentioned in the Tables below (Tables 3 and 4).

Based on research findings and recommendations and consultations in various meetings and workshops, the government established a total of 6 (six) hilsa sanctuaries for conservation and management of the hilsa fishery resources of Bangladesh.

Table 3. Demarcation of the new sanctuary in the lower Padma River and fishing ban period.

Boundary (GPS points)		Boundary	Fishing ban period
North-east	Kachikata Point of Bhedarganj upazila of Shariatpur district (GPS 23°19.80' N and 90°32.60' E)	Naria-Bhedarganj upazila in the North of Shariatpur district and in the South Matlab upazila of Chandpur district; 20 km long river stretches of lower Padma River	March to April every year
North-west	Bhomkara Point in Naria upazila of Shariatpur district (GPS 23°18.40' N and 90-28.80' E)		
South-east	Beparipara Point (GPS 23°15.90' N and 90°37.70’ longitude) of Matlab upazila of Chandpur district		
South-west	Tarabunia Point of Bhedarganj upazila of Shariatpur district (GPS 2.113.50' N and 90°35.10' E)		

Table 4. Area of hilsa sanctuary in Hijla-Mehendiganj upazila of Barisal district.

	Boundary (GPS points)		Area	Fishing ban period
North-east	Nachakati Point (Nayabhangani river) in Hijla upazila of Barisal district	23°2.75'N and 90°36.78'E	82.0 km	March to April every year
North-west	Harinathpur Point (Nayabhangani river) of Hijla upazila)	22°58.67'N 90°27.64'E		
South-east	Dhulkhola Point (Dharmaganj River) of Hijla upazila of Barisal district	22°51.91'N 90°37.52'E		
South-west	Barisal district's Mehendiganj upazila is a landmark point (Lata river)	227°44'N 90°26.16'E		

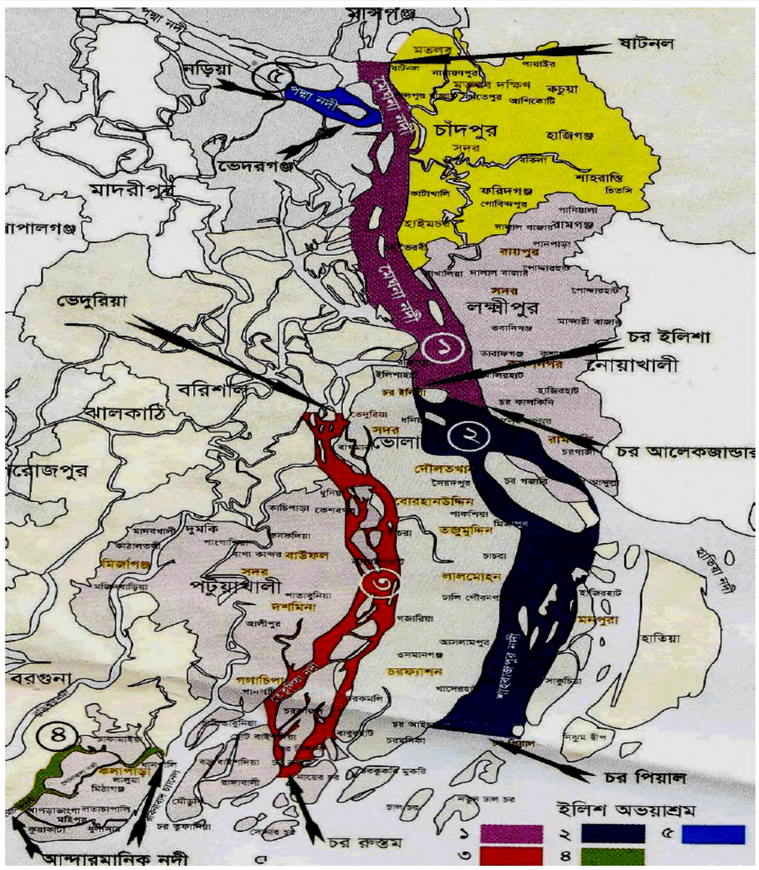

Figure 2: Hilsa sanctuaries in Bangladesh (Source: MoFL).

Fig. 2. Locations of hilsa sanctuaries in Bangladesh.

Production of Hilsa under Different Management Options

The Riverine Station of BFRI, Chandpur has been regularly monitoring the trends of hilsa production by collecting data from the Fisheries Resources Survey System (FRSS) of the Department of Fisheries. The hilsa production data since 2001-02 to 2017-18 has given in

Table 5. Under various management options, hilsa production has increased from 220,593 tonnes to 517,000 tonnes over a period of 17 years from 2001-02 to 2017-18, *i.e*. an increase of 134.45% growing at the rate of 8% per annum.

Table 5. Production of hilsa under different management systems.

Year	Hilsa production (tonnes)	Growth (%)	Management system implemented
2001-02	220,593		Traditional method of jatka conservation
2002-03	199,032	(-) 9.80	As above
2003-04	255,839	15.98	Hilsa sanctuary and conservation of jatka
2004-05	275,862	25.05	As above
2005-06	277,123	25.63	As above
2006-07	2,79,189	26.56	As above + 10 days brood fishing ban + food assistance
2007-08	290,000	31.46	As above + Alternate income generation activities (AIGA)
2008-09	298,458	35.30	As above
2009-10	313,342	41.71	As above
2010-11	339,845	54.06	As Above
2011-12	346,512	58.13	As above + 11 days brood hilsa fishing ban
2012-13	351,223	56.85	As above
2013-14	385,140	74.59	As above
2014-15	387,211	75.53	As above
2015-16	394,951	79.04	As above + 15 days brood hilsa fishing ban
2016-17	496,417	125.00	As above + 22 days fishing ban
2007-18	517,198	134.45	As above

The latest management option of 22 days fishing ban throughout the country along with AIGA for the fishers appears to be the most effective option for increasing hilsa production. In view of this, the present management option which includes maintaining hilsa sanctuaries, strict enforcement of jatka conservation rules, motivational activities, social safety-net program (food assistance, AIGA) for the fishers should be continued for sustainable production of hilsa fishery in Bangladesh.

Detection of Heavy Metals in Soil, Water and Hilsa Muscle

The presence of heavy metals such as lead, zinc, mercury and iron in water, soil and muscle of hilsa fish of the Meghna River was determined by atomic absorption spectrophotometric method. The presence of these elements was found lowest in the muscles of hilsa than in water and soil. Presence of lead, zinc and cadmium in the hilsa muscle was found to be less frequent in the fish from the lower part of the Meghna River and were less than the detection level. Besides, the pollution level of Buriganga, Shitalakhya and the upper Meghna River has turned to very serious level. The polluted water of these rivers is carried to the lower part of the Meghna river during the tidal flood and monsoon season. So, there is a possibility of damaging the nursery and breeding grounds of the hilsa of the lower Meghna River by this polluted water in near future.

Chapter X

BFRI Core Research Achievements on Hilsa

Introduction

Since inception of Bangladesh Fisheries Research Institute (BFRI), the Riverine Station of the institute at Chandpur and its sub-station at Khepupara, Patuakhali have been conducting research on assessment and monitoring of the hilsa fishery in all aspects of ecology, biology, biodiversity, habitat and environment, reproduction and population dynamics, identification of spawning and nursery grounds, product development and value addition, socio-economics and resource management strategies on continuous basis and generating scientific information. The knowledge and information that have generated through research has led to formulation of policy and management plans now being implemented by the government through the Department of Fisheries for sustainable development and enhancement of the fishery.

The regular research program of the Institute is called core research program. The core research programs on hilsa are identified, prepared, reviewed and prioritized in conformity with the national priority and implemented on yearly basis following the system as adopted for the National Agricultural Research System (NARS). So far, a large number of core research programs on various aspects of hilsa have been conducted by the Hilsa Research Group of the Institute. The achievements of some of the important research programs are presented in the following sections.

Research Programs

Limno-biological Characteristics in the Hilsa (Tenualosa ilisha) Nursery Grounds of the Meghna Estuary.

Objectives

- Study the selected limno-biological parameters in the nursery grounds of hilsa.
- Study the primary production and estimation of hilsa yield based on gross production.

Achievements

Environmental Characteristics of the Meghna River System

The study was conducted in four stations *viz.*, Mohonpur, Kaliganj, Charludua and Daulatkhan areas of the Meghna river system. For assessment of primary production, instead of Charludua, Chandpur was considered as a sampling station, as this area is the major nursery ground of hilsa. Investigation was carried out in area between latitude 22°35.494N" and longitude 90°49.061"E and 2 samples, one in post-monsoon and another in pre-monsoon were collected. Some of the parameters were analyzed in the field and others in the laboratory.

The data on physico-chemical characteristics of the Meghna River is presented in Table 1. The surface water temperature of the river was found always lower than the air temperature. The surface water temperature ranged between 24.1 and 26.0°C with a mean of 25.1±0.8. The Secchidisc visibility ranged from 25 to 90 cm at different stations. The clarity of water remained higher at the upper stretch of the river than that of lower stretch. The water was almost muddy in and around the estuarine region. The dissolved oxygen (DO mg/l) content gradually decreased from the upper to lower stretches of the river system. The mean value of DO was recorded 6.3±1.0. The highest value of CO_2 (7.7 mg/l) was observed in Mohonpur that also gradually decreased in a similar pattern as in case of DO. The pH remained on the neutral to alkaline level (7.0-8.0) in the sampling stations and exhibited a narrow range of fluctuation throughout the investigation period. Total alkalinity was found in suitable range (84.8-95.1 mg/l) indicating the water was nutrient enriched and hard type (73.2-81.4 mg/l) and such waters could be considered as optimum for fish growth. The ammonia concentration was found little high ranging from 0.4 to 0.8 mg/l. It showed a gradual decrease from the upper to lower stretches of the river. Except Mohonpur, the concentration of nitrite was found zero for the other stations. The chemical oxygen demand (COD) level was found very high at Mohonpur and Daulatkhan which was far above the critical level. Further study is needed to find the causes of such high concentration of COD in river water that reduce the DO and create anaerobic condition which is deleterious to fish and other aquatic organisms. Total dissolved solids (TDS) fluctuated between 0.12 and 0.32 mg/l with a mean of 0.22±0.1. The highest value (220 μS/cm) of conductivity recorded at Daulatkhan which was about 2.5 times higher than that of other sampling stations.

Abundance of Planktonic Organisms

A total of 22 genera of phytoplankton belonging 14 families and 8 genera of zooplankton belonging 6 families were recorded in the study area. Among the identified genera, 95.1% were Chlorophyceae, 3.9% Myxophyceae, 0.6% Bacillariophyceae and 0.4% Euglenophyceae. The zooplanktons were represented by the Rotifers (52.1%) followed by Copepoda (25.8%) and Cladocera (22.1%). Abundance of plankton in different stations of the Meghna river system is presented in Table 2. It is evident from the Table that a wide variation exists in the standing crop of total plankton in different stations of the river ecosystem. Phytoplankton largely dominated over zooplankton in the river throughout the study period. Phytoplankton contributed 95.2% of the total plankton population. Phytoplankton density (nos./l) ranged between 7,200 and 17,000 with a mean of 11,900. The highest count of phytoplankton was recorded in and around the estuarine area. Except Mohonpur (15.3%), zooplankton population recorded in other three stations were lower in number and ranged between 2.0-3.4%. Maximum quantitative difference between zoo and phytoplankton was recorded for Kaliganj (1.0:50) while minimum for Mohonpur (1.0:5.5). Among the phytoplankton, Chlorophyceae contributed the bulk and the other predominant genera were *Scenedesmus*, *Proticiccus* and *Pediastrum.* In case of zooplankton, Rotifers (*Brachionus)* contributed the bulk followed by Copepoda (*Cyclops*) and Cladocera (*Daphnia*).

Primary Productivity

Primary productivity of sub-surface water (15 cm below) of the study area is presented in Table 3. The net and gross production was higher at Chandpur region of the Meghna River (Table 3) compared to other regions. The net primary production (gC/m³/hr) in the euphotic zone of the Meghna River ranged between 0.115 (Daulatkhan) and 0.220 (Chandpur) and the gross primary production (gC/m³/hr) fluctuated between 0.125 and 0.352. Primary productivity showed that the upper stretches of the river had high productivity compared to the estuarine zones. During cloudy and rainy weather, the net primary production was very low to trace amount. However, during sunny weather and in clam area of the river, the photosynthetic productivity was found higher.

State of Jatka (Hilsa Juvenile) Catches

When jatka attained a size of 6.2 cm (4.4-7.9 cm) with a mean weight of 2.3 g, they became susceptible to catches of set bag nets (behundi jal) in the Chandpur region during January and the catch per unit effort (CPUE) of these nets was recorded as 32.4 kg/net/day (Table 4). When these jatka reached to the length between 11.0 and 12.0 cm, the fishers use gillnets (known as current jal) for capturing them during February-March. At this length range, jatka attain a mean weight of about 13.5 g (11.5-15.6 g). It is noted that although the use of monofilament gillnet (current jal) and set bag net are totally banned throughout the country, a section of fishers still using these nets for catching jatka indiscriminately.

Table 1. Physico-chemical characteristics of the Meghna river system during 2002-03.

Parameters	Mohonpur	Kaliganj	Chandpur	Daulatkhan	Mean±SD
Global position (Latitude/Long.)	23°23.987′ N 90°35.793′ E	22°51.252′ N 90°39.169′ E	22°42.456′ N 90°49.061′ E	22°35.494′ N 90°45.446′ E	-
Air Temp. (°C)	25.3	27.2	27.8	28.9	27.3±1.5
Water Temp.(°C)	24.1	24.8	26.0	25.5	25.1±0.8
Secchidisc Transp. (cm)	90	62	25	30	51.7±30.3
Dissolved Oxygen (mg/l)	7.4	6.8	5.9	5.1	6.3±1.0
Free CO_2 (mg/l)	7.7	7.3	6.4	3.6	6.2±1.8
pH	8.0	7.0	7.7	7.7	7.6±0.4
Alkalinity (mg/l)	84.8	94.3	95.1	84.8	89.7±5.7
Hardness (mg/l)	78.1	81.4	80.6	73.2	78.3±3.7
Ammonia (mg/l)	0.8	0.6	0.6	0.4	0.6±0.2
Nitrite (mg/l)	0.03	0	0	0	0.007±0.015
Chemical Oxygen Demand (COD) (mg O_2/1)	70.7	8.3	4.2	62.4	36.4±35.0
Total Dissolved Solids, (TDS) (mg/l)	0.26	0.12	0.32	0.18	0.22±0.1
Conductivity (µS/cm)	91	98	96	220	126.2±62.6

Table 2. Abundance of plankton in different regions of the Meghna river system.

Sampling stations	Phytoplankton (nos./l)	Zooplankton (nos./l)	Total plankton (nos./l)	Phytoplankton (%)	Zooplankton (%)
Mohonpur	7,200	1,300	8,500	84.7	15.3
Kaliganj	15,000	300	15,300	98.0	2.0
Chandpur	17,000	500	17,500	97.0	2.9
Daulatkhan	8,400	300	8,700	96.6	3.4
Mean±SD	11,900±4,829	600±476	12,500±4,593	95.2	4.8

Table 3. Primary productivity of sub-surface water of the Meghna river system.

Station	Net primary production ($gC/m^3/hr$)	Respiration ($gC/m^3/hr$)	Gross primary production ($gC/m^3/hr$)
Mohonpur	0.135	0.138	0.273
Kaliganj	0.220	0.132	0.352
Chandpur	0.144	0.162	0.306
Daulatkhan	0.115	0.110	0.225
Mean±SD	0.154±0.046	0.119±0.068	0.264±0.098

Table 4. Juvenile hilsa (jatka) catch of set bag net and gillnet.

Month (2003)	Fishing gear	CPUE (kg/net/day)	Jatka catch (%)	Mean length (cm)	Mean Weight (g)
January	Set bag net	32.4 (8.0-55.0)	11.5	6.2 (4.4-7.9)	2.3 (0.8-3.6)
February	Gillnet	6.4 (2.0-15.0)	100.0	11.2 (10.5-12.0)	13.4 (11.5-15.2)
March	Gillnet	4.0 (3.0-5.0)	99.1	11.7 (11.4-12.1)	13.8 (12.0-15.6)

Ecological Assessment of the Lower Meghna River

Objectives

- Study the limno-biological characteristics in the major rivers and estuaries.
- Estimation of primary production and fish yield.
- Study the catch-effort and catch composition of different fishing gears in the lower Meghna.
- Impact assessment of juvenile hilsa (jatka) ban program in the lower Meghna.
- Landing status of hilsa/juveniles around the lower Meghna.

Achievements

The study was carried out in twelve sampling stations viz. Mohonpur, Kaliganj, Alexander, Daulatkhan, Dhulia, Galachipa, Pyrakunja, Karkhana, Dabdabia, Jhalkati, Vashanchar and Hizla in the nine river systems (Meghna, Tetulia, Lohalia, Pyra, Karkhana, Kirtankhola, Bishkhali, Arialkhan and Lata) covering hilsa nursery and breeding grounds.

Limno-biological Characteristics of the Rivers and Estuaries

The depth of water of the sampling stations varied between 1.0 and 16.0 meter. The Secchidisc visibility ranged from 10 to 90 cm (Dhulia and Vashanchar, Barisal). The velocity of current was not above 2.0 m/sec. The higher velocity of current was found in the downstream of the lower Meghna and Payra River. The surface water temperature of the rivers always found lower than the air temperature. The water temperature at surface water ranged between 25.2 (Hizla) and 31.6°C (Pyrakunja). Water was almost muddy in and around the estuarine region. Dissolved oxygen (DO) concentration ranged between 5.0 and 6.0 mg/l during September, while 5.4 and 7.2 mg/l in February-March. The DO levels were congenial for aquatic life. The pH levels in the river water remained on the alkaline side (7.7-9.5) and exhibited a narrow range of fluctuation throughout the investigation period. The free CO_2 levels (1.9 mg/l) were low in several stations and were higher in Dhulia (9.1 mg/l) and Barisal (9.1 mg/l), respectively. The total alkalinity was found in fairly appropriate levels (50.0-152.9 mg/l) and indicated the river water as nutrient enriched which could be considered as good for optimum fish production. The hardness showed increasing trend towards the southern region of the country. It was also high in Alexander region of the Meghna estuary in February-March and was beyond the detection capacity of conductivity meter indicating a positive relationship between hardness and total dissolved solids (TDS). At the same period, the value of total alkalinity was low. The values of conductivity ranged from 108 to 995 μS/cm except the aforesaid station. Total dissolved solids (TDS) fluctuated between 0.008 and 0.093 mg/l.

Abundance of Planktonic organism in different river system

In the present investigation, 22 genera of phytoplankton belonging 14 families and 8 genera of zooplankton belonging 6 families were recorded. Abundance of plankton in different stations of the river systems is presented in Table 5. It is evident from the Table that a wide variation (26,600-78,000 nos./l) existed in the standing crop of total plankton in different stations of the river ecosystem. Phytoplankton density ranged between 26,100 and 77,800 nos./l. The contribution of phytoplankton was about 99.0% to the total plankton organisms. The highest count of phytoplankton was recorded in Alexander of the Meghna estuary followed by Lohalia River, Pyrakunja of Pyra River (Patuakhali). Among the planktonic algae, Chlorophyceae contributed the bulk and the predominant genera were *Scenedesmus*, *Protococcus* and *Pediastrum*. Among the zooplankton, Rotifers (*Brachionus*) predominated followed by Copepoda (*Cyclops*) and Cladocera (*Daphnia*).

Table 5. Status of phytoplankton and zooplankton in different rivers during 2003-04.

River (Station)	Phytoplankton (Nos./l)	Zooplankton (Nos./l)	Total	Phytoplankton (%)	Zooplankton (%)
Meghna (Mohonpur)	4,900	200	50,100	99.60	0.39
Meghna (Kaliganj)	38,100	300	38,400	99.2	0.78
Meghna (Alexander)	77,800	200	78,000	99.74	0.26
Meghna (Daulatkhan)	29,600	100	29,700	99.67	0.33
Tetulia (Dhulia)	37,500	600	37,100	98.42	1.58
Lohalia (Galachipa)	54,000	600	54,600	98.90	1.09
Pyra (Pyrakunja)	50,500	600	51,100	98.82	1.17
Karkhana (Karkhana)	43,600	300	43,900	99.32	0.68
Kirtankhola (Dabdabia)	26,100	500	26,600	98.12	1.88
Bishkhali (Jhalkati)	38,000	500	38,500	98.70	1.29
Arialkhan (Vashanchar)	29,300	200	29,500	99.32	0.68
Lata (Hizla)	33,300	200	33,500	99.40	0.59
Pyra (Pyrakunja)	50,500	600	51,100	98.82	1.17

Primary Production

Primary production of sub-surface (15 cm below) water of different rivers is shown in Table 6. It is evident from the Table that both net and gross production was higher at Kaliganj region in the Meghna River system. The net primary production ($gC/m^3/hr$) in the euphotic zone of the rivers ranged from 0.041 (Daulatkhan, Meghna river) to 0.139 (Kaliganj) during the period of investigation. Gross primary production ($gC/m^3/hr$) fluctuated between 0.062 and 0.307. Primary productivity showed that the upper stretches of the Meghna River has higher productivity compared to other rivers. During cloudy and rainy weather, the net primary production was very low to trace amount. However, during sunny weather and in calm condition, the photosynthetic productivity was high.

Table 6. Primary production in different rivers during 2003-04.

Date of sampling	Rivers (sampling station)	Gross primary production ($gC/m^3/hr$)	Respiration ($gC/m^3/hr$)	Net primary production ($gC/m^3/hr$)
Feb 28	Meghna (Mohonpur)	0.252	0.126	0.125
Feb 29	Meghna (Kaliganj)	0.307	0.167	0.139
Mar 01	Meghna (Alexander)	0.167	0.083	0.083
Mar 01	Meghna (Daulatkhan)	0.073	0.031	0.041
Mar 02	Tetulia (Dhulia)	0.062	0.021	0.041
Mar 03	Pyra (Pyrakunja)	0.168	0.028	0.139
Mar 04	Karkhana (Karkhana)	0.105	0.062	0.042
Mar 05	Arialkhan (Kalabadar)	0.111	0.056	0.054
Mar 06	Lata (Hizla)	0.139	0.125	0.140

Experimental Fishing in the Nursery Grounds

Experimental fishing was carried out in different nursery grounds of hilsa using gillnets having mesh size of 18, 20, 22, 25 and 30 cm. Catch per unit effort (CPUE) of gillnets ranged from 0.0 to 161 jatka/net/30min/haul (Table 7). Higher CPUE of gillnets was found in the major nursery grounds of the Meghna River system (Eshanbala and Mohonpur) followed by Hizla of Lata River. A diurnal variation of jatka catches was observed in different river systems. Higher catch of jatka was obtained in the evening and in the early morning indicating that jatka is photo- sensitive.

Table 7. Results of experimental fishing by gillnet in the nursery grounds of hilsa.

Date	Sampling station (Rivers)	Duration minutes	No. of Jatka	Mean length (cm)	Mean weight (g)
27.02.04	Mohonpur (Meghna)	30 (19.30-20.00)	124	10.81	11.83
28.02.04	Mohonpur (Meghna)	30 (04.30-5.00)	61	10.13	9.81
28.02.04	Eshanbala (Meghna)	30 (018.30-19.00)	161	9.65	8.45
29.02.04	Eshanbala (Meghna)	30 (06.10-6.40)	120	9.45	7.81
29.02.04	Kaliganj (Meghna)	45 (11.25-12.00)	-	-	-
29.02.04	Alexander (Meghna)	30 (17.00-17.30)	15	9.71	8.52
29.02.04	Alexander (Meghna)	30 (17.40-18.10)	01	8.9	8.5
01.03.04	Ilisha (Meghna)	30 (13.30-14.00)	07	8.80	6.95
01.03.04	Daulatkhan (Meghna)	30 (9.25-9.55)	04	9.87	8.25
01.03.04	Dhulia (Tetulia)	30 (19.30-20.00)	27	8.95	7.42
02.03.04	Dhulia (Tetulia)	30 (6.00-6.30)	04	9.36	7.16
02.03.04	Galachipa (G. River)	30 (17.20-17.50)	09	9.45	7.66
03.03.04	Pyrakunja (P. River)	30 (13.50-14.20)	02	9.35	8.00
03.03.04	Pyrakunja (P. River)	30 (19.00-19.30)	03	9.07	7.50
04.03.04	Karkhana (K. River)	30 (9.10-9.40)	-	-	-
04.03.04	Dabdabia (Kirtankhola)	30 (13.35-14.05)	-	-	-
05.03.04	Jhalkati (Sugandha River)	30 (6.25-6.55)	12	10.04	9.25
05.03.04	Barisal (Kirtankhola)	30 (10.25-10.55)	-	-	-
05.03.04	Vashanchar (Arialkhan)	30 (13.35-14.05)	-	-	-
05.03.04	Vashanchar (Kalabadar)	30 (14.20-14.50)	01	13.5	23.0
05.03.04	Hizla (Lata-Meghna)	30 (18.30-19.00)	59	8.81	6.74
06.03.04	Hizla (Lata-Meghna)	30 (5.50-6.20)	29	9.54	7.87
06.03.04	Satnol (Meghna)	30 (17.50-18.20)	13	10.45	11.81

Estimation of Catch per Unit Effort (CPUE) of Different Fishing Nets

Monitoring of catch by hilsa fishers using gulti, chandi and current nets in the Meghna River system was carried out through *in situ* observation to estimate the CPUE. The CPUE of gulti net was found higher followed by current and chandi net (Table 8). The mean CPUE ranged from 14.6 to 35.0 kg/net/day. Number of hauls per day ranged between 2.0 and 5.0. A wide variation in CPUE (10.8-50.0 kg/net/day) was found among the nets used for jatka fishing.

Table 8. Mean CPUE of different fishing nets used for catching hilsa in the Meghna River.

Type of net	No. haul/day	CPUE (kg/net/day)
Gulti jal (Kona ber jal)	4 (3-5)	35.0 (20-50)
Chandi jal (Vashan jal)	2 (2-3)	14.6 (8-22.50)
Current jal (Fashjal)	4 (3-5)	15.5 (10.8-22.60)

Observation on Hilsa Landing

Survey of hilsa landing centers around the Meghna River system during winter season (January-March 2005) found that the landings of hilsa were 50-60% higher than that of the previous years and the major amount of production was contributed by large and medium sized hilsa. Almost similar pattern of landings was observed during May-June. The landing of *Tempo hilsa* (sub-adult hilsa) started increasing significantly at the advent of June.

Assessment of Reproductive Activity and Status of Grown up Hilsa and Jatka at the Major Nursery Grounds

Objectives

- To investigate the maturity and recent spawning status of hilsa.
- To study the degree of abundance and distribution of jatka at major nursery areas.
- To study the catch per unit effort (CPUE) and landing status of grown up hilsa.

Achievements

Physico-chemical Characteristics of the River and Estuarine Waters during Spawning Period

This study was carried out in seven stations *viz.* Alexander, Hatia, Daulatkhan, Ilisha, Sripur, Tetulia and Hizla of four rivers (Meghna, Ilisha, Tetulia and Lata) covering spawning and early nursery grounds of hilsa. The water depth of the sampling stations varied between 4.6 and 11.8 m, and the Secchidisc visibility ranged from 0.16 m (Hatia) to 0.28 m (Daulatkhan). The velocity of current ranged from 0.7 to 1.5 m/second. The surface water temperature of the rivers and estuarine area ranged between 30.9°C (Sripur) and 33.7°C (Dhulia). Almost muddy water prevailed in and around the estuarine region.

The concentration of DO ranged between 5.4 and 6.7 mg/l indicating congenial state of the water for aquatic life. The pH values remained 7.7-8.0, exhibiting a very narrow range of fluctuation throughout the investigation period. The levels of free CO_2 (1.9-2.9 mg/l) were low in several stations. Total alkalinity was found suitable (>50.0 mg/l) in different stations with an exception for Ilisha River (36.0 mg/l in Sripur). The hardness showed an increasing trend towards the estuarine environment and was exceptionally high in Hatia (155.1 mg/l). The hardness of water was found suitable for fish production. The conductivity was recorded exceptionally high at Hatia area (938 μS/cm) of the Meghna estuary.

Physico-chemical Characteristics of the Major Nursery Grounds

The results of physico-chemical parameters from 6 sampling stations of five rivers done in March (2005-06) are presented in Tables 9 and 10. The water depth in the sampling stations varied between 3.0 and 15.3 m, and the Secchidisc visibility ranged from 0.30 m (Kaliganj) to 0.52 m (Hizla). The clarity of water in the nursery grounds was relatively higher than the spawning grounds indicating that jatka prefers relatively clear water for growth and survival. The velocity of current was recorded between 0.7 and 1.5 m/second, and the surface water temperature ranged from 28.1 to 30.6°C and was always lower than air temperature.

Table 9. Physical characteristics of hilsa nursery grounds during March 2005-06.

Sampling station	Water depth (m)	Transparency (m)	Velocity of current (m/sec)	Air temp. (°C)	Water temp. (°C)
Meghna (Mohonpur)	12.2	0.38	1.0	33.7	28.1
Meghna (Kaliganj)	15.3	0.30	1.5	33.1	28.0
Tetulia (Dhulia)	6.7	0.40	1.0	33.5	29.5
Karkhana (Baherchar)	3.0	0.47	0.8	31.5	30.0
Kirtankhola (Barisal)	4.0	0.49	0.7	37.2	29.0
Lata-Meghna (Hizla)	4.2	0.52	1.0	37.5	30.6

Table 10. Chemical characteristics of water of hilsa nursery grounds during 2005-06.

Sampling station	DO (mg/l)	CO_2 (mg/l)	pH	Hardness (mg/l)	Alkalinity (mg/l)	Conductivity (µS/cm)
Meghna (Mohonpur)	8.0	1.4	8.0	87.8	45.0	148.0
Meghna (Kaliganj)	8.0	4.8	8.0	77.1	42.5	98.0
Tetulia (Dhulia)	8.8	0	9.2	93.6	34.5	190.0
Karkhana (Baherchar)	7.7	4.8	8.5	90.3	40.0	165.0
Kirtankhola (Barisal)	7.4	3.4	8.0	85.9	42.5	170.0
Lata-Meghna (Hizla)	8.8	4.8	8.5	85.9	47.5	164.0

The concentration of DO ranged between 7.4 and 8.8 mg/l indicating it is environmentally benign for juvenile hilsa (jatka). The values of pH remained on the alkaline side and never recorded below 8.0. Water hardness recorded more than 77.0 mg/l. It is noted that the levels of DO and pH recorded from the nursery grounds of hilsa were relatively higher than that of the spawning grounds. The concentration of free CO_2 (0-4.8 mg/l) exhibited variations in different stations. The alkalinity levels were found relatively lower (34.5-47.5 mg/l) than the spawning grounds. In May, the samples were collected from three stations of the Meghna and Lata–Meghna rivers. The depth of sampling stations varied from 4.2 to 5.8 m. The transparency was relatively lower (<0.17 m) than in March. The velocity of current followed more or less similar pattern for all the stations covered under the study. Water temperature was found little higher in May than that of March (Table 11).

Table 11. Physical characteristics of hilsa nursery grounds during 2005-06.

Sampling station	Water depth (m)	Transparency (m)	Velocity of current (m/sec.)	Air temp. (°C)	Conductivity (µS/cm)
Meghna (Sofarmali)	5.8	0.17	1.2	31.6	30.4
Meghna (Eshanbala)	4.2	0.20	1.4	34.4	33.0
Lata-Meghna (Hizla)	4.6	0.20	1.2	32.6	31.8

Table 12. Chemical characteristics of hilsa nursery grounds during 2005-06.

Sampling station	DO (mg/l)	CO_2 (mg/l)	pH	Hardness (mg/l)	Alkalinity (mg/l)	Conductivity (µS/cm)
Meghna (Sofarmali)	7.2	1.9	9.0	62.8	30.0	121
Meghna (Eshanbala)	6.4	2.2	8.5	65.1	37.5	128
Lata-Meghna (Hizla)	7.2	1.9	8.0	74.9	37.5	125

The concentrations of DO were relatively low in May for all the stations than that of March. The values of CO_2 never exceeded 2.2 mg/l, pH value also remained on the alkaline side (8.0-9.0) and never was lower than 8.0 and hardness recorded >60.0 mg/l (Table 12). However, alkalinity was comparatively lower than that in March. The range of conductivity values varied between 121 and 128 µS/cm.

Abundance of Jatka in the Nursery Grounds during March and May

The abundance of jatka was determined by experimental fishing using a gillnet having 18.0, 20.0, 22.0, 25.0, 30.0, 35.0 and 40.0 mm mesh size from 15 sampling stations of 6 rivers during March and from 6 sampling stations during May. Experimental fishing was conducted for 30 min/haul. The catches of jatka ranged between 03 and 98 individuals during March and the highest number of 98 individuals was caught from Kirtankhola (Barisal) followed by Tetulia (Dhulia-93 nos.) and Meghna River (Mohonpur-49 nos. and Kaliganj-48 nos.). Total length of the jatka that were captured varied between 7.8 and 16.2 cm. However, during May, jatka was almost absent in the Meghna and Lata rivers. During this period, water of these rivers was found turbid and it is anticipated that most of the jatka have migrated from the rivers might be due to turbidity of water.

Fishers Opinion on the Spawning Status of Hilsa

To assess the recent spawning status of hilsa, experience of the hilsa fishers of Alexander, Hatia and Ilishaghat of the Meghna River and the estuarine area were collected through interview. Most of the fishers disclosed that they observed oozing hilsa near different chars of the lower Meghna during full moon of September-October at daytime. The rest of the fishers said that most of the hilsa spawn in the Hatia-Sandwip areas during September-October.

Fishers Perception about Recent Status of Hilsa Production in the upper Meghna

The hilsa fishers of Mohonpur, Amirabad, Chandpur, Haimchar, Charbhairabi and Eshanbala along the Meghna River were interviewed to get their perception about the recent trend in hilsa production. All fishers appreciated the recent government measures taken for jatka protection. According to their opinion, the overall hilsa production in this region was less than that of previous years. Medium size hilsa contributed the bulk of the total production. Amount of *Tempo* hilsa catch was also less than that of the previous years.

Aratdars Opinion about Recent Landing Status of Hilsa in the upper Meghna

An opinion survey was conducted among the Aratdars of Amirabad, Haimchar, Charbhairabi and Eshanbala along the Meghna River to get their views on recent hilsa landings. Almost all the Aratdars expressed their opinion that less amount of hilsa has landed in the current year than the previous years. However, the large sized hilsa contributed bulk of the production. All the Aratdars expressed their views that two months of effective ban on jatka catching is enough for enhancing hilsa production in the country. They suggested for effective implementation of jatka conservation rules in all the jatka susceptible areas at a time.

Impact of Different Management Measures on Hilsa Fishery

Objectives

- To study the maturity of hilsa and present status of spawning grounds.
- To assess the abundance and distribution of jatka in the major nursery grounds, covering Sureshwar- Mawa region in the Padma river confluence.
- To study the impact of jatka fishing ban on the abundance and distribution of jatka and grow out hilsa.
- To assess the spawning success of hilsa due to imposing fishing ban in the major spawning grounds.

Achievements

Maturity of Hilsa at Different Size Groups

The mean percent composition of matured hilsa was found higher under maturity stage IV (24%) and V (47%) while investigating fishes at length range between 18 and 52 cm in and around the spawning grounds (Hatia, Kaliganj and Charbhairabi areas) during October-November 2007. The percent composition of gravid (Stage-V) hilsa found increasing gradually with the increase in length classes and the oozing hilsa (Stage VI) estimated about 9%. The most oozing hilsa (29.2%) belonged to the size group of 25-31 and 39-45 cm (Table 13).

Table 13. Maturity stages of hilsa of different length groups.

Length group (cm)	% of fishes at different maturity stages (Ms)					
	Ms I	**Ms II**	**Ms II**	**Ms IV**	**Ms V**	**Ms VI**
18-24	0.00	0.00	60.00	20.00	20.00	0.00
25-31	0.00	5.89	17.65	41.18	27.45	7.83
32-38	0.00	0.00	8.33	29.17	33.33	29.17
39-45	3.45	3.45	0.00	17.24	68.96	6.90
46-52	0.00	0.00	0.00	14.29	85.71	0.00
Mean	0.69	1.87	17.20	24.38	47.09	8.78

Recent Status of Spawning Grounds

BFRI and GEF studies identified four spawning grounds of hilsa by the occurrence of fully ripe/ oozing, spent hilsa and on the availability of hilsa fries. In present investigation, higher number of spent hilsa and fries were observed in the identified spawning grounds and adjacent areas. Moreover, availability of larger sized and higher percentage of matured hilsa (maturity stage V to VI) in the previously identified spawning grounds indicates no changes of the spawning grounds.

Abundance of Jatka in the Major Nursery Grounds

Comparative assessment of jatka was carried out in four sampling points of the Padma River and 5 sampling points in the Meghna River during March and April. Jatka abundance was determined by experimental fishing using a monofilament gillnet having total length of 100 m and mesh sizes of 20, 22, 25, 30, 35 and 40 mm. Experimental fishing was conducted for one hr/hauling, twice daily, in the morning (06.00-7.00) and evening (18.00-19.00). The number of jatka catches ranged from 0-31 and 1-49 with the mean of 8 and 28 for the Padma and the Meghna River, respectively (Table 14 and 15). In the Padma River, the abundance of jatka was found only at Tarabunia point, which is about 8 km down of Sureshwar in the district of Shariatpur and at other sampling points, the abundance was recorded almost nil (0-2). However, jatka was not found in March sampling at Mawa point of the Padma River. Thus, to develop management guidelines for the lower Padma River, more detailed study is required during February to May particularly, in the Mawa point of the river. In the Meghna river, the highest catches were observed at Hizla point of Barisal (49 nos.) followed by Sofarmali point of Chandpur (48 nos.). The abundance of jatka catches at Eshanbala and Mohonpur sampling points were comparatively lower (17-23). Abundance of jatka at Alexander point of Laxmipur district was observed as almost nil (1).

Table 14. Abundance of jatka in the Padma River.

Location	Month	Nos. of jatka caught/100 m net/hr	Other fishes
Mawa (Padma, Munshiganj)	March	0	0
Digirpar (Padma, Munshiganj)	March	0	2
Tarabunia (Padma, Shariatpur)	April	31	24
Sureshwar (Padma, Shariatpur)	April	2	1
Mean	-	8	7

Table 15. Abundance of jatka in the Meghna River.

Location	Month	Nos. of jatka caught/ 100 m net/hr	Other fishes
Mohonpur (Meghna, Chandpur)	March	17	25
Sofarmali (Meghna, Chandpur)	March	48	43
Eshanbala (Meghna, Chandpur)	April	23	15
Hizla (Meghna, Barisal)	April	49	3
Char Alexander (Meghna estuary)	April	1	1
Mean	-	28	17

Abundance of Jatka under Different Management System

To protect jatka, different management measures have been enforced since 2005 and onwards. The abundance of jatka during different management system was determined by conducting experimental jatka fishing using 100 m long current net in the lower Meghna river. The duration of each haul was one hour, and fishing conducted usually at dawn and dusk. About 0.72 and 1.9 kg of jatka was captured/haul in 2007 and 2008, which was 18% and 163% higher than that of 2006 and 2007, respectively (Table 16). Hilsa sanctuary was established and jatka conservation activities strengthened during 2005 and 2006. However, since 2007, in addition to sanctuaries and jatka conservation activities, 10 days fishing ban during the peak breeding season was imposed in the main spawning grounds to facilitate spawning of hilsa and increase jatka abundance in the river system.

Table 16. Relative increase in jatka abundance during different management system.

Year	Jatka catch/100 m current net/hr (kg)	% decrease	% increase	Management system
2005	0.94	-	-	Sanctuary
2006	0.61	-35.10	-	As above
2007	0.72	-	18.03	As above + 10 days fishing ban during peak breeding season in spawning ground
2008	1.89	-	163	As above

Impact of 10 Days Fishing Ban on Spawning Success

The impact of 10 days fishing ban was determined by spawning success of hilsa *i.e.* by estimation of egg production, abundance of fry in the spawning grounds and adjacent areas and determination of percentage composition of spent hilsa. The results are discussed below:

Egg Production

The egg production of hilsa was calculated using the total number of fishing gears involved in fishing in the major spawning grounds immediately before the starting date of implementation of the fishing ban, catch per unit effort (CPUE)/boat, number of boat operated in the major breeding grounds, number of spent hilsa and male-female ratio. Thus, estimating the number of precluded hilsa from being captured (1.5 crore) during 10 days fishing ban period, the total egg production was calculated as 46,800 kg in 2007. From these eggs 293,000 million larvae (considering 50% hatching rate) could have been produced, and from those larvae 29,300 million fry/jatka could have been produced as well considering 10% survival.

Abundance of Larvae and Fry

The abundance of larvae and fry of hilsa was determined by experimental larvae collection using larvae collection net from the adjacent areas of Hatia and Monpura. The number of larvae/fries per haul varied between 20 and 54 individuals and the mean length range of these larvae was 1.99-2.75 cm and corresponding mean weight range was 0.07-0.23 g (Table 17). The anticipated age of these larvae was 5 to 25 days.

Table 17. Size, weight and age of captured fries and jatka from the major spawning grounds.

Location	Lowest size (cm)	Highest size (cm)	Av. size (cm)	Minimum weight (g)	Maximum weight (g)	Av. weight (g)	No. of jatka/haul	Age (day)
Hatia	1.6	2.6	1.99	0.01	0.15	0.07	20	10-15
Char jonaki	1.9	3.7	2.54	0.04	0.48	0.17	20	15-20
Sakuchia	0.9	3.8	2.05	0.04	0.45	0.17	30	5-10
Janata (ht*)	2.1	4.0	2.75	0.08	0.54	0.23	45	15-25
Janata (lt**)	1.9	4.2	2.70	0.05	0.52	0.19	30	15-20
Monpura	1.8	3.7	2.60	0.04	0.45	0.15	54	15-20
Dhalchar	2.4	2.8	2.57	0.11	0.22	0.15	45	20-25

*ht=high tide, **lt=low tide

Estimation of Spent Hilsa

During 2007, about 5.4% spent hilsa was observed in the fish landing centers in and around the major spawning grounds. This data was compared with the data of BFRI-GEF studies (Haldar 2004) and found about 2.8 times higher in 2003 and 10.8 times higher in 2007 than that of 2002 (Table 18).

Table 18. Percentage of spent hilsa in the landing centers before and after implementation of different management measures.

Year	% of spent hilsa	increase (time)	Types of hilsa management
2002	0.50	-	Without management
2003	1.40	2.80	Strengthened jatka conservation activities
2007	5.40	10.80	Strengthened jatka conservation and 10 days fishing ban in the major spawning grounds

Thus, it could be concluded that improved management along with 10 days fishing ban has significant impact on the breeding success of hilsa. Besides, analysis of the fishers' catches from the major spawning grounds before implementation of the fishing ban reflects that more than 95% of the captured hilsa was gravid and their weight was around 1.0 kg.

Chapter XI

Socio-economic Aspects of Hilsa Fishery in Bangladesh

Introduction

Hilsa shad being the largest single species capture fisheries play an important role in employment, poverty reduction and economic development of Bangladesh. More than 1.0 million hilsa fishers (0.50 million freshwater and 0.54 million marine) earn their livelihood through hilsa fishing, which is specially the main source of livelihood for coastal fishers. About 2% (0.34 million) of the country's total population (170 million) are directly or indirectly involved in hilsa fishing and related activities as fishermen, middlemen, aratdar, mohajon/dadondar, trader, boatbuilder, net maker and repairer. Hilsa fishers are the poorest and mostly landless and vulnerable section of the population. Their annual income is about Tk. 60,000-80,000 (US$ 833) based on locations which is very insufficient to maintain their family consisting of 6 members on average. So, they live a very substandard life with no savings. They cannot afford buying or hiring fishing equipment (fishing boat, net, engines etc.) and bear the operating cost of fishing in the rivers or the sea. In the circumstances, the fishers take specific loans from the local money lenders who are known as mhajons/aratdars (warehouse owners) on terms of delivering their catch to the lending aratdars at a much lower price fixed up by them which comes to only 40% of the real total catch value after deducting loan instalment, commission and other handling charges. Thus, the fishers are exploited by the money lenders in different ways.

Management interventions like conservation of juveniles, brood hilsa and providing Alternate Income Generating Activities (AIGA) to the hilsa fishers from 2004-05 has made incremental production of 0.24 million tonnes up to 2017-18, worth about Tk. 96.4 billion (US$ 1.15 billion). But the benefits of incremental production mostly go to the traders who are involved in the supply chain. Therefore, arrangements should be made for hilsa fishers for direct access to the marketing channel by reducing the middlemen to ensure equity and improve the living standards of the hilsa fishers.

Crafts and Gears, and Fishers Employed in the Fishery

Crafts and Gears

The hilsa as diadromous fish inhabits both in inland and marine waters of Bangladesh. Various types of fishing crafts and gears are used for hilsa and jatka fishing in different riverine and marine sector of the fishery. In the inland sector, gillnet having various mesh size is the most commonly used gears followed by beach seine net, clap net etc. In the marine sector, the artisanal fishers use both mechanized and non-mechanized boats and they are the key players of the fishery. Before mechanization of the Chandi boat in the fishery under the Bay of Bengal Program (BOBP) in 1980-83, hilsa fishing was carried out by using wooden sailboat and fishing was concentrated within the coastline area of the Bay of Bengal. After implementation of BOBP project, hilsa fishing was dispersed into the offshore area of Bangladesh and the number of fishing crafts and gears stared to increase. During 2000-01, the number of fishing boats and nets were 26,169 and 106,316, respectively and now it has increased to 37,190 boats (MB and NMB), 118,353 nets, and the increase of boats and nets are 42.11% and 11.32%, respectively (Table 1). Besides, bottom trawl net and industrial fishing boat also catch a considerable amount of hilsa. Due to increase of fishing boats and nets, the fishery is under high fishing pressure and is facing over-exploitation.

Table 1. Mechanized and non-mechanized fishing boats and gears engaged in the marine sector.

Years	Number of boats			Number of nets		
	MB	NMB	Total	MB	NMB	Total
2000-01	18,992	7,177	26,169	75,968	44,923	106,316
2017-18	20,359	16,831	37,190	77,768	40,585	118,353

Number of Hilsa Fishers

The total number of hilsa fishers was estimated to be about 0.45 million in 2004. The hilsa production in the country and the number of boats and nets have also increased. So, it is assumed that the number of hilsa fishers has also increased proportionately and the present number would be around 1.00 million. It is worthy to mention here that according to DoF (2019), the total number of fishers in Bangladesh is 1.31 million of which, 0.80 million are in the inland sector and 0.51 million in the marine sector. However, not all fishers, particularly those of the inland sector are employed in hilsa fishing.

Status of Jatka Catches

The jatka are the recruitment phase of hilsa and thus, much emphasis has been given to control jatka catching in the hilsa management plan. The government is making all-out efforts to control jatka catching by declaring sanctuaries, deploying navy, coast guards and police forces for effective enforcement of jatka protection and conservation regulations, awareness building activities, providing food assistance and arranging AIGAs for the affected fishers. Meanwhile, relevant rules and regulations also have been reviewed, updated and enacted. Yet, some fishers still catch jatka violating the rules. Earlier, the small-scale fishers had been catching jatka by using monofilament gillnet but presently, the commercial fishermen are catching jatka along with catching of large hilsa by using small meshed gillnets. Proportion of jatka in the commercial catch of the commercial fishermen in 2003-04 and 2017-18 is given in Table 3.

Table 3. Proportion of jatka in the commercial catches of hilsa fishermen.

Year	Production of hilsa (million MT)	Percent of jatka	Total jatka (MT)	Size group of jatka (cm)	No. of jatka caught (million)
2003-04	0.25	23.49	0.60	18.00-25.00	18.90
2017-18	0.51	8.21	0.42	10.00-25.00	9.59
Changes	0.26	15.39	0.12	-	9.31

* Table generated using LF data of hilsa fish of 2003 (Haldar) and 2019 of BFRI.

From the above Table, it appears that jatka fishing has decreased by 15.39% in 2017-18 compared to 2003-04, which contributed about 0.26 tonnes of hilsa. If this amount of jatka could be protected, then an additional amount of 0.40-0.50 million tonnes of fish could be produced. Thus, it is absolutely necessary to introduce selective fishing restricting mesh size of gillnets up to 7.0 cm for effective control of jatka catching.

Socioeconomic Changes of the Hilsa Fishers

The previous studies reported poor socio-economic conditions of hilsa fishers. However, increased production of hilsa due to implementation of various actions under the hilsa management plan and providing food assistance and AIGA, the socio-economic condition of the hilsa fishers improved significantly. The impact of the management program on the socio-economic parameters of the hilsa fishers is briefly discussed below:

Family Size

In earlier studies, the family size of the fishers was found around 6.7 members except in Cox's Bazar where there was above 8.0 members (Haldar, 2004) per family. However, in a recent study (IMED, 2018), the average family size was found 5.10 persons per family. The number of earners per family earlier was 2.6 and in recent time, it dropped to 1.5 persons per family. Both the family size and the number of earners has reduced by 1.6 and 1.10 persons per family, respectively. However, the family size of the hilsa fishers is yet bigger by 0.7 persons than the national average family size of 4.4 persons (Population Census, 2011).

Educational Status

About 82.7% fishers were found illiterate in earlier studies and in the recent year, it has come down to 38% (IMED study 2018). Although, the literacy rate of the fishers has improved, yet it is 10% lower than the national average rate of 72.76% (2016).

Status of Land Holdings

More than 88% of the fishers belonged to the category of landless (below 0.5 acre) earlier. Most of the fishers are professional and depend essentially on fishing or as laborer fisher. In the IMED study, it appears that 51% fishers (reduction of 37.0%) are yet landless. About 50% fishers live on the leased lands of other people or in the khas land (public land). So, most of the fishers have limited scope of AIGA support in their homestead area.

Duration of Fishing

In the IMED study, it appeared that 80% of the fishers are engaged in fishing for 6-7 months, 11% for 3-4 months, 5% for 8-9 months in a year and 2.0% are seasonal fishers. The principal occupation of the fishers is fishing. However, most of them could not be engaged in fishing for more than 6-9 months in a year due to fishing ban and other reasons. Therefore, alternate income generating activity is essential to sustain their family income and maintain livelihood.

Income, Expenditure and Debt Conditions

Average monthly household income of the hilsa fishers was Tk. 7,919 in 2007 and increased to Tk. 12,388 in 2018, which is 56.0% higher than the incomes of 2007 (IMED studies, 2018). However, the household income of the hilsa fishers' family is 7.3% lower than the average national rural household income of Tk. 13,353.00 (BBS, 2016). Similarly, expenditure of the hilsa fishers also found to increase from Tk. 9,186 to 11,548 in 2018. When hilsa resources were first brought under a sound management system, most of the hilsa fishers (57.0%) were in debt for Tk. 20,000 in average per family per year (Haldar, 2004). Now, very few hilsa fisher families are found indebted.

Chapter XII

Hilsa Fisheries Management Initiatives

Introduction

Earlier, very little initiatives were taken for conservation and management of the hilsa fisheries in Bangladesh except some isolated efforts for implementation of hilsa conservation rules enacted in 1952. Although, the government in 1988 banned the use of monofilament synthetic fiber gillnet locally called 'current jal' under mesh size 4.5 cm which is most harmful for jatka (hilsa juveniles) catching, there had been very little enforcement of it. This resulted in decline in hilsa production since 1980s due to over exploitation. This necessitated generating scientific information through continuous research for preparing management plan to sustain hilsa production in the country. In view of this, BFRI since its establishment in 1984 started doing hilsa research and drafted a management plan for development of the fishery. Subsequently, DoF and BFRI also conducted a study under the GEF component of the Fourth Fisheries Project and further revised and finalized the preparation of HFMAP and suggested following specific actions for implementation, management and development of the hilsa fishery:

- Conservation of gravid hilsa for uninterrupted spawning and subsequent recruitment.
- Conservation of hisa juveniles locally called as jatka.
- Rehabilitation of the jatka fishers.
- Conservation of hilsa species diversity.
- Regulation of over exploitation by controlling fishing effort.
- Protection and improvement of hilsa habitats
- Awareness building about the importance of hilsa fishery and its conservation needs.
- Human resource development for hilsa fisheries research and management.
- Review and improvement of catch monitoring system of hilsa.
- Identification and implementation of adaptive research.
- Regional initiatives for hilsa fisheries management and conservation.

The progress and impact of implementation of the above actions are briefly discussed below:

Conservation of Gravid Hilsa for Uninterrupted Spawning

The peak breeding season and main breeding grounds of hilsa identified earlier by BFRI were confirmed through further research under BFRI-GEF studies of FFP. During the breeding season, about 60 to 70% of the hilsa were found sexually mature. The spawning and subsequent recruitment of hilsa were hampered due to indiscriminate catching of brood hilsa from the spawning grounds during the peak breeding seasons. In view of this, initially a 10-day fishing ban (five day before and five days after the full moon of Ashwini Purnima) was imposed in an area of about 7,000 sq. km of the main breeding grounds of hilsa from 15 to 24 October every year. This 10-day fishing ban was implemented up to 2011. The abundance of jatka significantly increased due to imposing the fishing ban in the river system and appeared very effective for successful breeding and subsequent natural recruitment of hilsa fishes. The timing of Ashwini Purnima varies year to year with the lunar cycle and advanced or delayed by 10-11 days every year. Hence, the 10-day fishing ban actually did not fully cover the peak spawning duration of hilsa due to fixed date of fishing ban. In order to avoid this problem, the fishing ban was elevated to 11 days from 10 days and implemented by issuing a government gazette notification every year consulting the lunar cycle to become sure about the timing of full moon in the Bengali month of Aswin. This period of ban was in force from 2012 to 2014.

Due to imposing fishing ban in the lower section of the river, the upward migration of hilsa increased significantly. It was also reported that some hilsa also breed in the upper stretches of the rivers following the new moon period of the full moon. In view of this, the government has extended the duration of the hilsa fishing ban for 15 days throughout the country and subsequently increased to 22 days to cover the new moon and has been implementing since, 2016.

Conservation of Jatka

The most important measures suggested for effective conservation of jatka in the management plan were strengthening implementation and monitoring of the Fish Conservation Rules about hilsa and declaration and proper management of hilsa sanctuaries. In HFMAP, the constraints of jatka conservation were mentioned with probable mitigation measures. The government so far addressed the constraints and achieved a remarkable success in jatka conservation. The milestones of successes in jatka conservation briefly are as follows:

- The government has created a new sub-head under the revenue budget for funding jatka conservation activities on regular basis;
- Every year jatka conservation week is observed with mass participation of the relevant stakeholders;
- So far, six sanctuaries have been established in the main nursery grounds of jatka and all types of fishing ban imposed for the period of two months from March to April every year for five sanctuaries and November to January for the Andharmanik River sanctuary.
- Jatka conservation Rules and Regulations have been further updated and ban period elevated up to June every year;
- Along with police force, Bangladesh Navy, Coast Guard and Rapid Action Battalion (RAB) have been involved in jatka protection activities in order to prevent catch, sale, transport and possessing of jatka during the banned period;
- Lunching Mobile Court in the sanctuaries and jatka abundant areas regularly every year during the peak jatka catching season;
- Forming special teams by DoF every year for monitoring jatka conservation activities;

- Developed legal procedures for disposal of the seized crafts, gears and fishes;
- Water transport provided to DFOs and UFOs of the most important jatka areas;
- During jatka season, provision has been made to deploy officials on deputation against the vacant post in the jatka abundant upazilas to resolve manpower problem;
- Conducting huge awareness campaign during jatka season and distributing awareness building materials by BFRI, DoF and other relevant organizations;
- Integration and coordination among Police, Magistrate, local administration and DoF have been ensured to implement fish Conservation Rules and Regulations;
- Eliminated social and political interference and awareness developed about the benefit of jatka conservation;
- Providing food assistance and AIGA to the jatka fishers;
- The DoF has obtained the court order in favor of the rule under which DoF had prohibited the use of current jal. So, now production, sale, possessing and use of current jal is illegal in the country;
- DoF has taken massive initiatives to remove illegal set bag net from the fishery; and
- The government has introduced national award for officials of DoF and relevant law enforcing agencies for contributing to successful implementation of Fish Conservation Acts and Rules.

Present Constraints in Jatka Conservation

Despite of achieving notable success in jatka conservation, there remain several problems and constraints yet in the fishery such as:

- Some fishers are still indiscriminately catching jatka heather and thither using current net for maintaining their livelihood ignoring the Rules in force and the prohibition;
- Current nets are imported through illegal way from the neighboring countries and bartered secretly;
- Set bag nets are reappearing;
- Livelihood of the jatka fisher yet not significantly improved to the desired level;
- Some Aratdar and Dadondar yet patronizing jatka catching; and
- An efficient and effective ways of sanctuary management not yet developed etc.

For maximum and sustainable hilsa production in Bangladesh, the government should resolve the above problems urgently.

Rehabilitation and Social Safety Net Program for the Fishers

The government has brought the fishers under a social safety net program by providing food assistance and Alternate Income Generating Activities (AIGA) since 2004-05 as discussed below:

Food Assistance to the Jatka Fishers during Sanctuary Implementation Period

The government is providing food assistance to the affected jatka fishers living around the sanctuary and the adjacent area from 2004-05. The amount of food assistance provided so far is given in Table 1.

Table 1. Food assistance provided to the hilsa fishers.

Year	Fishers family	Amount (kg)/family	Duration (months)	Amount of food allocated (tonnes)
2004-05	33,300	10	3	1,000
2005-06	0.0	0.0	0	0.0
2006-07	103,000	15.0	1	1,546
2007-08	145,335	10.0	3	4,360
2008-09	143,252	10.0	3	5,730
2009-10	164,740	30.0	4	19,768
2010-11	186,264	20.0	4	14,470
2011-12	186,264	30.0	4	22,351
2012-13	206,229	30.0	4	24,747
2013-14	226,852	40.0	4	36,296
2014-15	226,852	40.0	4	36,296
2015-16	236,176	40.0	4	37,144
2016-17	238,673	40.0	4	38,188
2017-18	248,674	40.0	4	39,788

Food assistance is given to the fishers, particularly to the very poor group of fishers who are living around the sanctuary areas. The program was initiated in 2004-05 under Vulnerable Group Feeding (VGF) Program. Earlier, the amount of food assistance given varied from 10.0 to 30.0 kg of rice per household for the duration of 1 to 3 months beginning from February/March. During the regime of the present Government, the amount of food incentive has been increased to 40 kg/month/family for the duration of four months from February to May. A total of 248,674 hilsa fishers' families of 85 upazilas belonging to 17 districts were brought under the coverage of Social Security Program in 2017-18 (DoF, 2019, Fish Compendium). The number of families and the area of coverage appear to be satisfactory. However, there is complain that the food reach to the fishers later than the scheduled time.

Food Assistance to the Hilsa Fishers during Ban Period

Ban on hilsa fishing was first imposed for 11 days during the peak breeding season in the main spawning grounds of hilsa. Subsequently, the ban period was elevated to 22 days from 2016-17 and made effective throughout country. During the ban period, catching, carrying, transportation, sale, possessing and stocking of hilsa is prohibited throughout the country including the coastal area. In order to feed the hilsa fishers who refrain from catching brood hilsa for 22 days, the government gives them 20 kg rice/per family under VGF program. The amount of food assistance provided to the fishers during 2016-17 to 2018-19 is shown in Table 2.

Table 2. Amount of food assistance provided to the fishers during brood hilsa ban period.

Sl. No.	Year	Fishers family	Amount (kg)/family	No. of upazila covered	District covered	Amount of food allocated (tonnes)
1	2016-17	356,720	20.0	76	14	7134
2	2017-18	384,862	20.0	122	25	7689
3	2018-19	395,709	20.0	127	29	7914

Alternate Income Generating Activities

Assistance in cash and kinds was provided to 32,509 hilsa fishers along with training on various alternate income generating activities like small trade, poultry and livestock rearing, distribution of rickshaw/van, sewing machine, hilsa catching net and cage culture of fish and such other activities to make them self-reliant. All these supports were provided under the Jatka Conservation Alternate Income Generation and Research project implemented during 2008-15. However, hilsa fishers AIGA program should be continued and a permanent arrangement should be made for this.

Conservation of Hilsa Species Diversity

The status of one particular species of the genus *Tenualosa,* the *T. toli* (Chandana ilish) was found very vulnerable in Bangladesh and their catches are declining. The details of biology of the fish, their breeding behavior and nursery are not yet clearly known. So far, neither BFRI nor DoF has taken any initiative for the development of management measures for conservation of the species. Nevertheless, due to effective conservation of *T. ilisha* from its jatka to brood stage, the species *T. toli* is reappearing in the fishery.

Controlling Over Exploitation

The government banned catching of jatka up to 25.0 cm size from earlier 23 cm size by enacting new regulation. In the recent year, the size of hilsa at first capture has increased up to 27.0 cm (Rahman *et al.*, 2018), which were 13.12 cm, 19.87 cm and 21.21 cm during 2000, 2002 and 2003, respectively (Haldar and Amin, 2002, 2003). The exploitation rate (E) of the fish remained almost close to 0.58-0.67 during this period in the commercial fishing. The number of fishing boats and nets increased from 26,169 and 106,316 in 2000-01 to 37,190 and 118,353, respectively in 2019 and the exploitation rate increased from 0.58 in 2003 to 0.71 in 2019 (BFRI Studies, 2019), which is very alarming for sustainability of the fishery, unless natural recruitment is further enhanced by protecting more brood hilsa. Thus, it is absolutely needed to regulate fishing pressure by introducing selective fishing.

Protection and Improvement of Hilsa Habitats

From BFRI/GEF study (2002-04), it was found that hilsa has completely lost or almost near to totally disappear from about 40 rivers of Bangladesh during the last 20-25 years. The estimated loss of production from these rivers was found to be about 12,000-15,000 tonnes/yr. However, no effective measures for restoration of the degraded hilsa habitats have so far been undertaken by the government except re-excavation of the Gorai River.

Awareness Building of the Fishers and Other Stakeholders

Awareness building among all the stakeholders about the importance of the hilsa fishery in national perspective is very important to organize support, make them involved and compliant to the fishery regulations for conservation of the fishery. DoF and BFRI are engaged in various awareness building activities for different type of stakeholders. Among them, training of the fishers, traders and local people, organizing public meetings and rallies, preparation and distribution of leaflets, posters and publicity in radio and television, telecasting popular documentaries on jatka and brood hilsa conservation, and hoisting billboard are important.

Review and Improvement of Catch Monitoring System

Hilsa is a large fishery and it needs a separate system for catch monitoring. But no separate system has yet been developed for hilsa and as such the catch statistics of hilsa are collected along with the catches of Riverine and Marine fishes of Bangladesh**.** When HFMAP was finalized, the catch monitoring system of the Riverine fishes was reviewed, and a plan of action was submitted. Nevertheless, DoF is updating the numbers of artisanal mechanized and non-mechanized boats and gears used for hilsa fishing in the coastal and marine sectors of Bangladesh and reporting accordingly.

Conduct Adaptive Research

Some potential research programs were identified under HFMAP and a few of them have been implemented by BFRI, Riverine Station at Chandpur. In the recent years, along with BFRI, different Universities and donor organizations including WorldFish Center have come forward and are implementing several adaptive research projects on hilsa fishery of Bangladesh and some new information generated. The national and international research efforts on hilsa fisheries management should be continued and further strengthened to follow up the changes in the fishery with respect to fishing pressure and environmental and climate change impact and to update the management guidelines.

Regional Initiatives for Hilsa Management and Conservation

Hilsa is a migratory fish. Although Bangladesh represents about 75% of the hilsa production, it is also available in some of the other Asian countries. Therefore, regional cooperation is important to harmonize and adopt uniform management system for a balanced development of the fishery in all the hilsa producing countries. To initiate regional cooperation, several dialogues were held at different times between Bangladesh, India and Myanmar for management, development and conservation of hilsa. So far, no effective mechanism was developed for regional cooperation and coordination.

Chapter XIII

Ongoing Hilsa Research of BFRI

Introduction

Presently, 11 hilsa research programs are running under the 'Strengthening of Hilsa Research Project' at the Riverine Station of BFRI at Chandpur. Of this, 3 research programs are conducted by the Riverine Station, Chandpur and 8 are in collaboration with different Universities. These researches cover a wide range of topics which include biology, ecology and biodiversity; productivity and carrying capacity of hilsa ecosystem, stock assessment and population dynamics, product development, climate change impact, breeding and culture potential, socioeconomics and marketing. It is expected that lot of new information and processes will come out on the latest status of the fishery that would help update and develop better management options for sustainable production of hilsa in Bangladesh. Before elaborating the ongoing research programs, a brief description of the Hilsa Research Strengthening Project is given hereunder, and details of ongoing research will follow.

Strengthening of Hilsa Research Project

Hilsa is a popular and national fish of Bangladesh. The present production of hilsa is about 0.52 million tonnes (2017-18), representing about 12% of the country's total fish production of 4.27 million tonnes having worth of Tk. 206,800 million at the average price of Tk. 400/kg. About 0.5 million fishers of 145 upazilas under 40 districts are directly employed in hilsa fishing and over 2 million are involved in its processing and trade. Therefore, the fishery is playing a vital role in nutrition and economic development of the country.

However, the fishery is facing serious threats due to construction of dams and barrages that caused serious reduction of water flow and depth of water in the upstream rivers by siltation, changes in habitat and riverine ecology, pollution, climate change impact on hilsa biology, excessive harvest of mother fish and indiscriminate catching of jatka etc. All these factors greatly affected the reproductive performance, migratory routes, spawning and nursery grounds and dynamics of the hilsa fishery. So, there is a need for continuous research to constantly monitor the trend in changes of the fishery over time that will enable us to develop and upgrade a well-defined and sound management plan for sustainable production of hilsa.

Considering the importance of the hilsa fishery, The National Committee on Fish and Shrimp in its meeting on 01 April 2014 chaired by Hon'ble Prime Minister Sheikh Hasina decided to establish a separate research wing at the Riverine Station of BFRI at Chandpur for conducting research to develop appropriate management strategy for sustainable increase in hilsa production. According to this decision, Strengthening of Hilsa Research project has been undertaken for a period of 5 years from 2017-2021 to conduct hilsa research and establish a Hilsa Research Wing at the Riverine Station of BFRI at Chandpur.

Objectives of the Strengthening Project

- To establish necessary infrastructures for strengthening of hilsa research in the Riverine Station.
- To carry out demand driven research for the development of appropriate management strategy for increasing production and conservation of hilsa resources.
- To provide technology-based training to different stakeholders on production and conservation of hilsa fisheries.

List of Ongoing Hilsa Research Programs

A. Core Research Project of Riverine Station, Chandpur, BFRI

Sl. No.	Name of Project	Name of Principal Investigator and Affiliation
1	Population dynamics and stock assessment of Hilsa, *Tenualosa ilisha* in Bangladesh.	Dr. Mohammad Ashraful Alam, Senior Scientific Officer, Bangladesh Fisheries Research Institute, Riverine Station, Chandpur.
2	Trial on semi-natural breeding and early larval rearing of Hilsa for its stock enhancement in the Meghna River estuary.	Dr. Md. Anisur Rahman, Principal Scientific Officer, Bangladesh Fisheries Research Institute, Riverine Station, Chandpur.
3	Assessment of feasibility of cage culture of Hilsa, *Tenualosa ilisha* (Hamilton, 1822) in Andharmanik River, Khepupara, Patuakhali.	Dr. ASM Tanbirul Haque, Senior Scientific Officer, Bangladesh Fisheries Research Institute, Riverine Sub-Station, Khepupara, Patuakhali.

B. Collaborative Hilsa Research Project with Universities

Sl. No.	Name of Project	Name of Principal Investigator and Affiliation
1	Studies on the causes of gonadal development in small size Hilsa: Assessment of the factors associated with the early gonadal development.	Dr. A.K. Shakur Ahammad, Associate Professor, Dept. of Fisheries Biology and Genetics, Faculty of Fisheries, Bangladesh Agricultural University Mymensingh
2	Investigation on improved methods of value-added fishery products from Hilsa, *Tenualosa ilisha*.	Dr. A.K.M. Nowsad Alam, Professor, Dept. of Fisheries Technology, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh.
3	Estimation of population parameters of Hilsa shad, *Tenualosa ilisha* in Bangladesh through multi-model inferences: A key for sound stock assessment.	Dr. Md. Yeamin Hossain, Associate Professor, Dept. of Fisheries, Faculty of Agriculture, University of Rajshahi.
4	Assessment of energy transfer pathways (13C and 15N) from primary producer to Hilsa shad in the Meghna River estuary.	Dr. Md. Jahangir Sarker, Professor, Dept. of Fisheries and Marine Science, Noakhali Science and Technology University, Noakhali.

Sl. No.	Name of Project	Name of Principal Investigator and Affiliation
5	Impact of climate change and anthropogenic causes on Hilsa fishery management: Focusing the sustainable management policy.	Dr. Md. Azharul Islam, Associate Professor, Dept. of Environmental Science, Bangladesh Agricultural University, Mymensingh.
6	Developing marketing strategy for Hilsa fish distribution: Emergency supply chain management.	Dr. Mahmud Akhter Shareef, Professor, School of Business and Economics, North South University.
7	Determination of genetic structure of Hilsa shad, (*Tenualosa ilisha*) populations in Bangladesh using Single Nucleotide Polymorphisms (SNPs) developed by Next Generation Sequencing (NGS) technology.	Dr. Md. Rashedul Kabir Mondol, Associate Professor, Dept. of Fisheries, University of Rajshahi.
8	Development of vacuum and modified atmosphere packaging of fresh and value-added products of Hilsa fish, *Tenualosa ilisha* under different storage condition.	Dr. Md. Tariqul Islam, Associate Professor, Dept. of Fisheries, University of Rajshahi.

Details of the Ongoing Projects

Details of the ongoing research projects being implemented (2017-21) are briefly described below.

Name of the Project

Population dynamics and stock assessment of Hilsa, *Tenualosa ilisha* in Bangladesh.

Name of Principal Investigator and Organization

Dr. Mohammad Ashraful Alam, Senior Scientific Officer, Bangladesh Fisheries Research Institute, Riverine Station, Chandpur.

Background and Rationale

Hilsa is the unique fisheries of Bangladesh for its wide spatial distribution and seasonal variation in abundance. Therefore, the magnitude, dynamics, and resilience of hilsa pose a great challenge to their assessment and management. In order to sustainably exploit and manage the fisheries, it is a prerequisite to have accurate information on the status of the stock in respect of growth, natural mortality, fishing mortality, recruitment, the size and rate at first catch, maximum sustainable yield (MSY) etc. The present study will generate such information, which will help formulating a sound management policy for sustainable production of hilsa in Bangladesh.

Objectives

- To determine the temporal and spatial variations in population parameters of hilsa.
- Study on Virtual Population Analysis (VPA) of hilsa.
- To estimate the exploitation rate, MSY and Biomass of hilsa.

Expected Output

- The status of hilsa stock and population and biological characteristics of the races/stocks of hilsa in the major rivers of Bangladesh estimated.
- Information on recruitment rate, exploitation rate, MSY and biomass generated for formulating policy and action plan for sustainable management of hilsa fisheries.

Contribution to Hilsa Fisheries Development

Data on growth, mortality, recruitment pattern, catch per unit effort of adult and juvenile hilsa, exploitation rate, maximum sustainable yield, etc. are still inadequate and need reassessment as imposition of management interventions may require adjustment with new information on population parameters of the changing hilsa fishery. The project is expected to provide current information on population parameters, which will help to select the best possible management intervention for maximum sustainable production of hilsa resources.

Name of the Project

Trial on semi-natural breeding and early larval rearing of Hilsa for its stock enhancement in the Meghna River estuary.

Name of Principal Investigator and Organization

Dr. Md. Anisur Rahman, Chief Scientific Officer, Bangladesh Fisheries Research Institute, Riverine Station, Chandpur.

Background and Rationale

Hilsa is the most important single species fishery of Bangladesh contributing 12% of total fish production and playing an important role in nutrition, employment, and foreign exchange earnings. However, hilsa fishery has been suffered greatly by environmental degradation of inland open water bodies due to construction of dams and barrages and for growth and recruitment overfishing. Although its production has increased in recent years due to establishment of hilsa sanctuaries and introduction of fishing ban on catching of mother fish for 22 days during peak spawning season as a part of the conservation measures under hilsa management action plan, excessive fishing of mother fish and indiscriminate catching of jatka is preventing to reap its full benefit.

The abundance of hilsa is progressively declining in the river system and it has already disappeared from 30-40 rivers due to serious reduction of water flow and water depth, pollution from industrial effluents, municipal wastes, and agro-chemicals. One of the important options to rejuvenate the fishery is to develop its artificial breeding and aquaculture for enhancement of natural stock. Although, past initiative in this respect did not achieve much success, yet there is prospect to continue research on artificial propagation in modified conditions. In this perspective, the present research has been undertaken to conduct trial on semi-natural breeding and early larval rearing of hilsa for its stock enhancement in the Meghna River estuary.

Objectives

- To run semi-natural breeding trial of hilsa.
- To develop early larval rearing technique of hilsa in semi-natural condition.
- Observation on hilsa breeding success in the spawning grounds.

Expected Output

- Breeding potential of hilsa in semi-natural condition will be understood.
- Possibility of early larval rearing of hilsa determined.
- The breeding success of hilsa in the spawning grounds known.

Contribution to Hilsa Fisheries Development

Both natural breeding and fresh recruitment to population are seriously affected by excessive fishing of mother fish and indiscriminate catching of jatka, particularly in the spawning season causing serious decline in population in the inland open waters. This problem can be overcome by enhancement of natural stock by artificially bred and reared hilsa fry. The success of the present project on semi-natural breeding and larval rearing of hilsa will create this opportunity, which will enhance the production of hilsa in the inland open water by ranching program.

Name of the Project

Assessment of feasibility of cage culture of Hilsa, *Tenualosa ilisha* (Hamilton, 1822) in Andharmanik River, Khepupara, Patuakhali.

Name of Principal Investigator and Organization

Dr. A.S.M. Tanbirul Haque, Senior Scientific Officer, Bangladesh Fisheries Research Institute, Riverine Sub-Station, Khepupara, Patuakhali.

Background and Rationale

Hilsa is a popular and commercially important food fish in South Asian countries. So far, entire hilsa production comes from the capture fisheries. However, the natural production of hilsa is dwindling in the region due to over exploitation of adults and juveniles and ecological degradation of inland rivers and estuaries, which serve as spawning and nursing grounds for the fish. Inland open water production can be increased if breeding and aquaculture of hilsa can be successfully developed and established. One such possibility is development of cage culture of hilsa by stocking hilsa juveniles collected from natural sources and rearing them in cages set in the rivers, estuaries and near shore waters. With is in view, the present project has been undertaken.

Objectives

- To study the survival and growth rate of hilsa in cage culture system.
- To determine suitable size and shape of cages.
- To compare the survival rate of hilsa under different stocking density in net cages.
- To domesticate hilsa and study its food and feeding habit cultured in net cages.

Expected output

- Feasibility of cage culture of hilsa in brackishwater assessed.
- A baseline data on domestication and strategy for adaptation of hilsa to culture environment become available.

Contribution to Hilsa Fisheries Development

Hilsa production depends only on its harvest from natural sources. The present study is the first of its kind, wherein attempt will be made for this fast swimming migratory fish to grow and culture in captivity. If it is successful, it will create a new opportunity to increase hilsa production through its aquaculture.

Name of the Project

Studies on the causes of gonadal development in small size Hilsa: Assessment of the factors associated with the early gonadal development.

Name of Principal Investigator and Organization

Dr. A.K. Shakur Ahammad, Associate Professor, Dept. of Fisheries Biology and Genetics, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh.

Background and Rationale

Hilsa constitutes an important part of total fish production of Bangladesh. About 12% of the total fish production of Bangladesh comes from hilsa. However, at present, the smaller sized hilsa is getting matured with less fecundity. Thus, the recruitment rate of hilsa is decreasing greatly due to breeding of low fecund small size hilsa, which has negative impact on production. Therefore, it is important to know the causes of attaining early gonadal maturity of small size hilsa, determination of age at maturity, cellular analysis of ovarian maturation, and analysis of expression of gene in matured ovary.

Objectives

- Determination of age of hilsa at different size.
- Estimation of Gonado-Somatic Index (GSI) of hilsa during spawning season.
- Determination of stages of gonad maturation through histological analysis of ovarian cells.
- Qualitative and quantitative expression level of genes involved in gonad development.

Expected Output

- Age at different size of fish is known.
- Status of gonadal developmental at different ages of hilsa are known.
- Causes of early gonad development of hilsa are known through gene expression.

Contribution to Hilsa Fisheries Development

The outcome of research will identify the causes behind early development of gonads of hilsa which will help the regulating agency to take necessary measures to reduce early gonadal development and increase fecundity and production.

Name of the Project

Investigation on improved methods of value-added fishery products from Hilsa, River Shad, *Tenualosa ilisha*.

Name of Principal Investigator and Organization

Dr. A.K.M. Nowsad Alam, Professor, Dept. of Fisheries Technology, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh.

Background and Rationale

Hilsa is the highly popular fish in the sub-continent owing to its taste, flavor and culinary properties. However, people face difficulties in eating hilsa due to presence of huge pin bones, which also make it difficult to filleting. Fresh hilsa is normally preserved with ice. Salting is a long-time preservation method. High lipid content of hilsa makes it very susceptible to oxidative rancidity, autolytic and bacteriological decomposition. One of the important ways to avoid these problems and to make hilsa available to all classes of people is to make hilsa products as stable mince block or in powder form. Hilsa minced block or powder is useable in various presentable forms like curry, soup, noodles, cube or stock, hilsa crackers, corn hilsa snack, extruded protein cereals etc. which can be commercially produced by the food industry. With this in backdrop, this research project has been undertaken to produce value-added bone-free hilsa products for domestic and international consumers.

Objectives

- Production of value-added products fortified with hilsa mince or powder like hilsa cookies, hilsa crackers, corn hilsa snack, hilsa khichuri, extruded protein cereals etc.
- Production of hilsa can for whole fish, slice/chunk, flake or fillet.
- Production of ready-to-eat cooked hilsa curry and other products.
- Production of hilsa frozen block to use in nugget or croquette preparation.
- Market testing of value-added products and entrepreneurship development for commercial production.

Expected Output

- Taste-active components of hilsa are known and techniques developed to keep the taste-active components in the formulated products intact.
- Boneless hilsa frozen mince block with adequate frozen-storage ability produced.
- Stable hilsa can for whole fish, slice/chunk, flake or fillet produced.
- Ready-to-eat hilsa curry or other products presented in retort pouch developed.
- Snack extrusion of hilsa, hilsa crackers, corn hilsa snack, and extruded protein cereals produced.
- Production process developed for commercial hilsa product processing and marketing.

Contribution to Hilsa Fisheries Development

Hilsa is a seasonal fish. Even it has strong demand, it is not available round the year due to lack of its preservation and processing. The present project will develop methods for production of some value-added products like curry, soup, noodles, cube or stock, hilsa crackers, corn hilsa snack, extruded protein cereals etc. for commercial production and household consumption that will increase the food and economic value of hilsa fisheries while the product will be available round the year.

Name of the project

Estimation of population parameters of Hilsa shad, *Tenualosa ilisha* in Bangladesh through multi-model inferences: A key for sound stock assessment.

Name of Principal Investigator and Organization

Dr. Md. Yeamin Hossain, Associate Professor, Dept. of Fisheries, Faculty of Agriculture, University of Rajshahi.

Background and Rationale

Hilsa, *T. ilisha* is the largest single species fishery in Bangladesh. According to the world fisheries statistics, Bangladesh shares about 75% of the total world hilsa landings. About 12% of the country's total fish production is contributed by the hilsa fishery. Although production of hilsa has increased recently up to 0.52 million tonnes because of taking some conservation measures, there is a need to update the Hilsa Fisheries Management Action Plan for sustainable increase in production.

Fish population has four parameters such as growth, reproduction, recruitment, and mortality. Almost all previous studies on hilsa stock assessment using growth parameters are based on single model. However, in the present study, assessment of the status of the stock is being done through multi model inferences, which will enable us to select the best growth model from the multi model using some biological index. As hilsa lives in all the three different habitats as the sea, coastal and freshwater to complete their life cycle, multi model method is appeared to be better than the single model to better predict the population parameters that can give more correct status of the stock.

Objectives

- Development of a best-fitted model for estimation of population and assessment of hilsa stock through using a multi-model method for its sound stock assessment.
- Recommend a management policy using the findings of the study of population dynamics based on the unit stock's status in Bangladesh, which will clearly define the period of fishing ban for mother fish and jatka by confirming peak-spawning season and span and period of abundance of jatka for conservation of the hilsa fishery.

Expected Output

- The status of each hilsa stock in the major rivers, estuaries and in the Bay of Bengal known.
- The size at sexual maturity, length at first capture and length at which it reaches maximum biomass determined that would help formulating hilsa fishery management policy for the major rivers, estuaries and the marine waters separately through mesh-size selection.
- The period of fishing ban for mother hilsa and Jatka conservation justified unit-stock-wise.
- Information on exploitation rate, MSY, and biomass provided generated for making policy and action plan for future management of the fishery.

Contribution to Hilsa Fisheries Development

The project will provide adequate information on the population parameters and stock status for judging the fishery as to when and where, how much fish could harvested. Also, the findings will be helpful to recommend fishing at certain level of exploitation. Furthermore, this study will help the regulating agency to correctly enforce the regulations for the period of fishing ban and selection of mesh-size for sustainable hilsa fishery management in the fresh, coastal and marine waters of Bangladesh.

Name of the project

Assessment of energy transfer pathways (13C and 15N) from primary producers to Hilsa shad in the Meghna River estuary.

Name of Principal Investigator and Organization

Dr. Md. Jahangir Sarker, Professor, Dept. of Fisheries and Marine Science, Noakhali Science and Technology University, Noakhali.

Background and Rationale

Hilsa is euryhaline and can withstand a wide range of salinity. Hilsa lives in the sea for most of its life and migrates to the rivers for spawning. The Padma and the Meghna Rivers are its most common spawning grounds. However, in the meantime, the average size of hilsa has decreased from 60 cm to 40 cm in the last 20 years, which is affecting its production. This may be due to insufficient food and nutrients in the natural water. Recent studies indicate that the level of phytoplankton and zooplankton density in the surface water of the Meghna estuary is insufficient and almost five times lower than the level required for the species suggesting hilsa starts feeding on detritus when there is insufficient amount of phytoplankton and zooplankton and increasing amount of turbidity in the water. Stable isotope 13C and 15N analysis of all producers and consumers (primary to tertiary) will clearly depict what amount of energy is being transferred from different trophic levels to hilsa, its pathways and whether, protein sources for the growth of hilsa in the Meghna river estuary is enough. The results will provide answer why the size of hilsa is getting smaller and will suggest measures to increase natural productivity of coastal waters to the support optimum growth of hilsa.

Objectives

- To know the status of natural food abundance in hilsa spawning and nursery grounds.
- To find out the feeding preference of hilsa (phytoplankton, zooplankton, detritus, benthos or others) at its different stages of life.
- To analyze the transfer of organic carbon and nitrogen from all the producers and consumers to hilsa shad.

Expected Output

- The abundance of natural food, feeding habit of hilsa and isotope ratios (13C, 15N) in the spawning and nursery grounds of the Meghna estuary in different months determining its production potential are known.
- Comparative effectiveness of isotope studies over traditional studies in determining natural productivity of inland open waters is known.
- The causes of size reduction of hilsa in the riverine environment known.
- A new horizon will be opened for isotope studies in the field of fishery and/oceanography in assessing natural productivity of our valuable water resources.

Contribution to Hilsa Fisheries Development

The findings of the project will give a precise picture of productivity level and preferable food items of hilsa in the spawning and nursery ground stretches along the Meghna estuary. The information will help to predict the future production trend of the fishery. It will identify the exact causes why is hilsa gradually becoming smaller and will recommend measures for overcoming the problem and increasing the production.

Name of the Project

Impact of climate change and anthropogenic causes on Hilsa fishery management: Focusing the sustainable management policy.

Name of Principal Investigator and Organization

Dr. Md. Azharul Islam, Associate Professor, Dept. of Environmental Science, Bangladesh Agricultural University, Mymensingh.

Background and Rationale

Hilsa is a tasty and popular fish of Bangladesh. It plays an important role in nutrition and economic development. As hilsa is an anadromous fish, it migrates from the sea to the rivers in quest of fresh water for spawning, nursing and growing. Gravid hilsa prefer turbid, fast flowing freshwater for spawning but young prefer clear and slow flowing freshwater. Past research on hilsa are mainly concentrated to biological aspects. However, there is no information available on climate related aspects except a few published reports. Climate change (salinity intrusion, sea level rise, temperature rise, impact of freshwater flow), has a profound impact on thermal tolerance, growth, metabolism, breeding performance, spawning season, spawning ground, survivable and migration of hilsa. Unplanned developmental and other anthropogenic activities have also adverse effects on the hilsa stock and its habitats. The present study has been undertaken to assess the impact of climate change on the fishery to recommend management measures for resilience while maximizing the economic benefits.

Objectives

- To identify few geomorphic features within the selected river basin in Bangladesh.
- To explore the effects of temperature, rainfall, salinity and day length on growth, reproduction, recruitment and mortality of hilsa.
- To provide an overview of man-made changes affecting hilsa fishery ecosystems.

Expected Output

- The geometric features of the riverine ecosystem identified.
- Information on the impact of climate change on biological parameters of hilsa fisheries available to plan mitigating measures.
- The chemical characteristics of river water will be determined indicating its suitability for the growth of hilsa.

Contribution to Hilsa Fisheries Development

The project will identify the impact of climatic change on salinity intrusion, over exploitation, breeding performance, use of small mesh size fishing nets, agro-chemicals, municipal and industrial pollution, sedimentation etc. on hilsa habitats, hilsa populations and their upstream migration. This information will suggest adaptation strategies and adjustment or updating the management plan for this highly migratory trans-boundary fish.

Name of the Project

Developing marketing strategy for Hilsa fish distribution: Emergency supply chain management.

Name of Principal Investigator and Organization

Dr. Mahmud Akhter Shareef, Professor, School of Business & Economics, North South University, Dhaka.

Background and Rationale

Although hilsa has a high market demand, the fishers normally do not get fair price due to its complex marketing system. Under the existing system, fishers are bound to supply their catches to investors called mohajons at whatever price they offer as the fishers borrow money from the mohajons for buying fishing equipment. Hilsa passes through a long supply chain from harvest to retailing and although price increases at every stage, the benefits go neither to the fishers nor to the consumers. So, it is necessary to develop an effective and fishers friendly supply chain involving handling, packaging, transportation, distribution, processing, wholesale, and retailing to ensure fair price to the fishers and reasonable price at purchase by the consumers. Occasionally, supply of hilsa surpasses local demand, which needs emergency distribution of excessive amount to keep balance between supply and demand curves through management of logistics so that demand does not fall. The present study has been undertaken to develop an effective marketing strategy through better management of regular and emergency supply chain for hilsa.

Objectives

- Identify the weaknesses and problems of the existing supply chain and the critical factors that affect the supply chain of hilsa at the procurement, local storage, wholesale, transportation, storage, distribution and retailing throughout the country.
- Developing a sustainable hilsa marketing strategy by establishing an appropriate supply chain for both regular and emergency supply when production surpasses demand.

Expected Output

- Overview of present marketing system of hilsa obtained
- Regular supply chain from harvest to consumption assessed.
- An emergency supply chain when production surpasses local demand developed.
- Strategy for sustainable distribution and marketing of hilsa will be developed.
- A business model for evenly distribution and profit maximization and sharing developed.

Contribution to Hilsa Fisheries Development

The project will analyze and provide an overview of the existing supply chain involved in hilsa fish marketing and the role of all types of stakeholders including the government from production to consumer in supply chain management. It will also identify the limitations and weaknesses at all levels of the hilsa supply chain. Finally, the project will recommend an effective supply chain management system for regular and emergency supply for hilsa marketing in Bangladesh ensuring equity.

Name of the Project

Determination of genetic structure of Hilsa shad, *Tenualosa ilisha* populations in Bangladesh using Single Nucleotide Polymorphisms (SNPs) developed by Next Generation Sequencing (NGS) technology.

Name of Principal Investigator and Organization

Dr. Rashedul Kabir Mondol, Associate Professor, Dept. of Fisheries, University of Rajshahi.

Background and Rationale

Hilsa is the largest open water commercial fishery and is a part of culture and heritage of Bengali people. The species has wide distribution along the rivers, estuaries and marine waters of Bangladesh. The riverine habitat of this fish extends to more than 100 rivers of which the Padma, Meghna, Jamuna and the Karnaphuli are important. Hilsa migration for spawning in the rivers has severely declined in recent time and its concentration to the downstream and the sea is a serious concern for its reproduction and recruitment, which is a prerequisite for sustaining the production. In order to conserve and manage the fishery, detailed studies on population are essential. Traditionally, population structure is determined by tagging a large number of individuals and monitoring their movement and dispersal, which is practically impossible to track movement of transboundary migratory fish, in vast water bodies, is also a time consuming, expensive, and has low rate of success. The present study will assess the genetic diversity, migration and other population parameters in hilsa by DNA sequencing using Single Nucleotide Polymorphisms (SNP) across the hilsa genome, which is regarded as a powerful tool for extensive population studies.

Objectives

- To detect hilsa population structure across its distribution from riverine, coastal and marine environments in Bangladesh.
- To characterize hilsa population structure by using various powerful Single Nucleotide Polymorphisms (SNPs) markers to facilitate development of a rationale management plan for the hilsa fisheries.

Expected Output

- Genetic diversity of hilsa populations across its distribution in different habitats is known.
- Identification of unique population, sub-population or hilsa stock in freshwater, coastal and marine environments in Bangladesh.
- Genetic monitoring system for hilsa fisheries in different environments adapted.

Contribution to Hilsa Fisheries Development

The study will help to develop a well-defined genetic management and conservation program for the unique population, sub-population or stock of hilsa. It will also help to establish hilsa sanctuary based on genetic information. Further, the genetic data will assist in monitoring of Maximum Sustainable Yield (MSY) of hilsa fishery from different environments. The study will also help in managing migratory routes of hilsa spawners and jatka. Finally, the genetic information will help to increase hilsa production through a management plan that developed based on genetic information of hilsa populations.

Name of the Project

Development of vacuum and modified atmosphere packaging of fresh and value-added products of Hilsa fish, *Tenualosa ilisha* under different storage condition.

Name of Principal Investigator and Organization

Dr. Md. Tariqul Islam, Associate Professor, Dept. of Fisheries, University of Rajshahi.

Background and Rationale

Hilsa has a high demand in the local market. About 60-70% of hilsa are consumed fresh in Bangladesh and the rest is exported to India, USA, EU countries, Japan and to the Middle East. Hilsa is traded in the domestic markets in fresh and frozen state. It is mostly transported by bamboo baskets with or without hogla mat or polythene covered with ice. Hilsa is also transported in plastic drum, steel made half drum, aluminum container, wooden, fiber glass or plastic container including ideal boxes. However, high lipid content makes hilsa very susceptible to oxidative rancidity, autolytic and bacteriological decomposition. Therefore, maintaining cool chain is essential to minimize product deterioration and achieve maximum shelf life.

In Bangladesh, the common short time preservation method for hilsa is icing and the long-term method is salting. Freezing of hilsa is also done in some cases. Improvement of icing and freezing methods and development of value-added products from hilsa will help increasing the shelf life and making the products available throughout the year. In this project, vacuum packaging with icing, and vacuum and modified atmosphere packaging (MAP) along with low temperature storage will be developed for fresh hilsa and its value-added products to ensure supply of quality fish and fishery products with extended shelf life.

Objectives

- To know the effects of vacuum packaging on overall quality and shelf life of hilsa under ice storage condition.
- To develop vacuum packaging and modified atmosphere packaging with ice and frozen condition and assess their effects on overall quality and shelf life.
- To determine the quality and shelf life of ready-to-cook (RTC) hilsa fish ball under vacuum and modified atmosphere packaging at refrigerated (4°C) storage condition.

Expected Output

- Shelf life of hilsa fish under vacuum packaging at icing and freezing storage conditions increased.
- Process for preparation of fish ball from hilsa by modified atmosphere packaging and stored at refrigerated condition developed and shelf life increased.
- Qualitative and quantitative losses of hilsa under vacuum and MAP at different storage conditions reduced.

Contribution to Hilsa Fisheries Development

As hilsa is generally marketed in fresh condition in Bangladesh, the keeping quality and shelf life is an important issue. This project will develop methods for vacuum packaging for iced hilsa and modified atmosphere packaging for frozen hilsa products to prevent loss of quality and extend shelf life that will make the hilsa products available throughout the year.

Chapter XIV

Future Research Needs for Hilsa Fisheries Development of Bangladesh

Introduction

Hilsa shad (*Tenualosa ilisha*) is the most important and largest single species open water fishery of Bangladesh. The fish is inseparable from the culture and heritage of the Bengali nation. It is the most widespread among the five species of tropical shads (genus *Tenualosa*) and is the basis of important fisheries in Bangladesh, India, Burma, Pakistan and Kuwait and probably forms the largest estuarine fishery in the world in terms of production. Hilsa inhabits in a wide range of environment such as the marine, estuarine and riverine. In the seas, its distribution extends from the Persian Gulf, the Red Sea, the Arabian Sea, the Bay of Bengal, the Vietnam and the China Sea. The riverine habitat covers the Satil Arab, and the Tigris and Euphrates of Iran and Iraq, the Indus of Pakistan, the rivers of eastern and western India, the Irabaty of Myanmar and the Padma, Jamuna and Meghna and other coastal rivers of Bangladesh. However, Bangladesh alone shares about 75% of the hilsa resource followed by Myanmar about 15%, India 5% and other countries have the rest 5% only. It is extremely migratory in nature. Hilsa tagged by Bangladesh Fisheries Research Institute (BFRI) in Bangladesh waters has reported to have been caught in Iranian waters.

Because of regional importance of hilsa as a popular fish, its research drew much attention of the scientists of the Indian subcontinent. In the 19th century, hilsa research shaped into academic form (Russel 1803; Hamilton, 1822) and boosted up during the 20th century and continuing till date. In Bangladesh, Ahsanullah (1964); Ahmed Shamin (1976); Amin (1975); Doha and Hoque (1968); Haldar (1977); Hossain (1971, 1983); Quddus (1982,1983); Rahman (1980); Shafi (1976) conducted a good amount of research on different aspects of hilsa biology, abundance and distribution, migration, fishing crafts and gears and population dynamics. However, such studies were fragmented, scattered and not conclusive enough to formulate any management plan.

BFRI after its establishment in 1984-85 by an Act of the Government, first initiated organized, systematic and comprehensive research covering all aspects of hilsa fisheries of Bangladesh. Hilsa research in Bangladesh got its momentum from the Riverine Station, Chandpur of BFRI through implementation of two long-term comprehensive research projects by BFRI in cooperation with IDRC, Canada, and ACIAR/CSIRO, Australia and Government of Bangladesh during 1986 to 2001. These two projects identified the spawning and nursery grounds of hilsa, determined the peak spawning season, assessed the damage being caused to the fishery by catching jatka (hilsa juveniles) and gravid hilsa, effects of destructive fishing gears and mesh size used, determined the critical size and age of fish in the population, assessed the stocks and exploitation levels etc. are the milestones in the history of hilsa research in Bangladesh. An annotated bibliography on hilsa was prepared under IDRC supported project which documented 368 publications in this subcontinent and adjacent countries including Iraq, the Philippines and Malaysia during 1803 to 1986 (Jafri and Melvin, 1988). Since then, BFRI has been continuing uninterrupted hilsa research. The findings of BFRI research in the meantime have attracted donor agencies to intensively involve in hilsa research activities of Bangladesh.

Again, a large number of studies on reproductive aspects of hilsa give conflicting results which showed that the size and age at sexual maturity varied between 16 cm and 1+ year of age in the Hooghly River, India, to 40 cm and 4+ years age in the Meghna River in Bangladesh, as summarized by Raja (1985), Pillay (1958) and Dunn (1982). BFRI studies show that hilsa reaches maturity at 20 cm (SL) or less (1+ years old) and can spawn at this size. It is yet to confirm whether hilsa in Bangladesh spawn more than once a year.

As has been mentioned earlier (chapter II) that the IDRC supported hilsa research project was the first comprehensive research project implemented by BFRI in Bangladesh during 1986 to 1992 under which it was for the first time the spawning season, spawning and nursery grounds of hilsa were identified, impact of jatka catching and crafts and gears used in hilsa fishing were determined, gear selectivity studied, stocks were assessed and exploitation level determined. However, the fishery is still facing many challenges from ecological, environmental and human activities that are continuously impacting the fishery. In order to face the challenges and sustainably manage the fishery, it is absolutely necessary to continue uninterrupted research on hilsa. In this context, future research needs for Bangladesh have been identified and provided in this chapter for the proper development and management of the hilsa fishery.

Future Hilsa Research Needs

Sl.	Research Topic	Justification	Researchable area
	A. Biology and Genetics		
1	Study of the biological aspects of hilsa including age, changes in maturity, fecundity in relation to age and size, sex ratio, sex change issue and environmental changes.	Recent studies indicate that relatively smaller sized hilsa is getting matured with less fecundity. As a result, recruitment rate of hilsa has greatly reduced due to breeding of low fecund small sized hilsa, which has negative impact on recruitment and production. BFRI research with ACIAR, Australia shows that hilsa reaches sexual maturity at 20 cm and one year of age and that both males and females are able to spawn at this size. Although there is no evidence of sex change in hilsa, males are predominant between 10 and 25 cm size and the sex ratio of the smaller fish is almost 1:1. The majority of fish over 30 cm and almost all fish over 40 cm are females which may be due to females live longer.	More studies on biological aspects are required to know the causes of attaining early gonadal maturity of small sized hilsa, determination of age at maturity, cellular analysis of ovarian maturation, and analysis of expression of gene in matured ovary. The issue of no sex reversal in hilsa needs to be confirmed with further study.
2	Monitoring and investigation of spawning and nursery grounds of hilsa.	BFRI/IDRC research has first identified a large spawning ground of hilsa in the lower stretches of the river Meghna in the region of Hatia, Sandwip and Monpura. Hilsa was found to spawn in the	It is important to regularly monitor the status of spawning and nursery grounds of jatka in the

Sl.	Research Topic	Justification	Researchable area
		major rivers (the Padma, Meghna, Jamuna and other deltaic rivers) of Bangladesh almost round the year. Jatka migrate from estuaries into the freshwater for feeding purposes. However, under BFRI/ACIAR research, hilsa was also found to spawn in the estuaries and the coast although in lesser proportion. It was presumed that it was not the salinity, but the temperature may be more related to spawning as hilsa moves to the sea from October when temperature drops in the upstream rivers. However, no information is available about the coastal spawning grounds of hilsa. Hilsa juveniles (jatka) are shifting grounds due to intense fishing pressure and environmental degradation. It is now even found in the haors and beels (natural depressions) connected to the upstream rivers.	rivers, estuaries and the coast, assess the seasonal abundance, and investigate the food, feeding and migratory habits of jatka. The information to be obtained from these studies will help to update the management plan for jatka and hilsa fishery in the country.
3	Study of population genetics for confirmation of the availability of different stocks/races in the fishery by molecular marker and DNA sequencing.	Previous investigation on biometric aspect of hilsa indicated the possibility of having four stocks/races of hilsa in Bangladesh. However, electrophoretic studies indicated availability of two stocks/races in the country. On the other hand, BFRI and ACIAR, Australian studies indicated that hilsa in Bangladesh are a single population and fish in the Meghna river move freely between riverine and coastal habitats, but some population found in the upper reaches in the Surma and Kushiara rivers may be the permanent resident there. Therefore, more work on this aspect through DNA sequencing is needed to establish the number of hilsa races present in Bangladesh waters. Besides, in the market, along with silver shot with gold and purple color in some fishes, a dark blotch behind gill opening followed by a series of small spots in their flank are found, particularly in the juveniles which is very close to see the *T. thibaudeaui* (Laoshian shad). Rahman found clear PGM variation and indicated tentative genotype distribution and existence of separate gene pools among the hilsa fishes of Bangladesh. Very recently, the scientist of BAU, Mymensingh and University of Dhaka claimed that they have decoded the genome sequence of hilsa fishes of Bangladesh. Thus, a broad based research is required to conduct to assess the genetic diversity, migration and other population parameters of hilsa by DNA sequencing.	Research should be conducted on permanent residency, genetic diversity, racial discrimination, unique population, sub-population across the distribution of hilsa in riverine, coastal and marine environments in Bangladesh.

Sl.	Research Topic	Justification	Researchable area
	B. Physiology and Behavior		
4	Study of relationship between hilsa landing, spawning and migration with lunar cycle.	The spawning cycle of hilsa was found to be closely synchronized with the lunar cycle and it was observed that hilsa largely spawn during the full moon and new moon period. During this time, a huge spawning migration and plenty of oozing hilsa is reported. It is assumed that high tidal action, strong current, turbulence, turbidity and heavy upwelling of water due to irregular bottom topography induce hilsa to spawn during this time. However, precise information on limno-biological parameters such as salinity, temperature, rainfall, velocity of water current across the habitat and its relationship with the influence of lunar periodicity is not known. It was also observed that the proper time of breeding for hilsa is afternoon to evening. However, maturity and abundance of ripe hilsa differs with areas, water current, and availability of food and with other environmental parameters. Therefore, in depth study is needed to establish the relationship between spawning with various stages of lunar cycle and other limno-biological parameters.	It is necessary to investigate the factors that relate spawning with lunar periodicity, comparison of spawning frequency and landings of hilsa along with the lunar calendar etc.
5	Study of relationship between salinity, temperature, conductivity and ascent of hilsa from the sea to the rivers and vice versa.	Salinity, temperature and conductivity have strong correlation that affects water quality and solubility of dissolved oxygen in water that are related to migration of fish. Conductivity is a measure of water capability to pass electrical flow which is directly related to the concentrations of ions in water. The dissolved ions such as alkalis, chlorides, sulfides, carbonate compounds and TDS (total dissolved solid) increase salinity and conductivity of water. Conductivity also increases with decreasing temperature. Thus, there is a need to study the relationship of these factors with ascent of fish to the rivers and vice versa.	Research should be undertaken to determine and compare the changes in salinity, temperature and conductivity between the rivers, estuaries and the sea throughout the year and their effects on migration pattern and migration route of hilsa for spawning and feeding.
6	Study of the causes of downward migration of hilsa from the rivers.	Juvenile hilsa (jatka) are assumed to migrate to the sea from the rivers to attain maturity to undertake spawning migration again in the next breeding season. Fishing pressure, siltation, pollution and other manmade problems also force their downward migration. However, the reasons and timings of downward migration of jatka are not clearly known.	Research is needed to identify the factors and the level of influence that causes downward migration, assess the biological demand for downward migration, affinity of hilsa for riverine environment and vice versa at different life stages and recommend management measures.

Sl.	Research Topic	Justification	Researchable area
	C. Movement, Migration and Distribution		
7	Study of abundance, distribution, migration and movement pattern of hilsa between inland, coastal and marine ecosystems.	The abundance, distribution and movement of hilsa between inland and coastal waters of Bangladesh are well studied. Hilsa occurs in entire coastal waters and about 100 rivers, and occasionally migrates to flood plains (Haldar, 2004). However, their marine distribution, major fishing grounds etc. are not specifically known.	In depth study is required on the marine distribution of hilsa including delineation of their fishing grounds for proper management and development of the fisheries along the coast.
8	Movement pattern and dynamics of migration of hilsa juveniles (jatka) and spent fish between different environment.	From otolith microchemistry study of BFRI and Australia, hilsa has been established as a diadromous fish. However, it is known that to complete its lifecycle, hilsa migrates from the sea to the freshwater and vice versa during their pre-adult, spent and juvenile stages. Further study is required to precisely know the time of their migration at each stage, including their migration route and migration pattern.	Research should be conducted on identification of new or changes of spawning and nursery grounds, seasonal abundance and distribution of jatka, oozing and spent fish; food, feeding and migratory habit at each stage of life cycle of hilsa between different environments on regular basis.
9	Species diversity of hilsa and hilsa like species.	Two species of the genus *Tenualosa* (*T. ilisha*, *T. toli*) and one species of hilsa (*H. kangurta/kelee*) are available in Bangladesh**.** Besides, some hilsa like fishes such as *Ilisha megaloptera; I. elongate; I. melastoma; I. filigera* (Coromondel ilish) etc. are also found in the country. However, the catches of *T. toli* are gradually decreasing in Bangladesh. Earlier, about 1% of the total landing in Cox's Bazar was comprised of *T. toli* which is now rarely found**.** The reasons for declining this species need to be studied.	Detailed studies should be conducted on the species diversity of hilsa and hilsa like fishes with particular emphasis to their taxonomic status, abundance, distribution, biology and fishing season, crafts and gears etc.
10	Study of transboundary migration of hilsa.	It was confirmed by BFRI and Australian studies that the Bay of Bengal comprised of a single population of *Hilsa ilisha*. Thus, it is anticipated that the population of *Hilsa ilisha* has a transboundary migration with india and Myanmar. Therefore, it is required to conduct broad based collaborative research with India and Myanmar for effective management of this shared resource. Otherwise, uncontrolled fishing in any neighboring country will affect the production and success of management measures of the other country.	Joint research with financial and technical support of international agencies is required to be undertaken with India and Myanmar in order to formulate Regional Hilsa Fisheries Management Strategies and Action Plan for joint management and development of this shared resource which will truly benefit all the three countries with sustainable hilsa production.

Sl.	Research Topic	Justification	Researchable area
	D. Habitat and Environment		
11	Study of degradation and loss of riverine habitat by manmade and natural phenomena and their effects on biology of hilsa and other fishes.	The construction of various dams and embankments and other flood control and drainage structures on various rivers contributed to loss of hilsa habitat and destroy the hilsa fishery of many rivers. The GEF studies revealed that hilsa production has completely lost or almost lost from about 40 rivers of Bangladesh during the last 20-25 years. The loss of production from these rivers was estimated between 12,000 and 15,000 tonnes/year along with the loss of some of the grazing and nursery grounds of the fish.	The causes of the loss of hilsa habitat from inland water bodies and potential remedies should be studied for sustainable production of hilsa in Bangladesh.
12	Assessment of chemical pollution (lead, mercury, cobalt, chromium, cadmium, magnesium, nickel, copper, zinc, iron and other harmful elements) in the river system by industrial, municipal and domestic wastes and agrochemicals and determination of the status of ecosystem health.	ADB study results published in the Daily Star News Paper on 24 August 2019 reported that pollution of the Meghna river from industries and other sources connected to the river through canals became severe in the pre-monsoon season. Concentration of dissolved oxygen necessary for survival of fish and other lives has decreased significantly. The level of heavy metal like chromium exceeded drinking water standards at many locations in the upstream Meghna. Uncontrolled dumping of untreated industrial effluents caused by rapid industrialization, domestic and urban waste disposal into the rivers and coastal areas, increased siltation and accumulation of pesticide residues, meanwhile have rendered the upper Meghna, Sitalkhya, Padma, Baral, Madhumati, Gorai and some other rivers unsuitable for hilsa habitation. If these increasing pollution cannot be controlled, the fishery of these rivers will be completely lost in future including loss of breeding and nursery grounds of fishes which will bring a total disaster to the fishery.	Detail research is needed to identify the sources and assess the pollution load by hazardous heavy metals like lead, mercury, cobalt, chromium, cadmium, magnesium, nickel, copper, zinc, iron etc in the rivers and coastal waters to recommend mitigation and control measures.
	E. Water Quality Monitoring, Biological Productivity and Biotic Balance		
13	Monitoring of water qualities of the rivers, estuaries and marine ecosystem on regular intervals.	Water quality indicates the status of ecosystem health for the fishes and other living aquatic organisms. Increasing deterioration of water quality of aquatic ecosystem by industries and human activities are regular phenomena. Inland capture fisheries are facing serious threats of highly poor quality and polluted water. However, very little work has been done earlier on this issue.	Water quality requires regular monitoring for all aquatic ecosystems as an index of ecosystem health to know the status and maintain the quality of water for propagation and growth of fish.

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14	Assessment of biological productivity and carrying capacity of hilsa ecosystem at different time intervals to obtain and maintain sustainable hilsa production.	No works have been done on this issue earlier. Assessment of biological productivity is the modern method for determination of carrying capacity and energy production balance of an ecosystem. It is the relationship between both the predator and prey species and the amount of primary and secondary energy production and the balance of energy.	Research is required to assess the biological productivity and carrying capacity through biotic balance of the hilsa ecosystem.
	F. Impact of Climate Change on Hilsa Habitat and Physiology of Fishes		
15	Impact of climate change such as sea level rise, sea surface temperature, salinity, rainfall, drought, velocity of current etc. on the hilsa fishery and strategy for adaptation.	Global climate change is currently assuming a new dimension. The countries across the globe from Canada, USA, and France to Australia have experienced a record high temperature in 2019 with France reaching 45.9°C. However, the negative impact of climate change is yet to receive the global attention it deserves. As Bangladesh is highly vulnerable to climate change, it is likely to be most seriously affected by global climate changes. Both coastal and freshwater fisheries are subject to profound impact by increase of air and water temperature, excess and irregular rain, drought, high rate of precipitation, sea level rise, saline water intrusion into inland freshwater, increased tidal surges and storms and cyclones etc. These climate factors exert negative impact on thermal tolerance, growth, metabolism, reproductive performance and breeding and nursery grounds, breeding and spawning seasons and survival and migration of hilsa. However, very little or no research has been doing on these issues so far.	Research should be undertaken to assess the impact of climate change on the hilsa fishery in respect of reproductive performance, shifting of breeding and nursery grounds, growth, migration and overall biology and production for adaptation and resilience of the fishery on urgent basis.
	G. Population Dynamics and Stock Assessment		
16	Population dynamics and stock assessment of hilsa in the riverine and marine ecosystems.	Studies on population dynamics and stock assessment of hilsa was first initiated in 1986-87 by BFRI under IDRC supported research project and since then being continued almost regularly. Meanwhile, important information on various population parameters has been generated based on which Hilsa Fisheries Management Action Plan was prepared. In order to sustainably exploit and manage the fisheries, it is a prerequisite to have accurate information on the status of the stock in respect of growth, natural mortality, fishing mortality, recruitment, size at first capture, exploitation rate,	The study should continue to determine the temporal and spatial variations in population parameters, virtual population analysis and estimate the exploitation rate, MSY and biomass of hilsa as a regular work as inputs to formulate and update management measures for sustainable development of the hilsa fishery.

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		maximum sustainable yield (MSY) etc. The study of population dynamics and stock assessment always provide information on current status of exploitation of the fishery as inputs to update and adjust the management measures and therefore, this work should be continued incessantly.	
	H. Fishing Crafts and Gear		
17	Identification of harmful/ destructive fishing crafts and gears and chemicals used for catching hilsa and other fishes in the open water ecosystem.	A huge number of destructive fishing gears such as current jal, large beach seine net (jagatber jal), charghera net and set bag net in inland waters, and ESBN and MSBN in the coastal and marine waters respectively are used for catching of hilsa juveniles (jatka) and other fishes. The use of these nets has been banned under the Fish Conservation Rules of Bangladesh. Very recently, DoF has lunched massive programs to destroy and eliminate these nets from the fishery. It is reported that fishing is also done by use of poisons in rivers and tributaries in the Sundarban and other areas of Bangladesh. Thus, a countrywide survey is required to be undertaken to determine the extent of the use of such harmful fishing gears and the damages causing to the fishery and recommend possible measures for their eradication.	An effective survey should be conducted in this regard on an urgent basis.
18	Monitoring of hilsa catch by crafts and gears and landings from major landing centers of the country.	Monitoring of catch landings at important landing centers and catch and effort data by major fishing crafts and gears and stock assessment will provide information on abundance and trend in exploitation of the fishery at different seasons. This information will help in conservation and management of the hilsa fishery. Major coastal and inland hilsa landing centers are located at Cox's Bazar, Chittagong, Teknaf, Kutubdia, Hatiya, Sandwip, Ramgoti, Bhola, Patuakhali, Khepupara, Mohipur/Kuakata, Pathorghata, Khulna, Chandpur and Dhaka. Most of the catches from the rivers, estuaries and sea are landed at these centers and hilsa is the main species. After meeting the local demands, surplus hilsa from these centers is sent to the different districts which are determined by market price.	In order to know the landing of hilsa in the major landing centers throughout the year and thus the status of the stock, it is required to regularly monitor the catch and catch and effort data for better conservation and management of the fishery effectively.
19	Improvement of artisanal fishing boat.	In Bangladesh, mechanized wooden boats are usually used by the fishers. These boats are not long lasting and almost every year considerable amount of money is spent by the fishers for their repair and maintenance. Besides, the boat is less resistant to storm and cyclones. On the other hand, fiberglass boats are long lasting and resistant to	Comparative cost effectiveness, longevity and fishing efficiency of wooden and fiberglass boats should be conducted.

Sl.	Research Topic	Justification	Researchable area
		storm and cyclones. Thus, a comparative study of longevity, cost effectives and efficiency of wooden and fiberglass boat should be conducted.	
	I. Impact of Sanctuaries and other Conservation Measures		
20	Assessment of the impact of sanctuaries and other conservation measures (brood and juvenile hilsa fishing ban) on spawning success of hilsa, abundance of jatka, hilsa production, and biodiversity of other fishes in the riverine and coastal ecosystems.	Government has established six sanctuaries in the Padma, Meghna, Shahbazpur channel, Tetulia and Andharmanik rivers to conserve hilsa juveniles (jatka) and facilitate breeding of other fish including hilsa. In the meantime, marine protected area (MPA) has also been established for 65 days. Studies on the impact of sanctuaries have demonstrated higher spawning success of hilsa and some other fishes and also have increased hilsa production. In the spawning grounds, relatively higher amount of spent hilsa and jatka were observed whereas fewer spent hilsa and jatka were found in the adjacent non-sanctuary spawning areas. About 43.93% spent hilsa was found and calculated egg production was 628,291 kg and the estimated number of jatka was 392,680 million which were much higher than the previous years. Besides jatka, spawns and fries of other fish species were also found in higher quantity in and around the spawning areas of hilsa than previous years. The impact of these sanctuaries towards conservation and improvement of riverine and coastal biodiversity should be assessed with special emphasis on potential alternate/new options, if there are any so that fishers livelihood is not affected.	Detailed study should be conducted to precisely quantify the impact of the sanctuaries on spawning success and production by species in comparison to non-sanctuary zones.
21	Assessment of the impact of Marine Protected Area (MPA) on hilsa biology, ecology and production, biodiversity of fish, crustaceans and cetaceans and socio-economic impacts.	Establishment of Marine Protected Area (MPA) is an important and critical management tool for protective management of the designated marine area to provide a safe zone, particularly for the threatened species to keep them in natural state, protect marine biodiversity and sustain fisheries production which is vital to food security, local livelihoods and the national economy. MPA is also important to control rampant exploitation of natural resources, especially at the coast where biodiversity is at the risk of extinction. Considering the above, government has already declared the Nijhum Dwip Marine Protected Area (MPA) on 24 June 2019 spanning across an area of nearly 3,188 sq. km, as the new marine reserve of Bangladesh for the protection of migration routes and spawning grounds of hilsa and various other endangered marine animals to ensure natural	Nijhum Dwip MPA is a new marine reserve. Therefore, detailed research and studies should be conducted to precisely know its overall impact and to determine the needs establishment of more such MPAs for critical habitats and resources. The study should include: assessment of migration, spawning, recruitment and production of hilsa and other fish inside and outside the protected area, biological productivity,

Sl.	Research Topic	Justification	Researchable area
		regeneration, sustaining fisheries production and improvements of livelihood of the coastal people who depend on these resources. The government has imposed ban on catching all types marine fish, crustaceans and cetaceans and use of all types of fishing crafts and gears for 65 days from May 20 to July 23 every year in the protected area. It is now essential to conduct scientific study and research to assess the impact of MPA establishment on migration, spawning, recruitment and production of hilsa in the protected area, productivity and biodiversity of other fish species along with the impact of livelihoods on fishing communities and socio-economic benefits of MPA. It is also necessary to determine AIGA needs of the affected fishers for the ban period. Besides, a coordinated management plan should also be developed for effective management of MPA through appropriate research for sustainable production of hilsa and other estuarine and marine fish.	and biodiversity of other fish species, impact of livelihoods on fishing communities and overall socio-economic benefits of MPA, AIGA needs of the affected fishers for the ban period etc. Besides, a coordinated management plan should also be developed for effective management of MPA through appropriate research for sustainable production of hilsa and other estuarine and marine fish.
	J. Impact of Conservation Measures on Livelihood of Hilsa Fishers		
22	Impact of fishing ban on production, supply and demand, and price of hilsa, hilsa fishers and adequacy and effectiveness of government alternate income generating activities (AIG) for hilsa fishers.	In order to increase hilsa production, government has banned catching, transportation, marketing, sale and storage of hilsa throughout the country including the coastal districts every year at the time when the moon rises first in the Bengali month Ashwin for 22 days (4 days before full moon, the day of full moon and subsequent 17days). During this banning period, about 0.2 million families of hilsa fishers are provided with VGF food assistance. Another 0.25 million hilsa fisher families of 85 Upazilas of 17 jatka rich districts who refrained themselves from catching jatka are given 40 kg of rice assistance to each family for four months. ECOFISH, a WorldFish program also provides support to project beneficiaries with alternate livelihood when fishing ban remains in force. Access to fishing by the fishers is restricted for considerable time for conservation of jatka and protection of brood fish. The impact of this conservation measures and the adequacy and effectiveness of AIGs need to be assessed to recommend more effective AIGs to improve the fishers' economic conditions. It is also needed to assess the impact of conservation measures on production, supply, demand and price of hilsa and other fishes.	Detailed analysis of the government restriction of fishing access to the fishers for conservation of the resources and its economic impact on the fishers and the effectiveness and adequacy of AIG programs including the impact on production, supply, demand and price of the fish is needed to recommend more effective programs to support livelihood of the hilsa fishers and further adjustment and updating of the conservation measures.

Sl.	Research Topic	Justification	Researchable area
	K. Induced Breeding and Aquaculture of Hilsa		
23	Development of induced breeding and seed production techniques of hilsa.	Past attempts on artificial breeding of hilsa has limited success both in India and Bangladesh. BFRI's own and BFRI/WorldFish conducted research on onboard breeding trials of hilsa by collecting oozing females and mature males during the peak breeding season. The experiments were partially successful. Even the ovulation and fertilization of eggs were good, but most of the eggs died except a few occasions. BFRI also reared hilsa in ponds to develop brood. Although eggs appeared in cultured hilsa, it did not attain proper maturity and not reach to ripening stage. Thus, more research is needed to achieve success in developing technique for induced breeding of hilsa.	Further research is needed to develop induced breeding technique of hilsa.
24	Adaptation and culture of hilsa in captive/semi captive condition.	Experimental pond culture of hilsa juveniles (jatka) was carried out with the stocking density of 2,500/ha in two ponds of the Riverine Station in Chandpur during 1986-91. A total of 600 and 300 jatka were stocked in two different ponds and reared on fertilization without any feeding. The average length and weight of the juveniles during stocking were 5.31 cm and 1.25 g, respectively which grew about 30 cm in length and 270 g in weight in a year. After rearing for 4/5 years, the maturity and gonadal development of hilsa were not satisfactory. The preliminary study showed the possibility of pond culture of hilsa. However, this would depend on the availability of seed.	Research trial on aquaculture of hilsa should be continued in the coastal environment.
	L. Value Addition and Product Development		
25	Development of canned, smoked and other value-added products including snacks from hilsa.	Hilsa is the highly popular fish in the Indian sub-continent owing to its taste, flavor and culinary properties. Fresh hilsa is normally preserved with ice. Salting of whole hilsa and eggs are long time traditional preservation method. However, production of canned and smoked products from hilsa like fish is quite popular to foreign consumers. There is potential also for production of canned and smoked products from hilsa in Bangladesh. Both the fresh and salted hilsa eggs have high demand and price in some south east Asian countries as like as black and red caviar (sturgeon and salmon roe). Since hilsa flavor is especially liked by the people of this region, hilsa product can be used in preparing soup, chips, crackers and other type of	Research should be undertaken to develop process for various value added products from hilsa that can be produced commercially by the food industries of Bangladesh.

Sl.	Research Topic	Justification	Researchable area
		snacks etc. Recently, process are being developed by the Dept. of Fisheries Technology, BAU Mymensingh to make hilsa minced block or powder to use in various presentable forms like curry, soup, noodles, cube or stock, hilsa crackers, corn hilsa snack, extruded protein cereals etc which can be commercially produced by the food industries. More research should be undertaken for development and refining of process for production of various value-added products from hilsa.	
26	Development of improved methods of icing, salting, packaging, storage and other traditional methods of hilsa preservation.	Hilsa is traded in the domestic markets as fresh whole fish preserved in ice. It is mostly transported through open trucks by bamboo baskets with or without hogla mat or polythene covered with ice. Hilsa is also transported in plastic drum, steel made half drum; aluminum container; wooden, fiberglass or plastic caters including ideal boxes. Insulated box with proper icing and refrigerated transport vans are essential to minimize product deterioration and achieve maximum shelf life as hilsa is susceptible to autolytic and bacteriological decomposition during handling, transportation and preservation. In Bangladesh, icing and salting are the common methods of hilsa preservation. Some hilsa are also preserved by freezing. Improvement of icing, salting, freezing and packaging methods and development of value-added products will help increasing the shelf life and making the products available throughout the year. It is thus essential to improve the present traditional practices of hilsa preservation and processing through product development research.	Research is needed to improve the traditional practices of icing, salting, packaging, storage, freezing etc. to maintain quality and increase shelf life of hilsa. Studies should be conducted on bacteriological and biochemical changes in fish during handling, transportation, processing and preservation which attributes to quality loss of hilsa.
	M. Marketing and Transportation		
27	Analysis, promotion and improvement of marketing system and distribution of hilsa by supply chain management.	Although hilsa has a high market demand, the fishers do not get fair price due to its complex marketing system. In the present system the boat and the net owners receive more than 60% of gross fishing income of hilsa fishing and the fishers get only 30- 40%. Under the existing system, fishers are bound to supply their catches to the money lenders called mohajons at whatever price they offer as the fishers borrow money from them for fishing crafts and gears. As soon as the fishermen land the fish in the landing station, the aratdars/mohajons take care of landing, handling, sorting, and auctioning by size	It is necessary to identify the weakness and the problems of the existing supply chain of hilsa at the procurement, storage, wholesale, transportation, distribution and retailing levels throughout the country and explore the ways and means to improve the marketing system and infrastructure. It is also necessary to

Sl.	Research Topic	Justification	Researchable area
		groups. The aratdars sell the fish through the open bidding system to the highest bidder. There are four levels of marketing system such as primary, secondary, higher secondary and final consuming market. So, hilsa passes through a long supply chain from harvesting to retailing and although price increases at every stage, the benefits neither go to the fishers nor to the consumers. So, it is necessary to develop an effective and fishers friendly supply chain involving handling, packaging, transportation, distribution, processing, whole selling, and retailing to ensure fair price for the fishers and reasonable price for the consumers.	determine the marketing costs and margins and recommend equitable profit sharing system between fishers and marketing intermediaries. Study should be conducted to recommend a suitable system so that fishers can directly participate in the auction process through organizing fishers association and to identify the sources of credit for small scale hilsa fishers.
	N. Socio-economics of Hilsa and Jatka Fishers of Bangladesh		
28	Assessment of socio-economic status of both marine and freshwater hilsa and jatka fishers.	An estimated two million people are employed in hilsa fishing. The fishery is playing a vital role in nutrition and economic development of the country. Hilsa fishers are the poorest group of people and their income from fishing is only Tk. 18,910 per hilsa season according to BFRI/ACIAR research study. Moreover, fishers are more vulnerable to social, economical and natural disasters as they live in the close vicinity of the rivers and coast. The hilsa fishers are the key actors in implementation of hilsa conservation measures. They must be involved in hilsa management planning process and their livelihood improved through adequate AIG support for better management of the resources and sustainable production. However, no complete study has been done on contemporary socio-economic conditions of the hilsa fishers in respect of livelihood, education, household status, trading system, gear and technology used in fishing, access to credit, problems and constraints associated with the open water capture fisheries etc. So, study should be undertaken to investigate the socio-economic characteristics of the hilsa fishermen, general features and characteristics of fishing technologies, boats, gears, cost of fishing, income sharing form hilsa fishing, problems in relation to hilsa fishing and marketing and the livelihood support they need for compliance to fishing ban.	Research should be conducted on socio-economic characteristics of the hilsa fishermen, general features and characteristics of boats, gears, cost of fishing, income sharing, problems in relation to hilsa fishing and marketing and assessment of livelihood support to fishers to refrain them from catching fish during period of fishing ban.

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29	Financing and credit facilities for fishing crafts and gears for hilsa fishers.	According to BFRI/ACIAR study, the skipper and the fishing crew are the poorest group having land holding size less than an acre compared to aratdars and paikers who have holding size up to 5 acres. About 60% crew fishermen have no cultivable land. About 51.32% of skipper and 22.61% fishing crew take specific loans called dadon from aratdar/mohajon to meet the cost of renting and repairing of boats and gears, and working capital to go to sea (fuel, ice, food etc) on condition to sale their entire catch through them. Out of total cost, the operating cost is about 68% for hilsa fishing. The head mazhi and crew take on an average Tk. 20,959 and Tk. 1,120 respectively per year as dadon. Two to six percent commission was collected on all fish auctioned by the aratdars. The income sharing is very low for the fishing crew which should be more equitable and at least 75% of total fishing income should be distributed among the crews as salary. Institutional credit program should be made available to the actual fishermen to meet the requirements of the fishing community.	It is essential to assess the credit needs of the hilsa fishers and their access to formal and informal credit facilities. NGOs and government should be encouraged to organize small fishermen into viable groups or cooperatives and provide them credit so that they can purchase fishing boats, gears etc.

Chapter XV

Declaration of Marine Protected Area for Conservation of Hilsa in Bangladesh

Introduction

Establishment of Marine Protected Area (MPA) is an important critical management tool for protective management of the designated marine area, especially for threatened species to provide a safe zone to keep the marine resources in natural state, protect marine biodiversity and sustain fisheries production which is vital to food security, local livelihoods and the national economy. MPA is also important to control rampant exploitation of natural resources, especially at the coast where biodiversity is at the risk of extinction.

Bangladesh has an area of 118,813 sq. km in the Bay of Bengal which is full of enchanted marine organisms of the blue waters of the ocean bed. However, due to unsustainable fishing practices, different human activities, marine pollution, unregulated shipping, increasing tourist pressure, and growing threats of climatic change, the valuable marine resources are under intense pressure. Thus, to protect the marine biodiversity and ensure safe natural propagation of the important fishery resources, it is essential to declare MPA in critical and potential habitats rich in biodiversity but is in the danger of depletion. It is crucial to protect habitats, rather than pick-up species-specific conservation measures. Only saving one species will do little, unless its home is protected. MPA will not only provide a plan to protect the species and their home, it will also deter any new development plans in the area that may be harmful for the natural resources there.

Selection Process of Nijhum Dwip Marine Protected Area

In consonance with the Convention on Biodiversity (CBD) Aichi Biodiversity Target 11, and the United Nations Sustainable Development Goal (SDG) 14, the Department of Fisheries (DoF) took an initiative to establish marine reserves in potential coastal and marine areas of Bangladesh, which are critically important for fisheries biodiversity and habitat as Marine Protected Area. WorldFish Center with technical assistance from IUCN under the USAID funded ECOFISH^{BD} Project and Wildlife Conservation Society (WCS), Bangladesh provided technical support in this initiative. Both IUCN and WCS conducted separate studies on biodiversity, ecological and socio-economic assessment of Nijhum Dwip Seascape and surrounding waters during 2015-2018 and submitted two separate proposals to DoF on establishment of MPA. Among several potential sites identified, the studies emphasized establishing Nijhum Dwip and the surrounding waters as MPA. After extensive consultations on the proposed MPA through organizing meetings and workshops by DoF with different stakeholders which include local community members, fisher organizations, government representatives, and academics and research organizations. Subsequently, the Ministry of Fisheries and Livestock (MoFL) requested IUCN, WorldFish and WCS to prepare a joint proposal in consultation with DoF incorporating the best elements of their proposals. MoFL constituted a Technical Committee on 4 December 2018, through letter no. 33.00.0000.129. 85.061.14.298 with representatives from DoF, BFRI, IUCN, WorldFish Center, Coast Guard and WCS to finalize the proposal for MoFL for declaration of the Nijhum Dwip MPA situated in the south-west estuary of the Meghna River.

Declaration of Nijhum Dwip Marine Protected Area

In the above background, the government by notification in the official gazette under Section 28 of the Marine Fisheries Ordinance, 1983, declared the Nijhum Dwip Marine Protected Area (MPA) [(SRO No. 211-Law/2019, dated 23 June 2019), (Ordinance No. XXXV of 1983), (Annexure 4)] along with the adjacent areas in the northern Bay of Bengal on 24 June 2019 spanning across an area of nearly 3,188 sq. km, as the second marine reserve of Bangladesh for the protection of spawning grounds and unobstructed movements of the national fish hilsa and various other endangered marine animals between sea and rivers, biodiversity conservation and improvements of livelihood of the coastal people who depend on these resources (Fig. 1). According to the provision of the above gazette notification, the government has imposed ban on catching of all types marine fish, crustaceans and cetaceans and use of all types of fishing crafts and gears for 65 days from May 20 to July 23 every year in the protected area. This regulation provides all stakeholders- government, law enforcers, fisherfolks, local communities and wildlife conservationists, a legal basis to protect and manage the waterways here for aquatic lives and their habitats.

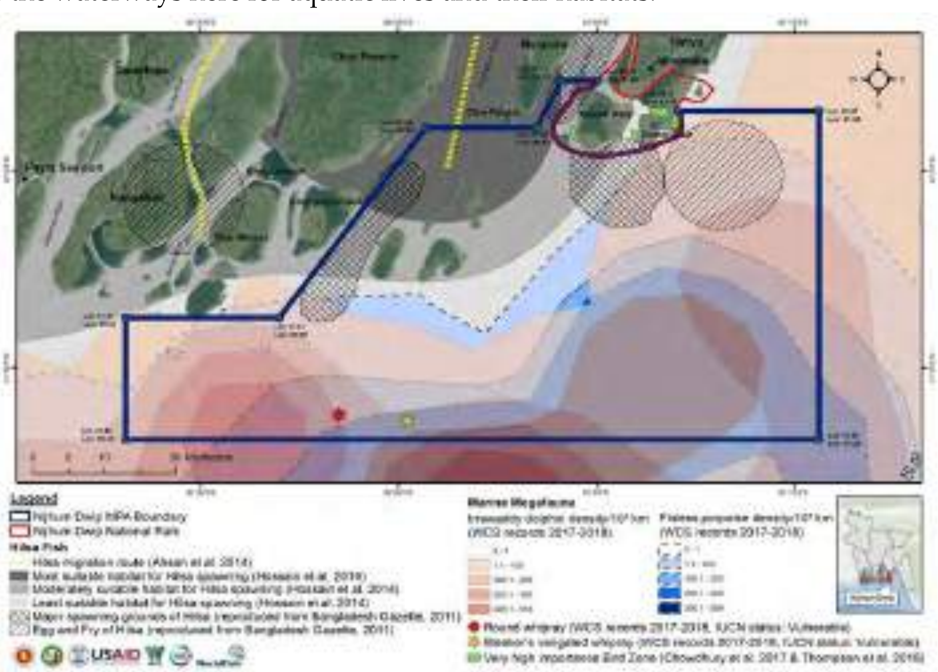

Fig. 1. Map of Nijhum Dwip MPA covering 3,188 km^2 (dark blue) and excluding Nijhum Dwip National Park (dark red), showing priority hilsa migration routes, suitability of hilsa spawning habitat, major spawning grounds and egg and fry of hilsa from the Bangladesh Gazette (2011); high density and low-density areas of Irrawaddy dolphin occurrence, and high density and low-density areas of finless porpoise occurrence (map prepared using ArcGIS 10.4) (source: WorldFish, IUCN, WCS) (Hossain *et al*., 2014).

Expected Benefits of New Marine Protected Area

The new MPA is a key area for spawning and migration of hilsa between the rivers and the sea and during this time a huge catch of hilsa takes place there resulting in over-exploitation. The establishment of MPA will provide safeguard to migration route of hilsa and control over-exploitation. The water of this area is extremely productive being at the mouth of the world's third largest river system: the Ganges/Brahmaputra/Meghna. The offshore of Nijhum Dwip is an island declared as a National Park managed by the Department of Forest, Bangladesh. The MPA spans an area that at its farthest is simply 30 km away from the shore.

Waters around the Nijhum Dwip Island are a biodiversity 'hotspot' supporting a large variety of iconic marine megafauna including globally threatened dolphins, porpoises and marine turtles. The new MPA will protect at least 15 species of globally threatened or near threatened marine wildlife species which include dolphins, whales, porpoises, sharks, rays, and marine turtles and as many as 73 fish species that occur in these waters. The population living in Nijhum Dwip is about 20,000 with about 64% of inhabitants directly or indirectly is dependent on fishing. Non-selective set bag nets and small mesh gillnets are the most common fishing gear used in the protected area.

After the declaration of the Nijhum Dwip MPA, it is expected that the government will now be able to regulate the fishing intensity that goes on in this area and thus allow time for species to thrive and rejuvenate and reduce the by-catch of hilsa significantly, which is currently a major threat. For effective regulation of the natural resources there, there is a need for an effective management plan with specific action and proper monitoring system to prevent illegal fishing or over-exploitation. Proper scientific research is needed to know the status of resources there, present level of exploitation, sustainable level of exploitation, crafts and gears used etc. to develop an appropriate management strategy and plan for implementation.

Management of New Marine Protected Area

Nijhum Dwip and its nearby areas are a busy place, owing to its proximity to the mainland and it being a tourist spot, lot of tourist launches, fishing vessels or fleet of hilsa fishermen operate there which exerts pressure on the resources and contribute to damage the environment. The Nijhum Dwip MPA is envisioned as a multiple-use MPA with distinct management zones ranging from strict reserves to community-based management areas. A participatory planning process, involving local communities, government agencies, public representatives and NGOs, will ensure producing a marine spatial plan optimizing biodiversity protection and maintaining healthy fisheries.

Aftermath of declaration of MPA, the government has brought the coastal and marine fishers who are barred from fishing in MPA for 65 days under the food assistance program to support their livelihood. In 2019, a total of 414,784 coastal and marine fishers of 42 upazilas under 12 coastal districts were given food assistance under the Vulnerable Group Feeding (VGF) program.

Declaration of First Marine Protected Area

The first MPA is the Swatch of No Ground Marine Protected Area, a submarine canyon in the Bay of Bengal known as a hotspot for cetaceans was declared by the government on October 27 in 2014. The declaration was made effective through a circular of the Ministry of Environment and Forest issued under the Wildlife (Conservation and Security) Act, 2012 spanning over 1,738 sq. km area with an average depth of 900 meters and located at south of Dublar Char. The announcement of the first MPA officially restricts fishing and other offshore commercial and any form of unauthorized activities in the area, ensuring long-term protection of marine life specifically, the endangered dolphins, whales, sharks, sea turtles, and other oceanic species live there.

Chapter XVI

Opportunities, Threats and Challenges of Hilsa Fisheries

Introduction

Hilsa, *Tenualosa ilisha* live both in freshwater and marine waters. They migrate from seawater to the freshwater for breeding. Some hilsa also stay back and permanently reside in the semi-captive freshwater environment. However, *Tenualosa toli* is a truly marine hilsa and their movement is restricted within the marine to coastal water ecosystem. The other species of the genus *Hilsa, Hilsa kelee and Hilsa kanagurta* are also coastal and marine water dwelling fish. So, their lifecycle is complex compared to other fishes and production is correlated with the aquatic environment (alteration, pollution), productivity of the ecosystem, fishing intensity, destructive fishing, scope and opportunity of reproduction, recruitment and survival of new generation, and adaptation to climate change. Bangladesh has a vast marine area and about 24,140 km waterway of 230 rivers, which have vast potential to significantly increase hilsa production. However, along with these opportunities, there are threats and challenges as well. In the above background, the opportunities, threats and challenges of hilsa fisheries in Bangladesh are briefly discussed in this chapter.

Opportunities

High Biological Productivity of Inland and Marine Waters

The biological productivity of inland, coastal and marine water bodies of Bangladesh ranged medium to high level due to adequate influx of biogenic element along with rain and flash flood water from the entire Himalayan region, high turbulence and more than 300 shiny days in a year. In the previous chapters, it was mentioned that the biological productivity of inland waters is not fully utilized by the fishes. Thus, there is enough space and food base to support more fishes in these water bodies and the production of hilsa could be increased further.

Primary Consumer in Food Chain of Aquatic Ecosystem

The hilsa mainly feed on plankton and belong to the primary category of consumers in the trophic chain of food web. The amount of energy at each trophic level decreases as it moves through an ecosystem. As little as 10 percent of the energy at any trophic level is transferred to the next level; the rest is lost largely through metabolic processes as heat. A generalized view of energy transfer is given below as per Sea Grant Institute of the University of Wisconsin (Fig. 1).

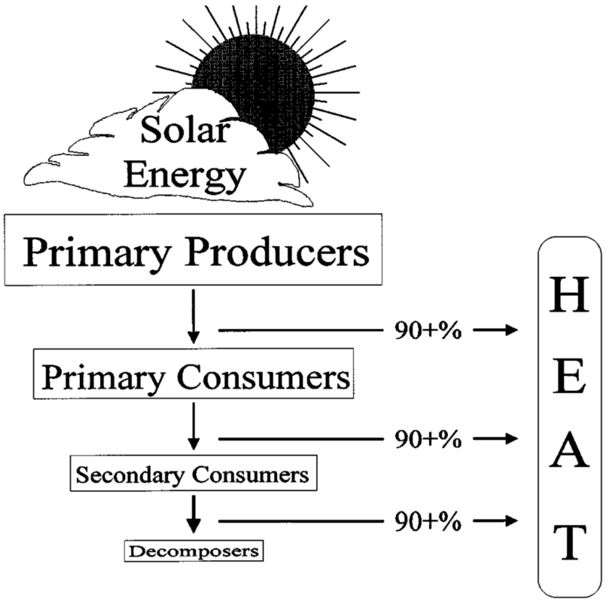

Fig. 1. Energy flow of aquatic ecosystem.

It is to be mentioned here that the more primary producers (plankton) are consumed by the secondary consumers. The primary production of the water bodies increases due to increase of biogenic elements of the aquatic ecosystem as fecal matter of the fishes.

Very Fast Swimmer and Limited Scope of Predation by Other Fish

Compared to other fishes, hilsa are very first swimmer and may cover as much as 70.8 km in a day (Pillay *et al.*, 1963) and thus, there is limited scope of becoming prey to other predator fishes. Even other predators preyed on them, nevertheless, the production of predator fishes would increase.

Moderately Faster Growth and Long-Life Span

The growth rate of hilsa is moderately faster, particularly for small size group during first and second year of their age (details in Chapter VII) and the life span is medium (about 5-6 years) and therefore, the management is easier. If the smallest size group hilsa can be protected from being captured, the production of hilsa can be increased up to 1.0 million tons by utilizing the primary production of the water bodies.

High Fecund Fish

Hilsa is relatively a high fecund compared to some other open water fishes of Bangladesh and is directly related with their age and size. Protection of brood hilsa thus could be an important management option to easily enhance the recruitment of new generation to its population. Although, the fish spawn almost round the year, there is a peak breeding season when more than 60% fish breeds. The breeding grounds of the fish are also situated in specific areas of some rivers and the coastal ecosystem of Bangladesh, which make it easier to develop and implement management measures for the fishery.

Adaptation to Climate Change

The ability of hilsa to climate change adaptation is quite high. It has wide range of adaptive ability to temperature and salinity variation. The fish live comfortably in saline, brackish and freshwater ecosystem. Due to variation of water temperature, they migrate from one place to another, where water temperature is moderate and comfortable for them.

Disease Resistant

So far, there is no instance of mortality of hilsa in the natural environment due to disease infestation, except the presence of a few parasites in their stomach. This indicates that the fish has high ability to resist any disease infestation. So, the fishery is easy and suitable for management and development.

High Price and Important Export Item

The hilsa has high demand and market price both at home and abroad and is making significant contribution in national economy, employment and export earnings. The fish is also playing an important role in economic and nutritional security for the people of Bangladesh. More investment in management and development of the fishery would result in much higher economic return.

Potential Commodity of Blue Economy

The marine water area of Bangladesh is 118,813 sq. km, which is contributing 654,687 tonnes of fish (about 5.5 tons/sq. km area). It has potential to obtain higher production. The biological productivity of the vast marine ecosystem within Bangladesh jurisdiction is not yet fully utilized by the existing fish stock. In the above context, it is anticipated that there are enough space and availability of fish food in the sea which can support a much higher hilsa population and the fish can be turned out to be the most important commodity of blue economy of Bangladesh.

Threats

Environment and Climate Change Impact

Bangladesh is one of the largest and active deltas in the world fed by the three mighty river systems, the Ganges, the Meghna and the Brahmaputra (GMB). Usually the physio-geography and ecosystem of the deltas are very unstable and constantly keep changing. The GMB river system drains a catchment area of 1,544,000 sq. km of which, only 7% is within Bangladesh. However, about 92% of the water runoff from the entire GMB system flows through the country. This runoff carries 2,179.0 million tonnes of sediment, which is being deposited into the Bay of Bengal through different rivers of the country. Three sides of Bangladesh are land locked and southern side is a funnel shaped coastline of the Bay of Bengal. Most of the area of the country is low lying and the average elevation is 10 meter above of the sea level ranging 0.0 meter to the highest 1,230.0 meter. Most area (75%) is within less than 10.0 meter and the coastline region is mostly less than 1.0 meter elevation of the Indian sea level. The average sea level rise of the country is 5.18 mm per year (Mahmood *et al.*, unpublished 1994). Thus, one-meter sea level rise would inundate about 800 sq. km area of the country.

The global surface temperature changes the climate, and thus the climate change factors would result in increase of air and water temperature. This will accelerate the process of ice melting in the polar and Himalayan region resulting increase of water volume and flow of the rivers and sea level rise. The excess water flow would also result in excess precipitation and heavy rainfall, flood and flash floods causing riverbank erosion and silt deposition in the river system and inundation of low-lying areas. Due to ice melting, water volume in the seas will increase and the saline water will be intruded in the inland waters, soil, sub-soil and underground water. The increased air temperature would result in frequent storm, cyclones and tidal surges. Some of these factors may change the ecology, biology, and physiological process of aquatic organisms and so the hilsa fishes. The hilsa is usually thought as the climate change resilient fish and being the fish lives in both fresh and saline water, is tolerant of wide range of salinity variation. However, some of the factors mentioned above may affect their migration and physiological process including changes of their habitats and food web. The summary of the potential impact of climate change factors on the hilsa fish and the fishery is given below:

Table 1. Potential impact of climate change on hilsa fishery.

Sl. No.	Climate change factors	Potential impact on environment and ecosystem	Impact on ecosystem and hilsa fishery
1	Air temperature increase	Excess ice melting resulting high precipitation, rain and flood, drought, cyclone etc.	Changes in ecosystem, siltation in river system and blockage of migratory route, high turbidity of water.
2	Water temperature increase	Relatively hot water.	Change in physiological process of hilsa, spawning and nursery grounds, migration pattern and food web.
3	Sea level rise	Salinity increase and intrusion into freshwater.	Inundation of coastal zone, changes of breeding and nursery grounds and food web of hilsa fishes.

Anthropogenic Impact

Construction of FCD, FCDI, Embankment and River Closures

Due to construction of Flood Control and Drainage (FCD) and Flood Control, Drainage and Irrigation (FCDI) structures, Embankment and River Closures, hilsa fisheries have lost from 41 rivers and river sections of the country with a loss of production of about 20,000-25,000 tonnes per year according to the survey conducted in 2003-04. Presently, the number of rivers having no hilsa and loss of production presumably has increased further.

Impact of Farakka Barrage

Due to construction of the Farakka Barrage on the Bhagirathi-Hoogly river in India, the flow of the Padma River in Bangladesh which is a lower riparian country has extremely reduced resulting in 25.8% lower production of hilsa during 1989 to 1994. Not only hilsa, the other fisheries of the river have also been seriously affected as significant portion of the upstream river almost dry out every year during the dry season is a catastrophe for the Padma river fisheries of Bangladesh.

Land Reclamation Program at the Meghna Estuary

The government of Bangladesh has a giant plan for the construction of cross-dams and barrages across Hatia, Bhola and other half-merged islands of the Meghna estuary for reclamation of land. These areas of the estuary are the major spawning grounds of hilsa in Bangladesh. It is apprehended that implementation of the Meghna estuary drainage and land reclamation project might have negative impact on the spawning and migration of hilsa, if proper mitigation measures are not taken.

Loss of Inland Waterways

Bangladesh has lost 16,400 km waterways in the last 60 years due to siltation, implementation of land reclamation projects and river encroachment and construction of illegal structures. There was 24,140 km waterway of 230 rivers in 1960, which now shrank to about only 7,600 km (The Daily Star, 24 June 2019). This has severely affected the riverine fisheries by way of obstructing the breeding migration, propagation, recruitment, grazing and growing of all types of river fishes including hilsa which was the main source of fish supply in the past.

Pollution

Pollution is a big concern for aquatic ecosystem and their resources in Bangladesh. Here people by habit, dispose all kinds of wastes into the rivers. The rapid industrialization, increased use of pesticides and other agrochemicals, urbanization and discharge of municipal waste is continuously polluting the river system. Fish kills and accumulation of toxic substances in fish have been recorded in the five industrial zones of Dhaka, Chattogram, Narayanganj, Khulna and Ghorasal due to indiscriminate dumping of all forms of industrial wastes, both solid and liquid into the rivers (Mazid, 2002). Sylhet pulp and paper mills at Chhatak, Karnaphuli paper mills at Chandragona, Fertilizer factory at Fenchuganj and Ghorasal, Hazaribag tanneries in Dhaka contributed to the depletion of fisheries resources of Surma, Karnaphuli, Kushiara, Sitalakhya, and Buriganga river, respectively (Mazid, 2002). Large-scale mortality of fish at Sitalakhya river was due to raw ammonia released from the urea fertilizer factory in Ghorasal (Ali, 1991). Besides, due to river-shore agriculture, many rivers of the country have already lost their character as river basin and either converted or being converted into wetlands. As a result, the viability of aquatic resources is seriously threatened.

Every year about 2,750 tonnes of pesticide waste (25% of the total used volume) is carried out from the agricultural land into the open water and the different river system of the country and polluting them. These pollutants are not only polluting the riverine eco-system but also the marine and coastal ecosystem (ESCAP, 1988) as well. The ESCAP report stated that, 144 industrial plants of Chattogram discharge their untreated toxic wastes directly in the Karnaphuli River and the Bay of Bengal. Most of the industrial units of Khulna city are polluting the river Rupsha and eventually the coastal areas. Moreover, the numerous rivers and their tributaries that traverse the country, carry pollutants of the whole catchment area including the upstream areas of India, Nepal and Bhutan. Therefore, the water pollution in Bangladesh will be endemic and widespread in the near future. Consequently, the important hilsa fishery of the country will be seriously affected, if appropriate protective and mitigating measures are not taken. At present, the most vulnerable area of pollution is the Buriganga, Shitalakhya, Padma, Karnaphuli, Upper Meghna and Rupsha River and their tributaries. Some of the above rivers still are the important nursery and feeding grounds of hilsa. Thus, it is very important to find out the ways and means of mitigating and controlling such pollution and save the aquatic environment from further degradation. It is also very important to urgently assess the present status and impact of pollution on fish and fisheries resources along with identification of pollution sources and both BFRI and DoF should strengthen their research, monitoring and control activities in cooperation with the relevant organizations and other stakeholders to recover and rehabilitate the degraded aquatic resources.

Fishing Pressure and Exploitation Level

Fishing pressure on hilsa is increasing day by day. Earlier, the total number of hilsa fishermen was about 0.45 million and now it has increased to 1.05 million, an increase of more than 200%. Similarly, the number of mechanized and non-mechanized boats has increased from 25,369 to 37,216 in 2001-02, and net from 106,316 to 118,353 in 2017-18. The present exploitation level of hilsa is 0.71; which was 0.60 in 2002 *i.e.* 28% more fish are now harvested from the fishery. The theoretical optimum exploitation level of any open water fishery is 0.50. Compared to the present exploitation level of 0.71, the rate exploitation of hilsa has increased by 48% above the theoretical optimum level. This is an alarming situation and there is a chance of collapsing the fishery. In order to avert this situation, it is absolutely necessary to ensure continuation of enhanced and uninterrupted recruitment process allowing maximum egg production and controlling jatka catching and reducing or maintaining static fishing pressure. In the above context, no more hilsa fishing boats and nets should be allowed for hilsa fishing either in inland or in marine waters of Bangladesh.

Challenges

Even there is huge potential for augmenting hilsa production; there are some challenges for the fishery as identified below. The challenges are mainly concerned with the environment, conservation, management and social aspects of the fishery and institutional capacity which need to be addressed on urgent basis. Some of the important issues are discussed below:

Control of Gravid Hilsa Catching during Peak Breeding Season

The main tool for increasing recruitment of new generation of hilsa to the population is the uninterrupted spawning of fishes during the peak breeding season. The government has enacted rules banning the catch and sale of hilsa in any place of Bangladesh for 22 days during peak breeding season and established strict monitoring system by deploying navy, coast guard, police forces etc. Most of the fishers obey the rules. However, some of the unscrupulous fishers still secretly catch gravid hilsa in remote areas. So, effective implementation of the rule is a challenging task for the Department of Fisheries which must be further strengthened to fully stop catching of gravid hilsa in the remote areas during the banning period.

Conservation of Jatka

Conservation of jatka is an important tool to sustain production of hilsa. The main ways for jatka protection are the creation of awareness among the fishers and strict implementation of fish conservation regulations. Due to conducting huge motivational programs by DoF and other organizations, awareness for jatka protection among the fishers, traders and other stakeholders has considerably increased (more than 90% are aware). DoF is also conducting huge drives and operation in the river in cooperation with the law enforcing agencies to apprehend the illegal fishers and seizure of their fishing equipment.

Eradication of Illegal Nets and Gears

The government has enacted required rules and regulations to prohibit and control the use of illegal nets and gears for conservation of jatka. Meanwhile, ban period for jatka catching has extended up to June starting from November of the previous year. Under the rules, production, use, barter, custody of monofilament gillnets has been banned and lunched drive to remove set bag nets and fixed engines from the fishery. However, they are still in use for catching jatka by some illegal fishers. Due to vastness and diversity of the fishery and habitats, control of illegal nets and gears for jatka fishing is the most challenging task. Recently, the marine sector is appearing as the most challenging in respect of jatka catching. The industrial fishing boats are catching jatka when they (jatka) start migrating back to the sea in the months of April-May locating the jatka shoal by echo sounder and using large size seine net and bottom trawler. The mesh size of artisanal gillnets needs to be re-fixed and implemented strictly.

Poverty Reduction of Jatka and Hilsa Fishers

The jatka fishers are the poorest group of people and most of them were living at the extreme poverty level before implementation of HFMAP in 2003-04. Since, the implementation of HFMAP, most fishers are covered with social security net program through food assistance and AIGA. Due to providing these assistances and increase of hilsa production, the socio-economic conditions of the hilsa fishers greatly improved. Even then, monthly income of the jatka fishers is about 7.3% lower than the poorest group of other rural people of Bangladesh. The main causes of jatka catching and use of illegal nets and gears is their poverty. Unless, their poverty is reduced or removed, jatka catching and use of illegal nets and gears will be hard to control effectively.

Inter Departmental Cooperation and Linkage

Management and development of hilsa fisheries are associated with different Ministries and Departments of Bangladesh such as, Ministry of Law and Justice, Ministry of Home Affairs, Ministry of Environment, Forest and Climate Change, Ministry of Water Resources, Ministry of Disaster Management and Relief, Ministry of Industries, Ministry of Local Government etc. and their sub-ordinate Departments. Coordination among the Ministries and Departments often becomes difficult in making decision and organizing cooperation for implementation of joint activities.

Capacity Building and Human Resource Development

BFRI has very limited skilled manpower and resources for conducting research on multifarious issues of hilsa fisheries. Thus, increase of research positions and development of skilled manpower and expertise is required by providing higher training at home and abroad on advanced techniques of population dynamics, molecular biology and biotechnology, biology and genetics, biological productivity and energy transfer of aquatic ecosystem, value addition and product development and socio-economics. The research facilities of the Institute are also inadequate which needs to be upgraded with procurement of modern research equipment including a seagoing research vessel, audio-visuals items and other logistic support like vehicles etc.

The organizational structure of the Hilsa Research Wing of BFRI needs to be reorganized and strengthened by creating specialized Research Divisions and Laboratories for effective research on permanent basis.

Chapter XVII

Hilsa Research by Universities and Other Organizations

Introduction

There are many universities in Bangladesh which conduct both academic as well as adaptive research on fisheries. However, a few of them are involved in hilsa research. Apart from the universities, some national and international development partners and agencies also conduct and support fisheries research including hilsa. Among the international agencies, FAO, World Bank, UNDP, UNIDO, USAID, USDA, IDRC, EU, NORAD, ACIAR/CSIRO, GEF, WorldFish Center, WCS, DFID, IUCN, Nofima etc. play important roles in fisheries research and development either alone or in partnership. Attempts were made to collect information on hilsa research from universities and other organizations. Some of the relevant research findings and information have been presented in this chapter.

Universities

Dr. M. Kamal and his research associates (Kamal *et al.*, 1994) of the Department of Fisheries Technology, Bangladesh Agricultural University (BAU) conducted studies on shelf-life and biochemical changes in hilsa during various storage conditions and reported that hilsa remain in acceptable condition up to 18 days if kept in ice in insulated box immediately after catching from the river. But fish obtained from local market when stored in ice in wooden box, had the shelf-life of 8 days only indicating that the quality of the fish reduces considerably even in ice condition during different stages of handling and transportation. Rigor plays an important role in quality changes in fish. Freshly caught fish when stored in ice and at room temperature (33°C), rigor starts in fish after 15 minutes in both conditions, but reached full rigor state (100%) in 2 hours in fish stored at 33°C and in 4 hours in fish kept in ice condition (0°C) (Haque *et al.*,1997). The rigor lasted only 16 hours in fish stored at 33°C but considerable deterioration take place during this time. On the other hand, rigor lasted for 26 hours in fish stored at 0°C without any sign of deterioration. The results indicate that the longer the duration of rigor, the longer is the freshness of fish. Low temperature also plays an important role in lengthening shelf-life of fish. The study also showed that freshly caught hilsa had a muscle pH around 7 and decreased rapidly with time in fish stored at 33°C while decrease was slow in fish stored at 0°C. The proportion of dark muscle in hilsa fish was 30.34% of the white muscle. White muscle of hilsa contains 32.0% sarcoplasmic, 57.6% myofibrillar, 9.4% alkali-soluble and 1.1% stroma protein, whereas these proteins in dark muscle were 29.9%, 58.4%, 9.8% and 1.9%, respectively.

Hilsa stored in ice were organoleptically in acceptable condition for 20 days. The bacterial load in muscles of fish stored for 4 days was 2.5×10^2 CFU/g, which gradually increased up to 1.8×10^5 CFU/g after 20 days when the fishes were still organoleptically in acceptable condition (Ahmed *et al.,* 1997).

Dr. A.K.M.A. Nowsad and his research team of the Dept. of Fisheries Technology, Bangladesh Agricultural University reviewed the status of post-harvest of the hilsa fishery of Bangladesh, particularly the handling, transportation, preservation, value-chain analysis and marketing systems of fresh hilsa and its products, and potentials for improvements (Nowsad, 2014). They also studied the nutritional quality of hilsa namely, fatty acid and amino acid profiles, macro and micro-nutrients and vitamins in both fresh hilsa muscles and in its products, reasons for hilsa being so tasty; and rancidity of lipid in order to formulate rancidity-free stable hilsa products storable at room temperature (Nowsad *et al.,* 2018 a, b, c, Nowsad, 2012).

Hilsa has the unique characteristic of being a high-protein and high-lipid fish. The omega-3 polyunsaturated fatty acids (PUFAs) of hilsa reduce the level of harmful cholesterol in human blood and increase the beneficial cholesterol and reduce the risk of myocardial infarction or stroke and cure heart disease. Hilsa was found to be rich in amino acids, minerals and lipids, especially with many essential and poly-unsaturated fatty acids (PUFA) (Nowsad *et al.*, 2014). Hilsa is little lower in ω-3 FA and higher in ω-6 FA.

The unique taste of hilsa was found to be attributed to the presence of huge quantity of mono and polyunsaturated fatty acids, *viz*. oleic, lenoleic, lenolenic, arachidonic, eicosa-pentaenoeic and docosa-hexaenoeic acids (Nowsad *et al.*, 2014). The tastiness of hilsa was found to be correlated with the sequential conversion of its muscular saturated fatty acids into mono-unsaturated fatty acids to poly-unsaturated fatty acids (Nowsad *et al.,* 2018). More it migrates towards freshwater rivers from marine environment, more its saturated fatty acids are converted to mono and then poly-unsaturated fatty acids. Hilsa was found to be tastier during pre-spawning than post-spawning or maturing stages, probably due to highest quantity of PUFAs in pre-spawning time (Nowsad *et al.*, 2012). Hilsa is a rich source of vitamins, particularly vitamin A, D, E in fatty fish, as well as thiamine, riboflavin and niacin (vitamin B_1, B_2, B_3).

Nowsad (2018) in collaboration with WorldFish (ECOFISH^{BD}) and DoF, produced ilish-soup, ilish-noodles and ilish-powder, keeping the taste and flavor of the hilsa fish intact without losing its nutritive values. In order to prepare hilsa soup and hilsa noodles, two basic products, ilish cube and ilish powder were prepared. Ilish cube was prepared by stabilizing ilish mince with cryoprotectants and filler ingredients and with various treatments of lipids and then by cooking, gelatinization, shaping and freezing at -35°C overnight. The cubes were wrapped by aluminum foil and kept frozen-stored at -20°C in a home kitchen freezer. With such a cube (1-1.5 cm^2, 10-12 g), it was possible to prepare a one serving size of noodles (70-80 g) and one serving size of soup (250 ml).

He also produced hilsa powder and hilsa cube from the whole hilsa. Fish was cooked to separate taste and flavor components, the mince was then added with stabilizers and protectants, dried in a hot-air oven, re-added stable flavor and taste components, pulverized, screened and packaged vacuum in polyethylene pouch. A 2 g pack of hilsa powder or 12 g hilsa cube is enough to prepare 1 serving size noodles or soup.

Nowsad (2019) developed various hilsa products such as minced hilsa block, hilsa snack, hilsa stock, crispy hilsa pickles, hilsa khichuri, etc. under the financial assistance from the 'Strengthening of Hilsa Research Project' of BFRI. He also developed techniques for preparation of boneless hilsa by using special tools like scissors, forceps and needles. The positions of pin-bones and other bones were detected through x-ray of fish and then the bones were removed manually in the cold room. It takes about 15 min to debone a fish. Research is in progress to reduce the deboning time to about 5 min.

The researchers at the Department of Fisheries Biology and Genetics of BAU led by Dr. M. Samsul Alam carried out a novel work on hilsa (*Tenualosa ilisha*) genome sequencing. From their research it is reported that hilsa genome has 7,680,000 nucleotides in terms of quantity. Each genome contains all the information needed to build and maintain a healthy hilsa stock. The researchers also reported that the hilsa of the Chandpur region is genetically very close to Kuakata hilsa but the marine hilsa is genetically a different group. The research will help to know the genetical distance among the hilsa of Bangladesh and other countries.

Dr. Zoarder Faruque Ahmed and his co-researchers (2016) of BAU studied the food and feeding habits of hilsa in Tetulia river in Bangladesh. They analyzed the gut contents, seasonal changes of food and feeding habits and size group relationship with their food and feeding habits. They identified 44 genera of phytoplankton and 8 genera of zooplankton from the guts of hilsa. Maximum plankton was found in the stomachs of 20-25 cm and minimum in 15-20 cm size group of hilsa. From the study, it was found that hilsa is a planktivorous fish with preference for phytoplankton to zooplankton. Among the plankton, Chlorophyceae was the most preferable food item to hilsa fish.

Zoarder and his research associates (2015) in another study determined the age and growth of hilsa from the same river. Age and growth of *T. ilisha* got progressed by direct fit length frequency data. Their predicted maximum total length was (TL) 41.88 cm for male and 52.40 cm for female (von Bertalanffy ELEFAN I). Initial asymptotic total length (TL) for both male and female was 40.42 cm and 50.61 cm, respectively. The values of Z/K were 3.362 for male and 2.676 for female. The growth coefficient (K) was obtained as 1.40 year $^{-1}$ for male and 1.00 year $^{-1}$ for female. The von Bertalanffy growth equations in terms of body weight (BW) for both male and female were $BW_{t} = 7.99.26[1\text{-}exp\{-1.40(t+0.002)\}]^3$, respectively. The length-weight relationship for both sexes were $BW=0.0101\ TL^{3.02}$ for male and $BW=0.0086\ TL^{3.08}$ for female. The value of coefficient (R^2) was estimated for both male and female were 0.969 and 0.968.

Dr. M. Shafi, Dr. M.M.A. Quddus, Dr. Niamul Naser and some other Professors of Dhaka University conducted a good number of researches on hilsa biology covering maturation, fecundity, spawning, genetics and age and growth of hilsa.

Studies from Dhaka University have found that (a) each hilsa spawns intermittently throughout the year (Shafi *et al*., 1978) or (b) two morphs spawn at different times of the year (September and February) (Quddus *et al*., 1984a) or (c) that spawning in the Meghna River takes place only in October and November (Moula *et al*., 1991). No study thus has unequivocally determined whether fish spawn more than once a year, although most earlier workers believed that separate stocks are involved in the monsoon and winter spawning events (Ghosh and Nangpal, 1970; Quddus, 1982). However, evidence from recent genetic and otolith chemistry studies (Milton and Chenery, 2001; Salini *et al*., 2001) shows that hilsa in Bangladesh belong to a single well-mixed stock, lending support to the hypothesis that they may spawn more than once a year.

However, Quddus (1982) indicated that fish can reach up to 35.5 cm at 1 year of age, and Dunn (1982) suggested that fish reach 15 cm in 6 months but take 5 years to reach 35 cm in Bangladesh. The only other study of age of *T. ilisha* by counting presumed annuli found that hilsa live for up to 5 years and reach about 14 cm in 1 year and 20 cm SL by 2 years of age (Quddus *et al*., 1984b).

Dr. Avizit Das, Department of Biochemistry and Molecular Biology, University of Dhaka and his research team in 2018, sequenced the genomic structure of *Tenualosa ilisha* from the Padma river to understand the genetic makeup and genetic distance between hilsa in the region. Illumina and PacBio sequencing platforms were used for high depth sequencing and the draft genome assembly was found to be 816 MB with N50 size of 188 kb. MAKER gene annotation tool predicted 31,254 gene models. Benchmarking Universal Single-Copy Orthologs refer 95% completeness of the assembled genome.

Dr. M. Niamul Naser, Department of Zoology, University of Dhaka conducted studies on abundance of plankton and population parameters of hilsa. Hilsa population studies indicated both recruitments overfishing and growth overfishing due to indiscriminate fishing of hilsa juveniles (jatka) and brood fish. He suggested to reduce fishing effort and rehabilitate the hilsa fishers to obtain sustainable production.

The Institute of Marine Science and Fisheries (IMSF), University of Chittagong is the first and leading academic organization of higher studies in the field of marine sciences and fisheries in Bangladesh. IMSF teachers and students carry out research throughout the onshore and offshore region of the northern Bay of Bengal and nearby islands and coastal habitat and their resources.

IMSF conducted research on bioaccumulation of organo-chlorine pesticides and trace metals residues (Cd, Cu, Pb, Zn, Ni, Cr, Mn), fecundity and seasonal variation of some trace metals in hilsa and its surrounding environment and food and feeding habits of juvenile hilsa of the Meghna river.

Dr. M. Shahadat Hossain *et al.* (2016) published a review paper documenting the past research findings on hilsa fishery to get a firsthand information on the present status and the potential gaps, necessary to comprehend for formulating an effective fishery management plan. The authors mentioned that there had been a decline in hilsa catches in the riverine system and change of fish migration routes, indiscriminate harvesting of brood and juvenile fish, and degradation of habitat. Specifically, the riverine hilsa catches peaked in the 1960s, declined thereafter, and became relatively abundant in marine waters since 1990s. Biological data indicated that hilsa goes through multiple reproductive cycles; therefore, a comprehensive understanding of reproductive biology, recruitment by various cohorts, stock abundance and habitats across the life cycle are necessary to accurately impose regulatory measures for the fishery, such as fishing ban in the spawning season in Bangladesh.

Shahadat Hossain and his coresearchers in a recent study described spatial and temporal variability of primary productivity in the Bay of Bengal (BoB) relating to hilsa fishery (Scientific Report, nature research, 10-5659, 2020). They characterized 0.131-0213 million km^2 area as the most productive with net primary production of 2000 $mgC/m^{2/}/day$, 0.373-0.861 million km^2 area as moderately productive with 500-2000 $mgC/m^2/day$, and 2.517-3.040 million km^2 area as the least productive with <500 $mgC/m^2/day$. Highest abundance of phytoplankton in the Ganges-Brahmaputra-Meghna (GMB) delta was observed during the months of August-November when 80% of total hilsa are harvested in Bangladesh annually. Variations in seasonal productivity linked with nutrients and phytoplankton abundance are important factors for predicting hilsa habitat and their migration patterns in the deltaic regions and shelf waters of BoB.

Dr. Md. Yeamin Hossain and his research associates (2018) of the Department of Fisheries, University of Rajshahi from a research in the Gajner *Beel* (Pabna, Bangladesh) reported that juvenile hilsa (*Tenualosa ilisha*) was found during monsoon and post-monsoon season (July to November). Fishers caught juvenile hilsa from this beel and sold them in the market as chapila fish (*Gudusia chapra*)**.**

They also conducted research on management policy and its implications on hilsa resources in the Padma River during 2018 and 2019. Total length (TL) of hilsa in the Padma River ranged from 15.35–34.90 cm for male and 21.90–40.20 cm for female. The body weight (BW) ranged from 33.05 to 500.0 g and 116.51-752.0 g for male and female, respectively. The *b* values for TL-BW relationship indicate positive allometric growth in both males and females throughout the year. The 31.99 -32.99 cm and 37.99-38.99 TL size group was dominant for both male and female hilsa. The size at first sexual maturity (L_m) for male and female hilsa was 23.18 cm and 23.03 cm, respectively.

Yeamin and his group studied temporal variations of length, weight and condition of *Tenualosa ilisha* from the Meghna River from July 2018 to June 2019. The value of KR ~ 1 indicates good health, >1 indicates over body weight with compare to length, whereas <1 indicates relatively poor condition of fish. The TL ranged from 15.3-57.8 cm, while the BW was 37.17–2250 g. The overall KR for *T. ilisha* was 0.65-1.66 in the Meghna River. The maximum KR was found in July while the minimum was in January. The KR was strongly correlated with BW of hilsa in the Meghna River. These findings will help to improve sustainable management of hilsa fishery in the Meghna river ecosystem and other adjacent waterbodies.

Dr. M.R.K Mondol and his research associates of University of Rajshahi conducted a research on the "Identification of different population of hilsa from two large riverine eco-systems in Bangladesh by using mitochondrial DNA (mtDNA) marker". This study was conducted to determine genetic structure of hilsa population from two large river networks for sustainable management of the fishery. A total of 35 individuals were analyzed for mtDNA control region. Among 35 individuals, 16 polymorphic sites and 14 haplotypes were detected (10 in Meghna and 8 in Padma population). These polymorphisms included 5 parsimony informative sites and 11 singleton sites. The haplotype diversity (*h*) of the analyzed population was high with observed values of 0.863 in Meghna and 0.901 in Padma population. The nucleotide diversity (P_i) within each population was very low, ranging from 0.0058±0.0039 in Padma to 0.0063±0.004 in Meghna population.

Dr. Abdus Salam Bhuyain and his research associates from the Department of Zoology, University of Rajshahi conducted a research on the estimation of the fecundity of *T. ilisha* using a total of 20 fully matured females caught from the Padma river near Godagari, Rajshahi during June to October 2002. The fecundity was found to vary from 558,700 to 1,867,000 with a mean value of 1,239,360.35 ± 405,068.97 for the size of fish 35.0-55.7 cm and weight of 600 -1,775 g.

Noakhali Science and Technology University (NSTU), established in 2006 offers degree on fisheries from the Dept. of Fisheries and Marine Science (FIMS). The newly established NSTU is in developing stage and conducting research mostly in collaboration with local and foreign organizations.

Dr. Md. Abul Hossain and his research group of NSTU through collaborative research with IUCN contributed in identification of marine protected areas (MPA) in EEZ of Bangladesh where roughly 80 spots in the Bay of Bengal (BoB) were preliminary identified and suggested to declare as MPA in three phases after validation; short term, medium term and long term basis as area of significance (AOS-12), area of interest (AOI-13), area of curiosity (AOC-21), and area in mind (AIM-34). Some of the selected areas have been declared as MPA by the government due to their importance as hilsa breeding and nursery grounds and migratory routes. The senior staff of FIMS also contributed to the formulation of Delta Plan (Fisheries, Sundarbans part) in cooperation with IUCN, where hilsa was an important component.

FIMS researchers also executed collaborative research with British Council, WorldFish Center and Stirling University (INSPIRE Project) on salinization, nutrition and livelihood development of coastal people, where intake of aquatic protein including hilsa was emphasized.

National and International Agencies

As mentioned earlier, many national and international development partners and agencies are involved in fisheries research and development in Bangladesh. Of them, BOBLME in cooperation with BFRI studied ecosystem-based resource management of the Bay of Bengal, transboundary and policy issues of the shared fisheries resources etc. International Development Research Center (IDRC), Canada provided technical and financial support for conducting first systematic research by BFRI for the development and management of hilsa resources in Bangladesh. Under this project, BFRI identified the spawning and nursery grounds of hilsa for the first time in Bangladesh. Among this study, food and feeding habit, reproductive biology (maturity, fecundity, sex ratio, GSI), population structure and stock discrimination, exploitation level, gear selectivity, crafts and gears, quantification of jatka catch in Chandpur region by monofilament gillnets are of paramount importance. Based on these research findings, first Hilsa Fisheries Management Action Plan (HFMAP) was formulated for hilsa fisheries development. Similarly, Australian Center for International Agricultural Research (ACIAR) and CSIRO in cooperation with BFRI conducted another comprehensive research on hilsa fisheries which included genetical characterization, migration, gear selectivity, stock assessment and population dynamics, socio-economics etc. This project also formulated another hilsa fisheries management action plan in 2001, which was handed over to Fourth Fisheries Project of DoF for further study and updating.

The WorldFish Center in cooperation with the DoF and BFRI implemented the ECOFISH^{BD} project for conservation of hilsa and livelihood development of the fishers. Under the project, gillnet selectivity of hilsa in the Meghna river, impacts of sanctuary on the abundance and biodiversity of fish, on-board breeding trial of hilsa etc. were determined by BFRI. Details are provided in chapter VIII.

International Institute for Environment and Development (IIED, UK) and Bangladesh Centre for Advanced Studies (BCAS) have studied power, profits and payment services and economic incentives for sustainable hilsa fishing in Bangladesh. In the study, it was reported that the government offers a small in-kind Payment for Ecosystem Service (PES) to the hilsa fishers in the form of rice, which is good but does not compensate for the loss of total income and household protein consumption during banning period. This study might be useful for policy makers to design better strategies to re-govern markets in more inclusive ways to achieve Sustainable Development Goals (SDGs).

Chapter XVIII

BFRI Publications on Hilsa Fisheries

BFRI always gives special attention to publication and documentation of aquaculture and fisheries management technologies; policies, plans and practices for their wider adoption. It regularly publishes research based scientific articles in various national and international journals. In addition, it also publishes scientific books for national and international scientific communities. Training manuals, booklets, leaflets, folders, posters etc. are regularly published in Bengali to sensitize and dissemination of knowledge and information among the people to create awareness and motivate them for responsible aquaculture and fisheries management. Besides technology-based publications, the institute also publishes policy guidelines, research reports and workshop/seminar proceedings. Fisheries Newsletter published quarterly and Bangladesh Journal of Fisheries Research published twice a year.

BFRI also produces documentaries casting the popular actors on important specific topics like brood stock management, inbreeding depression, harmful effect of using current jal (monofilament net) for catching jatka (hilsa juveniles) and other emergent issues of national interest and telecast them for public awareness. A list of important publications of the Institute related to Hilsa Fisheries Development and Management is provided in this chapter.

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মোঃ শহীল্লাহ মিয়া ও ড. জি.সি. হালদার, ১৯৯৫। ইলিশ মাছ উৎপাদন বৃদ্ধির জন্য জাটকা নিধন রোধের গুরুত্ব (Importance of jatka catching ban to increase hilsa production), মৎস্য সম্পদ উন্নয়ন প্রযুক্তি (মৎস্য পক্ষ সংকলন, ১৯৯৫), পৃ ৭৮-৮১.

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Annexures

1. Recommendations of the Final Workshop on Hilsa Fisheries Management Plan for Bangladesh

A workshop on Hisla Fisheries Management Plan for Bangladesh, jointly organized by the Bangladesh Fisheries Research Institute, Bangladesh and the ACIAR/CSIRO, Australia was held on 16 January, Tuesday, 2001 in the conference room of IDB Bhaban, Sher-e-Bangla Nagar, Dhaka.

Mr. A.S.M. Abdur Rob, Hon'ble Minister, Ministry of Fisheries and Livestock, Govt. of the Peoples' Republic of Bangladesh graced the inaugural session as the Chief Guest. Professor M. A. Quddus, Hon'ble State Minister for Fisheries and Livestock was also present in the inaugural session as a Special Guest. Dr. Z. Karim, Secretary of the Ministry presided over the inaugural and the concluding sessions.

There were two technical sessions in the workshop. Technical Session I dealt with current status of hilsa management and in the Technical Session II, group discussion was held on the proposed Hilsa Fisheries Management Plan that was presented by five different groups formed by the participants of the workshop. Technical Session I and II were presided over by Mr. A. K. Ataur Rahman, former Director General, DoF and Dr. M. A. Mazid, Director General, BFRI, respectively.

Recommendations of Different Sessions

Inaugural Session

1. The proposed Hilsa Fisheries Management Plan (HFMP) be termed as Hilsa Fisheries Management Action Plan (HFMAP).
2. Technological advancement so for made should be described in detail and the proposed works to be done should similarly be phased out with time bound schedule.
3. The implementation schedule should be phased up with time frame.
4. The resources (financial and manpower) needed for its implementation should be mentioned.
5. Hilsa and jatka fishermen be rehabilitated during ban season by FFWP, VGF cards to save berried hilsa and jatka (hilsa juvenile).
6. Fishermen's community be established, and arrangements made for rehabilitation, life insurance, loan for aquaculture and other alternate income generating activities be made.
7. Appropriate actions are to be framed out to check the illegal activities of money lender, craft and gear owners, mono-filament net producers and traders.
8. Hilsa and jatka sanctuaries be marked with floating red buoys and lights for easy demarcation.
9. Environmental aspects of habitat deterioration and degradation be further studied.
10. A social movement with strong patriotic mission be organized with the participation of all to conserve hilsa fisheries.
11. Criminal Acts be changed/improved to save the renewable resources like hilsa.
12. An appropriate project be submitted to the government for the implementation of the action plan to save the hilsa fisheries.
13 Another workshop should be arranged in the coming February with concerned Fisheries people (MoFL, DoF, BFRI, Universities, and NGOs), Ministry of Commerce and Industries, MP, DC, SP, Fishers, Fishermen's Association, Traders; Money Lenders, Crafts and Gear lenders, Poachers, etc.

14 Still there are many mysteries about hilsa biology on which more research information is needed.

15 Separate Hilsa Fisheries Action Plan is needed like Shrimp Fisheries Policy.

16 Until a HFMAP is framed out, ACIAR/CSIRO collaboration be continued for more strategic works on biology and management of hlsa.

Technical Session I

1. Hilsa is a single stock covering regional water bodies; hence a regional management policy for their sustainable production is needed.
2. Decrease of hilsa fecundity should be studied further.
3. For optimization in mesh size, gill net selectivity needs further study.
4. Attach priority to research on hilsa ecosystem analysis.
5. Develop analytical capability related to hilsa fisheries of various GO and NGO agencies.
6. Instead of terming Hilsa Fishery Management Policy, the prepared plan should be re-titled as Hilsa Fishery Management Action Plan (HFMAP).

Technical Session II

A total of five separate groups were formed to discuss the various burning issues relating to formulation of the proposed Hilsa Fishery Management Action Plan (HFMAP). Team Leader/Facilitator, members and subject area of discussions of various groups are shown at the end of the recommendations.

Subject-wise various recommendations put forward after threadbare discussions by different groups are summarized below:

Group - 1

Importance and Objectives of the Plan

1. National Fisheries policy covers the management and conservation of hilsa fisheries. Implementation strategies and plan of policy should be formulated.
2. Fish Acts cover conservation of jatka, ban of mono-filament gill nets (current jal), etc. But these are not properly implemented due to lack of proper planning and logistic supports. Necessary measures should be undertaken in this regard.
3. Management capacity of the implementing agencies should be developed.
4. Participation of the hilsa fisher-folk and the traders in management system including the local government representatives is necessary.
5. Loss of hilsa habitats and environmental degradation should be prevented.
6. Improvement of socio-economic conditions of hilsa fishers is necessary.
7. Continued research on hilsa fisheries management for updating data base and information is necessary.
8. Establishment of Regional Management Plan, as hilsa is being shared by neighboring countries is important.

Group - 2

Implementation of Fish Act (Hilsa)

1. The existing Fish Act should be revised and hilsa ban period should be extended from September to next May.

Declaration of Hilsa Sanctuary

1. For the coastal belt, the duration of the sanctuary should be from mid-September to January and for the riverine areas, the duration should be from February to May.

Measures for Regulation of Overexploitation

1. Selective fishing with selective gears should be introduced.
2. Alternate job/opportunities should be created.
3. Fisher-folk/communities should be rehabilitated with the introduction of food for works program during the no-fishing/banned period.
4. Awareness is to be created and the general people/fisher-folk should be motivated through NGOs.

Regulation of Gill Net's Mesh Size

1. Instead of banning nets of 4.5 cm mesh size, nets having 9.5 cm mesh should be recommended.
2. Import, production and marketing of all kinds of mono-filament twines and nets should be banned.

Protection of Hilsa Habitat and Environment

1. Indiscriminate discharge of different wastes, chemicals and industrial effluents into the aquatic habitat must be regulated.
2. Natural desiltation phenomenon should be adopted to cease siltation and improve water flow of the rivers and their tributaries.
3. Wherever possible dredging should be done to improve the river flow.
4. Fishing should be controlled and regulated instead of open and easy access.

Registration and Licensing of Hilsa Fishing Boats and Gears

1. All kinds of motorized boats and gears should be registered and should have license.

Identification and Rehabilitation of Jatka Catchers

1. A list of actual commercial and subsistence fishermen should be prepared.
2. Appropriate arrangements should be made for training, motivation and mobilization (group formation, savings, community-based management and marketing) of the fisher-folk.
3. A combined Mobile Implementation Team (MIT) should be formed under the leadership of DFO with the representatives from administration and security forces such as DC, SP, UNO, Coastguard/Navy supported by Magistrate and legal advisors.
4. Necessary and appropriate logistic support should be provided, and the MIT should be well equipped.
5. Arrangement should be made for mass motivation and awareness development of target fisher-folk.
6. Area of jatka zones should be extended including the districts of Rajbari, Faridpur, Manikganj and Shariatpur.

Group 3

Action Plan

1. Government should seriously implement the Fish Act, which has already been amended to prevent the indiscriminate killing of jatka under 23.0 cm.
2. Government should expedite implementation of the proposed rules which have been pronounced to prevent manufacture, import, marketing, carrying, transporting or possessing of mono-filament gill net (current jal) under 9.5 cm mesh size.
3. Government should at least ban fishing of mature and berried hilsa from the spawning grounds during the peak spawning season (September to October, Aswin-Kartik).
4. Government should undertake plan to uplift the socio-economic conditions of the jatka catchers and rehabilitate them.
5. Government should undertake necessary promotional and provocational activities to create public awareness and responsibility of the people in conservation of the fishery.
6. MoFL in collaboration with other Ministries and agencies should undertake appropriate measures to prevent habitat destruction, pollution and maintain optimum environmental condition as far as possible.
7. A separate Hilsa Fisheries Research Institute should be established.
8. The DoF should be strengthened to effectively implement fishery conservation rules and regulations.

Organization and Operating System for Implementation of Action Plan

1. A Multidiscipline National Council (NC)/National Advisory Committee (NAC) for Hilsa Fisheries Management Program should be set up chaired by the Minister, Ministry of Fisheries and Livestock (MoFL). The NC/NAC would serve as the focal point of national hilsa program.
2. Department of Fisheries (DoF) will be the lead organization and implement the national Hilsa Fisheries Management Action Plan (HFMAP).
3. A national HFMAP should be developed in order to co-ordinate all HFM activities in the country.
4. Within DoF, the organizational set up for implementing the program should have HFM co-ordinators at various levels (National, Divisional, District and Upazila). A team of hilsa fishery management to be formed and should consist with the trained DoF staff and fisher-folk at the grass-root level.
5. The field level staff will work for the HFMAP. They will train the fisher-folk, fish traders, form the fishermen/trader's association and will follow-up all the related activities for the promotion, expansion and sustainability of the program.

Funding

The international donor agencies/countries may also be requested for funding. The GO/NGOs should be involved for the socio-economic development of the fisher-folks.

Human Resources Development

The GoB will give importance and priorities to the development of human resources involved in HFMAP. Training and orientation about the fishery should comprise the major elements of human resources development initiatives and will include:

1. Training of
   - Fisher-folk, fish trasders, students and teachers
   - Field staff from Upazila level to Divisional level of the MoFL, MoA, MoFE, and coastguards (defense)
   - Field staff of NGOs working in rural areas
   - Concerned government staff
   - Policy makers
   - Parliament representatives
   - Students and faculty members of Agricultural Universities, Colleges and Fisheries Training and extension institutions
   - The general public
2. All efforts should be made to provide season long HFM training to as many fishers/traders as possible. In the first stage, at least 20% of the fisher family and ultimately one in each fisher family should be trained. This should be a continuous activity and the government will ensure availability of necessary manpower and funds.
3. All Upazila Fisheries Officers and Fisheries Extension Officers should receive training in HFMAP.
4. In line with the development of HFMAP trainers from the DoF, as many fishers/traders' trainers as possible should be produced through season-long apprenticeship training and through training of trainer's courses.
5. Facilities for national level training and for supporting field training in upazila and districts should be developed.
6. Provide opportunities to the trainers, policy makers and planners to visit other countries where the program like HFMAP are widely practiced and supported by the governments.

Group 4

Biology and Genetics

1. Study to be continued to identify reasons for change in migration.
2. Monitoring and investigation of spawning and nursery grounds to be studied/continued.
3. Study is to be conducted on size, age and rate of migration.
4. Reproductive physiological study is to be initiated.
5. Population genetics study should further be continued for confirmation of single species (stock) fishery by molecular marker.
6. Further research is to be continued for adaptation of hilsa in captive water including seed production.

Management

1. Regional collaborative research program is to be undertaken on hilsa fishery.
2. Study is to be conducted for identifying optimum mesh size of all types of gears used for hilsa fishing.
3. Study is to be conducted on impact of proposed jatka sanctuary on hilsa production.
4. Environmental influence on hilsa fishery is to be studied.
5. After completion of the present project, further research should be continued.
6. Studies of the 4th fisheries project should be included in the HFMAP under Global Environment Facility (GEF).

Catch monitoring

1. Catch monitoring using remote sensing or by any modern technique is to be initiated including existing technique.

Hilsa Habitat and Environment

1. Study is to be undertaken on impacts of already constructed and proposed dams.
2. Effect of river pollution on hilsa population need to be investigated.

Socio-economic Development

1. Assessment of socio-economic status of hilsa fisher-folk both marine and freshwater is needed.
2. Estimation of number of jatka and hilsa fisher-folk (both freshwater and marine) are needed.
3. Assessment of impacts of different jalmohal management system (Co-operative, Auction System, New Fisheries Management Policy and Community Based Fisheries Management) on the socio-economic status of hilsa fisher-folk is necessary.
4. Improvement of hilsa transportation facilities.
5. Quality restoration study during transportation and preservation.
6. Improvement of landing facilities.
7. Elimination of middlemen from the hilsa chain.
8. Easy loan facilities for small-scale traders.
9. Rehabilitation of hilsa fishers during off period.
10. Improvement of ice plant facilities, ice qualities and icing technique.
11. Improvement of salting technique of hilsa.
12. Product development by canning and smoking.

Group 5

Strategies

1. Formulated HFMAP for Bangladesh should be approved and implemented.
2. Review existing Fish Acts, Rules and Regulations incorporating HFMAP, if necessary.
3. Concerned Ministries, associated departments, related NGOs and fisher-folk should work together with the Ministry of Fisheries and Livestock to implement Fish Acts.
4. Spawning and nursery grounds of hilsa, which are to be declared as sanctuaries of jatka, should be protected.
5. The exploitation level (E) of hilsa should be maintained to the optimum level of 0.50 by regulating gill net's mesh size and fishing boats.
6. Selective fishing by mesh size regulation (mesh size of 9-10 cm) should be adopted for hilsa fishing in order to maintain their sustainable yield (Y/R).
7. Instead of open access fisheries, widely accepted jalmohal management system should be adopted. The user right of the jalmohals should be given to the fishers under jalmohal management system.
8. Fishers, traders and public awareness should be created through wide publicity in mass media- newspapers, radio, television etc. about the importance of the hilsa fishery and the responsibility of the people.
9. Intensive jatka fishers and fish traders training programs should be conducted.

10. Proper study should be undertaken to assess the impact of sanctuaries on hilsa production.
11. A national HFMAP should be developed in order to co-ordinate all HFMAP activities in the country. The national HFMAP should have the following organization tree. A sketch of the tentative organization tree for the implementation of HFMAP is given below:

Organization Tree and Responsibilities

i. National Committee

Representatives from the Ministry of land and fishermen/fish traders should be included as Member.

Responsibilities: Planning, Monitoring and Evaluation of Fish Act, HFMAP Implementation and coordination.

ii. Divisional Committee - Should be omitted.

iii. District Committee

Responsibilities: This part should only be added.

Implement Fish Act and HFMAP through the upazilas.

iv. **Upazila Committee**

Local Member of the Parliament or Nominated person of the Ministry should act as Adviser.

Responsibilities: Followings are to be included:

Create awareness through meeting, seminars, rally, etc.

Preparation and submission of report to the District committee.

Training and awareness creation.

Monitor and supervise the Mohalla/Community based committee activities.

v. **Mohalla/Community Based Committee**

Responsibilities: This part should only be added:

Fish Act and HFMAP implementation.

Rehabilitation work implementation.

The Hilsa Zones

In the proposed hilsa zones, some districts such as Khulna, Dhaka, Faridpur, Shriatpur are not included. These districts may be included in the Hilsa Zones as they are important in respect of jatka fishing and selling.

Concluding Session

i. Instead of hilsa fisheries management draft policy, hilsa fisheries management strategic plan should be prepared and implemented.
ii. The plan should be prepared within a month and submitted to the Ministry.
iii. The draft policy should be primarily adopted.
iv. The resources needed for implementation (type of project and financial resources including manpower) should be included in the plan.

2. S.R.O. No. 83-Law/2014, dated, 22 May 2014 on Establishment of Hilsa Sanctuaries

(English translated version of SRO from Bangla, and in case of any confusion, Bangla version shall prevail)

Government of the People's Republic of Bangladesh
Ministry of Fisheries and Livestock
Section-Fisheries 3
Notification
Date: 22 May 2014

S.R.O. No. 83-Law/2014. - In exercise of power conferred by section 3 of the Protection and Conservation of Fish Act, 1950 (E.B. Act XVIII of 1950), hereafter referred to as the said Act, the Government for the purpose of further amendment of the Protection and Conservation of Fish Rules, 1985, and in pursuance of provision of sub-section (5) of section 3 of the said Act, hereby published the proposed amendment for information of all concerned, as-

Rule 13 of the said Rules will be substituted by rule 13 as follows:

"13. **Catch, carry, transport, offer, sell, barter, expose or possess of all kinds of fishes prohibited in certain period areas-** (1) Notwithstanding anything contained in these rules, no person shall catch of cause to be caught-

a. all kinds of fishes in the Hilsa fish sanctuary area mentioned in colum (2) during the period mentioned in colum (4) of the Table below: -

TABLE

SI. No.	Hilsa Fish Sanctuary Area	Boundary Points	Period
1	2	3	4
1.	From Shatnol of Chandpur to Char Alexander of Laxmipur (100 km stretch of lower Meghna River).	1. Shatnol Point (90˚37.12'E and 23˚28.19'N) and 2. Char Alexander Point (90˚49.30'E and 22˚40.92'N).	From March to April each year.
2.	Char Ilisha to Char Pial of Bhola district (90 km stretch of Shahbazpur channel, a tributary of Meghna River.	1. Char Ilisha Mosque Point (90˚38.85'E and 22˚47.30'N) and 2. Char Pial Point (90˚44.81'E and 22˚5.10'N).	From March to April each year.
3.	Bheduria of Bhola district to Char Rustam of Patuakhali (100 km stretch of Tetulia River).	1. Bheduria Ferryghat Mosque Point (90˚33.89'E and 22˚42.31'N) and 2. Mandolbazar (Char Rustam (90˚31.40'E and 21˚56.32'N).	From March to April each year.
4.	Whole 40 km stretch of Andhermanik River in Kalapara Upazila of Patuakhali.	1. Golbunia Point (90˚19.20'E and 21˚57.68'N) and 2. Confluence of Bay of Bengal and Andhermanik River (90˚3.91'E and 21˚49.43'N).	From November to January each year.

SI. No.	Hilsa Fish Sanctuary Area	Boundary Points	Period
1	2	3	4
5.	20 km stretch of Lower Padma River between Naria-Bhedorganj Upazila of Shariatpur in the north and Matlab Upazila of Chandpur and Bhedorganj Upazila of Shariatpur in the south.	1. Kachikata Point of Bhedorganj Upazila of Shariatpur district in the northeast (90˚32.6'E and 23˚19.8'N). 2. Bhomkara Point of Naria Upazila of Shariatpur district in the northwest (90˚28.8'E and 23˚18.4' N). 3. Beparipara Point of Matlab Upazila of Chandpur district in the southeast (90˚37.7'E and 23˚15.9'N) and 4. Tarabunia Point of Bhedorganj Upazila of Shariatpur district in the southwest (90˚35.1'E and 23˚13.5'N).	From March to April each year.

b) all kinds of fishes in the Hilsa Spawning Grounds mentioned in colum (2) and in the rivers and estuaries of the districts Chandpur, Laxmipur, Noakhali, Feni, Chittagong, Cox's Bazar, Bhola, Patuakhali, Barishal, Barguna, Pirojpur, Jhalkathi, Bagerhat and Shariatpur during the peak spawning period of Hilsa as mentioned in colum (3) of the Table below:-

TABLE

Sl. No.	Hilsa Spawning Ground Boundary Points	Peak Spawning Period
1.	Mayani Point, Mirsarai, Chittagong in the northeast (91˚32.15'E and 22˚42.59'N).	3 (three) days before and 7 (seven) days after the full moon, including the day of full moon, that is, total 11 (eleven) days of the moon which will be first appeared in the Bengali month of *Ashwin* each year.
2.	Paschim Syed Awlia Point, Tajmuddin, Bhola in the northwest (90˚40.58'E and 22˚31.16'N).	
3.	North Kutubdia Point, Kutubdia, Cox's Bazar in the southeast (90˚52.51'E and 21˚55.19'N).	
4.	Lata Chapali Point, Kalapara, Patuakhali in the southeast (90˚12.59'E and 21˚47.56'N).	

2) No person shall catch, carry, transport, offer, sell, barter, expose or possess Hilsa fish only throughout the country during the peak spawning period as mentioned in the Table of sub-rule (1) (b).

3) Any fish caught, and gears used for fishing in contravention of sub-rule (1) and (2) may be seized and forfeited.

4) Every year Ministry of Fisheries and Livestock shall fix up the corresponding date in accordance with Gregorian calendar that relates to peak spawning period as mentioned in the table of sub-rule (1) (b) and will issue a notification in the official gazette to that effect."

Shelina Afroza PhD
Secretary in-charge

3. S.R.O. No. 107-Law/2018, dated, 12 April 2018 on Establishment of Hilsa Sanctuaries

(English translated version of SRO from Bangla, and in case of any confusion, Bangla version shall prevail)

Government of the People's Republic of Bangladesh
Ministry of Fisheries and Livestock
Section-Fisheries 2
Notification
Date: 12 April 2018

S.R.O. No. 107-Law/2018. -In exercise of power conferred by section 3 of the Protection and Conservation of Fish Act, 1950 (E.B. Act XVIII of 1950), the Government for the purpose of further amendment of the Protection and Conservation of Fish Rules, 1985, and in pursuance of provision of sub-section (5) of section 3 of the said Act, hereby published the proposed amendment for information of all concerned, as-

After Sl. No. 5 of colum (1) of TABLE of clause (a) of sub-rule (1) of rule 13 of the said Rules, following new Sl. No. 6 and against in its colum (2), (3) and (4), following entries shall be added as: -

6.	Total Length of 82 km between three different river point of Barisal district. Three points are: a. Total 13.70 km stretch of the Kalabadar River between Habinagar point, Barisal Sadar Upazila and Bamnar Char point, Mehendiganj Upazila of Barisal.	1. Habinagar Point: 22˚45'1.08''N and 90˚25'10.2′ E. 2. Bamnar Char Point: 22˚49'22.44''N and 90˚28'5.16'' E.	From March to April each year.
	b. Total 8.81 km stretch of the Gajaria River between Bamnar Char point of Mehendiganj Upazila and Hizla Launch Ghat point, Hizla Upazila of Barisal.	1. Bamnar Char point: 22.8229˚N and 90.468˚E. 2. Hizla Launch Ghat Point: 22.9067˚N and 90.5308˚E.	From March to April each year.
	c. Total 59.51 km stretch of the Meghna River between Hizla Launch Ghat point of Hizla Upazila and Dashkin-Paschim Jangalia point, Mehendiganj Upazila of Barisal.	1. Hizla Launch Ghat: 22.9067˚N and 90.5308˚E. 2. Dashkin-Paschim Jangalia point:22.7333˚N and 90.4917˚E.	

If anyone has any objection or advice about the proposed amendment, concerned person, organization and association are requested to send to the undersigned in writing in not more than two months of publication of this notification.

Md. Raisul Alam Mondal
Secretary in-charge

4. S.R.O. No. 211-Law/2019, dated, 22 June 2019 on Establishment of Nijhum Dwip Marine Reserves Area

(English translated version of SRO from Bangla, and in case of any confusion, Bangla version shall prevail)

Government of the People's Republic of Bangladesh
Ministry of Fisheries and Livestock
Notification
Date: 22 June 2019

S.R.O. No. 211-Law/2019. - In exercise of power conferred by section 28 of the Marine Fisheries Ordinance, 1983 (Ordinance No. XXXV of 1983), the Government hereby declared the area mentioned in the schedule below inside Bangladesh Fisheries Waters as 'Nijhum Dwip Marine Reserves Area' as: -

Schedule

Angular Point	Distance (km) and Direction from Reference Points	Geographic Location (boundary) GPS Coordinates	Total Area
1	Northwest of Marine Reserve/MPA; 23.5 km southeast from Payra Port	21°48′49.06″ N, 90°24′17.29″ E	3,188 sq. km.
2	North of Marine Reserve/MPA; 20.0 km east from the Angular Point No. 1; 38.3 km southeast from Payra Port	21°48′49.06″ N, 90°35′56.72″ E	
3	Northeast from Angular Point No. 2; 14.7 km southeast from Charfasson Sadar	22°3′14.21″ N, 90°47′2.44″ E	
4	14.5 km east from Angular Point No. 3; 22.9 km southwest from Manpura	22°3′14.21″ N, 90°55′27.51″ E	
5	7.4 km northeast from Angular Point No. 4; 15.9 km southeast from Manpura	22°6′48.57″ N, 90°57′21.98″ E	
6	4.8 km east from Angular Point No. 5; 16.2 km southeast from Manpura	22°6′48.78″ N, 91°0′7.23″ E	
7	West-south-east boundary/surrounding sides of Nijhum Dwip National Park from Angular Point No. 6 (11.2 km southeast) and 6.9 km southeast from Jahajmara	22°4′27.87″ N, 91°6′9.97″ E	
8	Northeastern most corner of Marine Reserve/MPA is 18.4 km east from Angular Point 7; 22.9 km southeast of Jahajmara	22°4′27.87″ N, 91°16′53.48″ E	
9	Southeastern most corner of Marine Reserve/MPA is 46 km south from Angular Point No. 8; 56.4 km southeast of Jahajmara	21°39′32.55″ N, 91°16′53.48″ E	
10	Southwestern most corner of Marine Reserve/MPA; 91 km west from Angular Point No. 9; 39 km southeast from Payra Port	21°39′32.55″ N, 90°24′17.29″ E	

By order of the President
S.M. Tarik
Deputy Secretary

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