The biophysical assessments of the hilsa fish (*Tenualosa ilisha*) habitat in the lower Meghna, Bangladesh

Kaisir Mohammad Moinul Hasan, Md Abdul Wahab,
Zoarder Faruque Ahmed, Essam Yassin Mohammed

Working Paper
October 2015

Fish

Keywords:
Ecological assessment, hilsa
Tenualosa ilisha, phytoplankton and
zooplankton

About the author

Kaisir Mohammad Moinul Hasan, Md Abdul Wahab, Zoarder Faruque Ahmed

Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

Essam Yassin Mohammed, Senior Researcher, International Institute for Environment and Development, 80-86 Gray's Inn Road, London, WC1X 8NH, UK

Acknowledgements

The authors acknowledge the financial support of Defra (UK) for funding the Darwin Hilsa project through a joint consortium of IIED, London, BAU and BCAS. Special thanks are given to the hilsa research team of BCAS and BAU for their active support for implementation of the research work. Cordial appreciation is due to Syed Arif Azad, Director General, Department of Fisheries, Bangladesh, for his continuous inspiration, sincere interest and support towards the implementation of the research activities. We are grateful to the anonymous referees for their insightful suggestions on the manuscript. Finally, the great enthusiasm and sincere support from the officials of the Department of Fisheries at the field level, as well as at headquarters, are gratefully recognised. This research and publication was funded by Defra's Darwin Initiative; however, the views expressed do not necessarily reflect the views of the UK government.

Produced by IIED's Sustainable Markets Group

The Sustainable Markets Group works for a vision of markets that promotes sustainable development at local and global levels, rather than undermining it. The group brings together IIED's work on the green economy, environmental economics, small and informal enterprise, and energy and extractive industries.

Partner Organisation

Established in 1961 Bangladesh Agricultural University (BAU) is the premier seat of higher agricultural education and research in the country. The missions of BAU have been to develop the art and science of agriculture for the wellbeing of mankind, and to educate agriculturists of high standards of scientific, managerial and professional competence in harmony with the environment, and to share knowledge and skills with world partners.

The Bangladesh Centre for Advanced Studies (BCAS) is an independent, non-profit, non-government, policy, research and implementation institute working on Sustainable Development (SD) at local, national, regional and global levels. It was established in 1986 and has grown to become a leading research institute in the non-government sector in Bangladesh and South Asia.

Published by IIED, October 2015

Kaisir Mohammad Moinul Hasan, Md Abdul Wahab, Zoarder Faruque Ahmed, Essam Yassin Mohammed. 2015. *The biophysical assessments of the hilsa fish (*Tenualosa ilisha*) habitat in the lower Meghna, Bangladesh.* IIED Working Paper. IIED, London.

http://pubs.iied.org/16605IIED

ISBN 978-1-78431-265-7

Printed on recycled paper with vegetable-based inks.

International Institute for Environment and Development
80-86 Gray's Inn Road, London WC1X 8NH, UK
Tel: +44 (0)20 3463 7399
Fax: +44 (0)20 3514 9055
email: info@iied.org
www.iied.org

@iied
www.facebook.com/theIIED

Download more publications at www.iied.org/pubs

The common Indian shad 'hilsa' (*Tenualosa ilisha*) is the most important anadromous fish species of Bangladesh that migrates through the Padma-Meghna River systems. A study was carried out between January and December 2014 to assess the physical, chemical, and biological parameters of the habitat of the hilsa fishery areas. While the parameters were found to be at 'acceptable' levels, some measures are needed to improve the quality of water to ensure successful migration and reproduction of the hilsa fish. Efforts must be made to minimize, or where possible, eliminate non-fishing related stresses such as siltation and pollution and integrate them into the overall hilsa fisheries management action plan.

Contents

Summary

The common Indian shad 'hilsa' (*Tenualosa ilisha*) is the most important anadromous fish species of Bangladesh that migrates through the Padma-Meghna River systems. A study was carried out to assess the physical, chemical and biological parameters of the habitat of the hilsa fish. The study was carried out in four sites (Site 1: Meghna River in Chandpur; Site 2: Meghana River in Daulatkhan, Bhola; Site 3: Tetulia River near Lalmohon; and Site 4: Andhermanik River, Kalapara, Patuakhali District) from January to December 2014. Higher total dissolved solids (TDS), conductivity, salinity, NH_3-N, and lower chlorophyll-*a* were found in Andhermanik River compared to the other rivers. The downstream of Meghna River at the Daulatkhan site contained more suspended solids (TSS), than the upstream Meghna River in Chandpur. Comparatively higher water current velocities and water depths were recorded from the sampling points in the Meghna river systems than the other two rivers. Water pH was slightly alkaline and dissolved oxygen (DO), pH, alkalinity, water nutrients were found within suitable ranges for fish. TDS, conductivity, alkalinity, pH, NH_3-N and chlorophyll-*a* parameters were found to be significantly different between Andhermanik River and the other three sites. A total of 76 genera of plankton, of which 58 genera of phytoplankton and 18 genera of zooplankton, were found in the Mehna River at Chandpur site, whereas 61 genera (44 of phytoplankton and 17 of zooplankton), 60 genera (43 of phytoplankton and 17 of zooplankton), and 31 genera (24 of phytoplankton and 7 of zooplankton) were observed at Sites 1, 2, 3 & 4, respectively. While the parameters were found to be at 'acceptable' levels, some measures are needed to improve the quality of water to ensure successful migration and reproduction of the hilsa fish.

1

Introduction

The common Indian shad 'hilsa', the national fish of Bangladesh, belongs to the *Clupeidae* family under the genus *Tenualosa* and species *ilisha,* and is anadromous in nature. The fish has a wide distribution and is found in marine, estuarine and riverine habitats. It is an important migratory species in the Bay of Bengal, Persian Gulf, Red Sea, Arabian Sea, Vietnam Sea and China Sea. Among the three species of hilsa, the largest catch comes from *Tenualosa ilisha*, which comprises up to 99 per cent of the total hilsa catch within the countries in the Bay of Bengal region (Rahman *et al.* 2012). About 50–60 per cent of global hilsa catch is reported from Bangladeshi waters, 20–25 per cent from Myanmar, 15–20 per cent from India and another 5–10 per cent from other countries (e.g. Iraq, Kuwait, Malaysia, Thailand and Pakistan) (Rahman *et al*. 2010). The hilsa fishery has had a glorious past in Bangladesh, when an abundance of hilsa was caught in more than 100 rivers. It was available almost throughout the year in the major rivers including the Padma, Meghna, Jamuna, Rupsa, Shibsa, Bishkhali, Pyra, and Ilisha, and in the coastal areas of the Bay of Bengal. In addition to these rivers, hilsa was also plentiful in the Karnafuly, Feni and Muhuri Rivers and in most of the branches and tributaries of the Padma (Ganges) and the Brahmaputra (Ahsanullah 1964; Quereshi 1968; Haldar *et al.* 1992). Poor fishermen were able to easily catch large amounts of hilsa from those rivers and sell them in the local market to earn their livelihood.

From the 1970s, the hilsa fishery began to decline gradually, with outputs reaching a low point of 0.19 million tonnes in 1991–1992. This situation was attributed to a combination of the closure of migratory routes, river siltation, over-fishing, indiscriminate harvesting of brood stocks and juveniles (locally known as *jatka*), use of fishing nets with very small mesh sizes, the mechanisation of fishing gear, increased numbers of fishers, pollution, and hydrological and climatic changes (Mohammed and Wahab 2013). At present, the species is mainly concentrated in coastal areas, estuaries and the major rivers such as the Padma, Meghna, Tetulia, Andhermanik, Kirtonkhola, Kalabodor, Rupsha, Shibsa, Bishkhali, Kocha, Payra, Pashur, Baleshor, Kornafuli, and their tributaries and distributaries. Due to a low discharge of water from the river Ganges and consequently heavy siltation in most of the rivers, the feeding, spawning, nursery and migratory areas of hilsa have been restricted to the upstreams.

In addition, the gradual growth of industries, growing urbanisation, the indiscriminate use of fertilizers, agrochemicals, pesticides and the discharge of municipal waste are continuously polluting the river system. This may become endemic and widespread in the near future and will severely affect the hilsa fishery, unless proper management measures are developed and implemented. Therefore, it is essential to enhance our understanding and assess water quality parameters in order to develop a viable hilsa fishery management action plan.

Physical, chemical, hydrological and biological factors have a great influence on the occurrence, distribution, and abundance of tropical fish and other aquatic organisms**.** As with other migratory species, the biological activities of hilsa are mainly stimulated by the complex interaction of the biotic and abiotic factors of the water. The term 'water quality' in its broader sense includes all the physical, chemical and biological factors of water (Ahmed *et al.* 2000), and it may directly or indirectly affect the distribution and production of fish and other aquatic animals (Moses 1983; Varshney *et al*. 2004). These include water temperature, salinity, turbidity, dissolved oxygen, and the pH of water that triggers the estuarine fish ecology (Whitefield 1999; Blaber 2000).

Hilsa fish migrate to the river stretches for spawning in favourable environmental conditions. In Bangladesh, the Ganges-Brahmaputra river system carries sediment which creates merged and submerged islands, changing the ecology and blocking migratory routes (Curray and Moore 1971). About 2.4 billion tons of sediment are carried yearly by the river system in Bangladesh (Holemen 1986). Rahman (1997) reports that the heavy inflow of fresh water and the intensity of the monsoon has triggered migration and breeding. Juvenile hilsa migrate from the nursery grounds (riverine or coastal) to the estuaries during the onset of the monsoon for feeding and growth (Raja 1985, BFRI/RS 1994). Water temperature and rainfall were also found as major influential factors for species distribution (Hossain *et al.* 2013).

Although some research has been carried out on the life history, population biology and management, and the socio-economic aspects of the fishery, little has so far been done on the ecological aspects of the hilsa fishery areas in Bangladeshi waters. Considering the importance of the species to the national economy, and so as to ensure a continuous supply of this popular fish and update the current hilsa fisheries management action plan, a study was conducted to assess the physical and hydrological, chemical, and biological profile of the environment of the hilsa fishery areas in Bangladeshi waters.

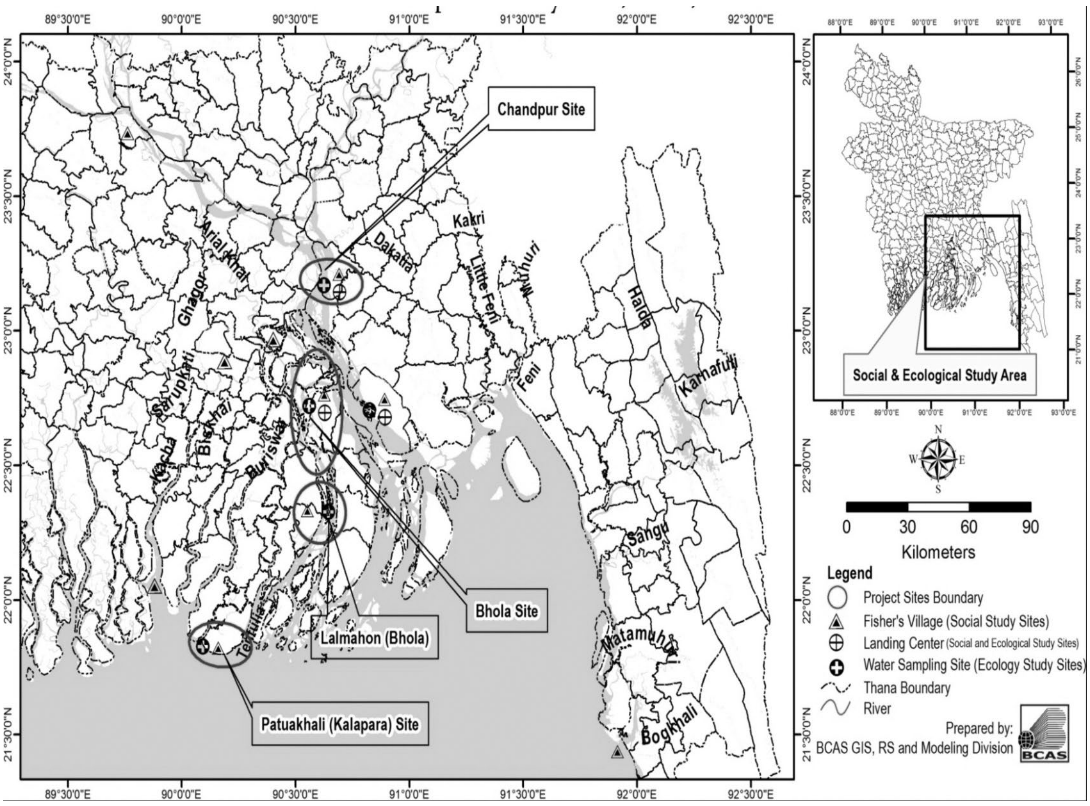
2

Methodology

2.1 Study areas and duration

The research was carried out for one year between January and December 2014 at four sites in the major hilsa fishery areas especially, in the sanctuary areas, where it is widely believed to be the major hilsa freshwater migration route – through which they migrate upstream to spawn. These were located in the Meghna River at Chandpur (23°12′47.58″N-23°13′32.39″N and 90°38′02.08″E-90°38′04.77″E) (Site 1), the lower part of the Meghna River in Doulatkhan, Bhola (22°34′54.47″N-22°36′16.95″N, and 90°45′22.49″E-90°46′05.64″E) (Site 2), the Tentulia River in Lalmohon, Bhola (22°15′47.26″N-22°19′25.15″N and 90°40′14.40″E-90°40′39.48″E) (Site 3) and Andhearmanik River, Kalapara, Patuakhali (21°52′24.01″N-21°54′03.14″N and 90°05′59.94″E -90°06′57.84″E) (Site 4).

Figure 1



The Government of Bangladesh had declared these areas as sanctuary for the purpose of protecting and conserving juvenile hilsa (locally known as *jatka*) as well as brood hilsa from exploitation during the breeding, nursing and grazing period. This is the primary reason why these sites were selected.

2.2 Physical and hydrological assessment

Physical water quality parameters, namely: air and water temperature, water transparency, total dissolved solids (TDS), total suspended solids (TSS), conductivity and hydro-dynamics, such as water current velocity and water depth at different sampling sites, were monitored each month. The temperature, TDS and conductivity were measured using digital multi-parameter (HQ 40D multi-meter) and water transparency was measured in situ using secchi-disc (30 cm in diameter). Total suspended solids were determined according to Stirling (1985).

2.3 Chemical and biological assessment

The chemical parameters of water such as pH, conductivity, DO and salinity, were measured on the spot using digital multi-parameter (HQ 40D multi-metre). Measurement of nitrogenous compounds (NO_3-N, NO_2-N and NH_3-N), phosphate compound (PO_4-P) was carried out in the laboratory by Hach Kit (DR 4000, direct reading spectrophotometer) (Wahab *et al.* 2003). Total alkalinity was determined from collected water samples using a methyl orange indicator and standard EDTA solution by titrimetric method (APHA, 1992). Chlorophyll-*a* was measured using DR 6000 spectrophotometer at 664 and 750 nm wavelengths, following Vollenweider's equation (Stirling 1985).

As a part of the biological parameters, plankton (food organisms in the form of phytoplankton and zooplankton) in the river water was studied qualitatively and quantitatively. For plankton analysis, vertical sampling using a flexible plastic tube (2.5 cm diameter) was carried out to collect samples from a vertical depth of 2 metres. The collected water was passed through a plankton net (mesh size 15 mm) and the concentrated plankton sample was transferred to a plastic bottle and preserved in 10 per cent buffered formalin. Plankton were identified and counted using S-R (Sedgwick-Rafter) cells containing 1,000 fields of 1 mm^3 under an electric microscope (Olympus BH2). The plankton in ten randomly selected fields in the S–R cell was identified up to genus level and counted, using the determination keys by Ward and Whipple (1959), Prescott (1962), Belcher and Swale (1976) and Bellinger (1992). Plankton density was calculated using the formula followed by Rahman *et al.* 2008:

$$N = (P * C * 100) * L^{-1}$$

Where N=the number of plankton per litre of original water; P=the number of planktonic organisms counted in ten fields; C=the volume of concentrated sample in the plastic bottle; L=the volume of original water sample.

3

Results and discussion

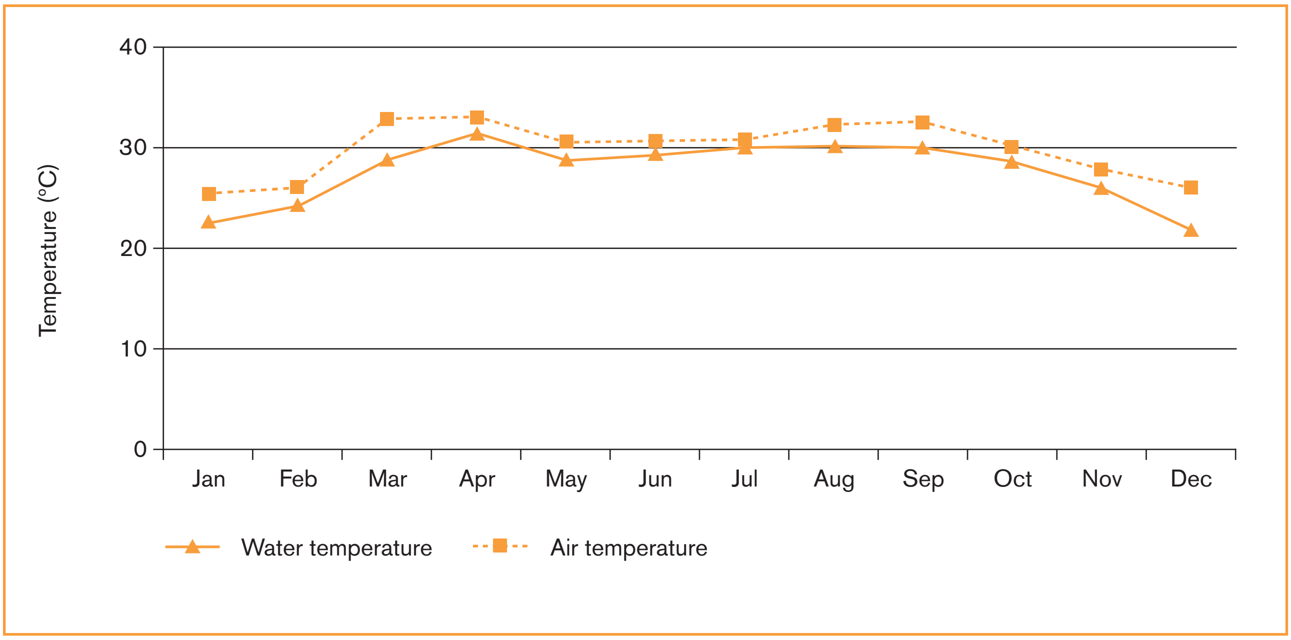
3.1 Physical and hydrological assessment

Analyses of various physical and hydrological factors of the water quality from different rivers (sites) are presented in Table 1 and combined graphical representations of the water quality parameter are shown in Figures 5 and 6.

Temperature

Water temperature is a vital factor of the environment which triggers physiological activities of aquatic organisms. Water temperature ranged from 21.8 to 31.5°C with the mean value of 27.75±3.09°C, 19.8 to 31.3°C with the mean value of 27.74±3.69°C, 20.9 to 31.4°C with the mean value of 27.76±3.2°C and 21.4 to 30.7°C with the mean value of 27.47±2.94°C in Site 1, Site 2, Site 3 and Site 4 respectively; whereas the air temperature ranged from 25.1 to 33°C with the mean

Figure 2. Monthly variations of air and water temperature in Meghna River, Chandpur



value of 29.87±2.76°C, 24°C to 33.2°C with the mean value of 29.62±2.86°C, 23.9 to 33°C with the mean value of 29.46±2.79°C and 22.1 to 31.7°C with the mean value of 28.82±2.87°C in Site 1, Site 2, Site 3 and Site 4 respectively (Table 1).

No significant difference (p>0.05) was found in temperature among the sites. The lowest air and water temperature was recorded in January in all sites and the highest air and water temperature was recorded in May in three sites except Site 1. The water temperature varied along with the changes in air temperature (Figure 2). Similar findings were reported by Ahmed *et al.* (2005), who recorded that water temperature of the Meghna River at surface level ranged between 24.1 and 30.5°C with a mean of 27.6 ± 0.68. Bhaumik *et al.* 2011 estimated the threshold values of physico-chemical parameters for hilsa migration, breeding, rearing and estimated that the ideal water temperature ranged from 29.3–30.2°C for breeding activities and 29.8–30.8°C for the nursery activities of hilsa in the Hooghly-Bhagirathi river system. In the past, Pillay (1958) estimated the most suitable water temperature ranged from 23–27°C and that temperatures of <20 °C, >30°C were not suitable for juvenile hilsa, whereas, Jafri (1988) reported the most suitable (20–25 °C), moderately suitable (15–20°C; 25–30°C) and least suitable (<15°C, >30°C) water temperature for hilsa spawning. On the other hand, the standard value of water temperature in the river is 20°C–30°C (ECR 1997), which shows similarity with the present findings and water temperature was found more or less within acceptable ranges for hilsa spawning and nursing.

Transparency

Water transparency (secchi disc) ranged from 20 to 83 cm with the mean of 44.97±22.41 cm, 22 to 46 cm with the mean value of 30.44±6.99 cm, 28 to 50 cm with the mean value of 36.39±6.89 cm and 38 to 62 cm with the mean value of 47.78±6.01 cm in Site 1, Site 2, Site 3 and Site 4, respectively (Table 1). Water transparency was higher in Site 1 and Site 4 in comparison with other two sites (Figure 5). Water transparency varied along with the changes of TSS and chlorophyll-*a* (Figures 3 and 4), which supports the findings of Ahmed (1993) who stated that chlorophyll-*a* showed an inverse relationship with water transparency. The maximum and the minimum transparencies were recorded in January and July at the three sites except Site 1. In Site 1, maximum and the minimum transparencies were measured in February and July (Figure 5). More or less similar results were found from the Meghna river system by Ahmed *et al.* (2005) and they stated that the transparency (secchi-disc visibility) ranged from 12 to 90 cm with a mean of 34.2 ± 18.08 cm at different stations. Water transparency was found to be higher at the upper stretch of the river and lower transparency was found in the lower stretches of the Meghna River (estuarine region), where muddy water was found. No significant difference (p>0.05) was found between Site 1 and Site 4, but a significant difference (P< 0.05) was found between Site 1 and Sites 2 and 3, and between Sites 4 and Site 2 and 3, and between Site 2 and Site 3.

Figure 3. Monthly variations of water transparency in relation to chlorophyll-*a* in Meghna River, Chandpur

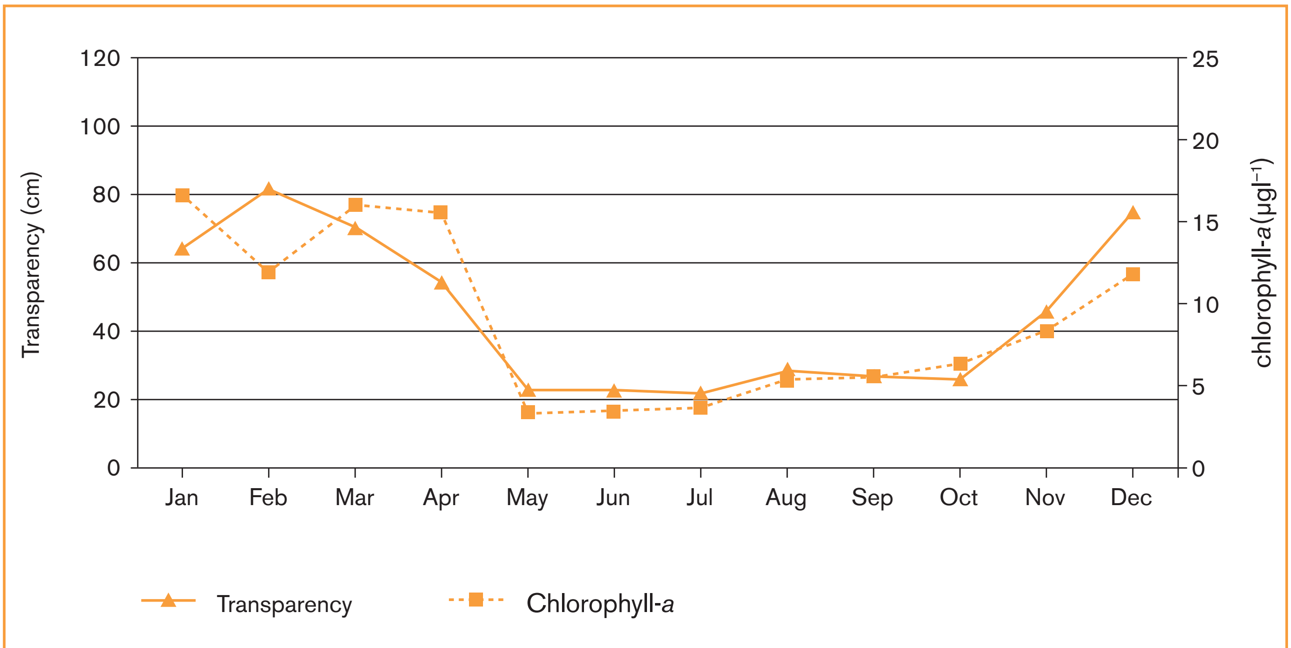
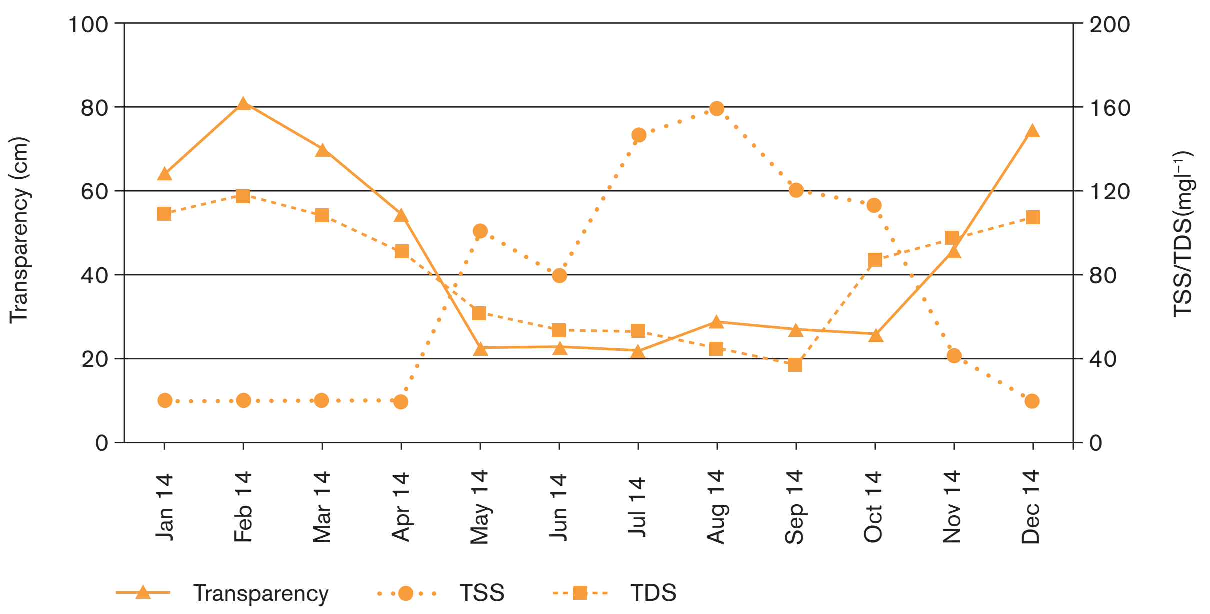


Figure 4. Monthly variations of water temperature, TSS and TDS in Meghna River, Chandpur



Total dissolved solids

Total dissolved solids (TDS) varied from 32.9 to 126 mgl^{-1} with the mean value of 80.84±28.38 mgl^{-1}, 95 to 2010 mgl^{-1} with the mean value of 461.45±669.43 mgl^{-1}, 72 to 256 mgl^{-1} with the mean value of 155.876±60.69 mgl^{-1}, and 11160 to 22800 mgl^{-1} with the mean values of 17068±33521 mgl^{-1} in Site 1, Site 2, Site 3, and Site 4 during the study period (Table 1). TDS was found much higher in Site 4 (Andhermanik River) than the other three sites. According to Ahmed *et al.* 2005, TDS fluctuated between 0.12 and 0.32 mgl^{-1} with a mean of 0.20 ±0.05, which differs from the present findings. No significant difference ($p>0.05$) was found among Site 1, Site 2 and Site 3, but significant difference ($P< 0.05$) was found between Site 4 and Sites 1, 2, and 3.

Total suspendent solids

Total suspendent solids (TSS) ranged widely over the period and varied from 20 to 200 mgl^{-1} with a mean value of 71.67±54.17 mgl^{-1}, 160 to 400 mgl^{-1} with the mean value of 251.67±71.97 mgl^{-1}, 40 to 140 mgl^{-1}, with the mean value of 105±23.84 mgl^{-1} and 120 to 240 mgl^{-1} with the mean value of 180.56±31.8 mgl^{-1} in Site 1, Site 2, Site 3 and Site 4 respectively. The higher TSS value was found in July and the lower was found in January (Table 1 and Figure 5). Higher TSS was found in the lower Meghna River (Site 2) compared with the other three sites. These changes might be due to the fact that lower Meghna River contained a higher concentration of suspended solids. The lower Meghna River in Bangladesh is a unique environment, where the constant process of land formation and erosion takes place because of the complex interactions between large river discharge, enormous sediment load, strong tidal forces, wind actions, wave, cyclonic storm surge and estuarine circulation. The Meghna river system carries a considerable amount of silt and deposits into the bottom of the river and the Bay of Bengal, which is continuously changing the river hydrology and creating many merged and submerged islands and sediment bars that may block the migratory routes and change the river ecology. TSS varied significantly ($P< 0.05$) among the four sites.

Table 1. Physical and hydrological parameters of water quality in the four sites

PARAMETERS	MEGHNA RIVER, CHANDPUR (SITE 1)	MEGHNA RIVER, DAULATKHAN, BHOLA (SITE 2)	TETULIA RIVER, LALMOHON, BHOLA (SITE 3)	ANDHERMANIK RIVER, KALAPARA, PATUAKHALI (SITE 4)
Air temperature (ºC)	29.87±2.76 (25.1–33)	29.62±2.86 (24.0–33.2)	29.46±2.79 (23.9–33.0)	28.82±2.87 (22.1–31.7)
Water temperature (ºC)	27.75±3.09 (21.8–31.5)	27.74±3.69 (19.8–31.3)	27.76±3.20 (20.9–31.4)	27.47±2.94 (21.4–30.7)
Transparency (cm)	44.97±22.41[a] (20–83)	30.44±6.99[c] (22–46)	36.39±6.89[b] (28–50)	47.78±6.01[a] (38–62)
TDS (mgl^{-1})	80.84±28.38[b] (32.9–126)	461.45±669.43[b] (95–2010)	155.87±60.69[b] (72–256)	17068±33521[a] (11160–22800)
TSS (mgl^{-1})	71.67±54.17[d] (20–200)	251.67±71.97[a] (160–400)	105±23.84[c] (40–140)	180.56±31.80[b] (120–240)
Conductivity (μScm^{-1})	173.35±59.19[b] (59.5–268)	640.28±725.43[b] (217–2310)	314.17±107.47[b] (160–526)	29280±5888[a] (19610–37200)
Water current velocity (ms^{-1})	0.55±0.32 (0.23–1.17)	0.54±0.31 (0.24–1.14)	0.49±0.29 (0.18–1.04)	0.48±0.28 (0.17–1.01)
Water depth (m)	15.32±3.4[a] (10.6–21.2)	16.08±5.88[a] (7.40–21.60)	9.92±3.57[b] (5.80–16.01)	10.43±1.52[b] (7.7–13.0)

All the values were reported as mean with standard deviation. Figures in the same superscripts are not significantly different ($p>0.05$), those with different superscripts are significantly different ($p<0.05$). Values in parentheses indicate the range of parameter.

Conductivity

Conductivity ranged from 59.5 to 268 μScm^{-1}, with the mean value of 173.35±59.19 μScm^{-1}; 217 to 2310 μScm^{-1}, with the mean value of 640.28±725.43 μScm^{-1}; 160 to 526 μScm^{-1}, with the mean value of 314.17±107.47 μScm^{-1}; and 19610 to 37200 μScm^{-1}, with the mean value of 29280±5888 μScm^{-1} in Site 1, Site 2, Site 3 and Site 4 respectively over the study period (Table 1). The conductivity values were found to be much higher in Site 4 (Andhermanik River) than the other three sites. Ahmed et al. (2005) reported that the highest value (220 mS/cm) of conductivity was recorded in the Meghna river system, which is very close to the finding of the present study. No significant differences ($p>0.05$) were found between Site 1, Site 2 and Site 3, but significant differences ($p< 0.05$) were found between Site 4 and Sites 1, 2, and 3.

Water current velocity

The water current velocities were found to range from 0.23 to 1.17 ms^{-1} with the mean value of 0.55±0.32 ms^{-1}; 0.24 to 1.14 ms^{-1} with the mean value of 0.54±0.31, 0.18 to 1.04 ms^{-1} with the mean value of 0.49±0.29 ms^{-1}, and 0.17 to 1.01 ms^{-1} with the mean value of 0.48±0.28 ms^{-1} in Site 1, Site 2, Site 3 and Site 4 respectively over the period. The maximum value was recorded in July and the minimum value was recorded in January. Variations of water current velocities are shown in Table 1 and Figure 6. The study revealed that the water current velocity during the monsoon was much higher than during the dry seasons. This might be due to the higher upstream discharge during the monsoon and the fact that the tidal action becomes stronger and dominates the water flow in the river. No significant difference ($p>0.05$) was found among the sites.

Figure 5. Bi-monthly variations of physical parameters of water quality at differenrt sites

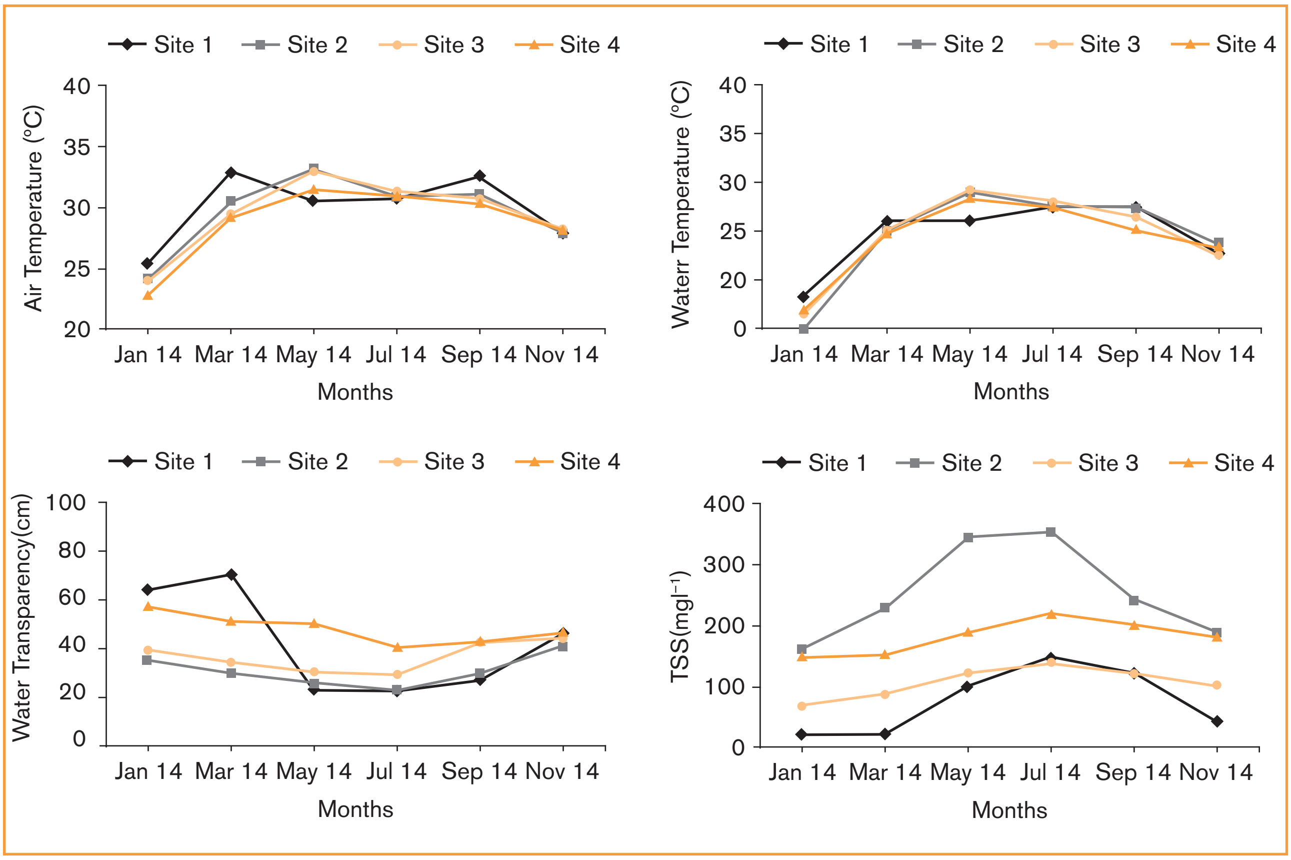
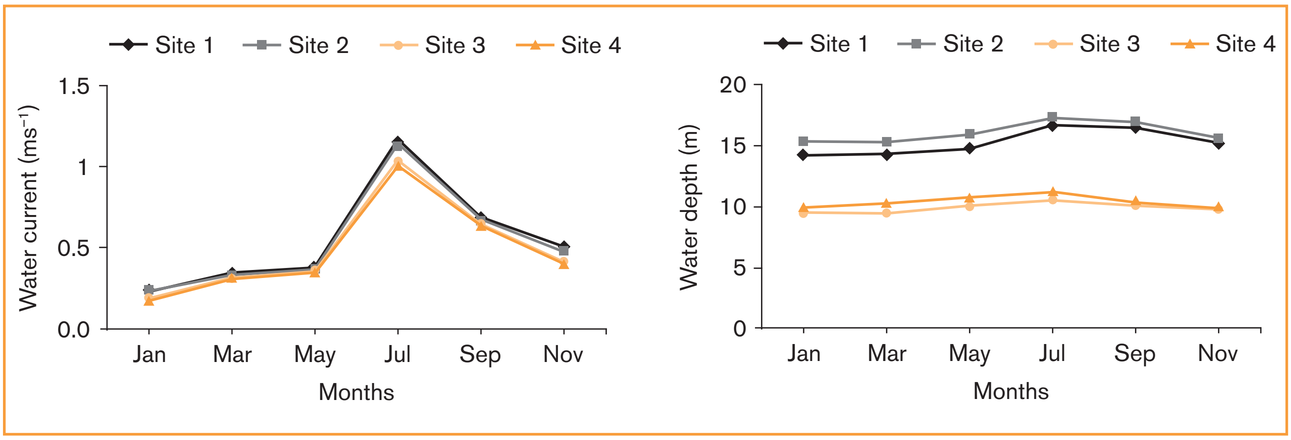


Figure 6. Bi-monthly variations of hydrological parameters of water at different sites



Water depth

The water depth at the sampling points varied from one area to another and between the seasons. It varied from 10.6 to 21.2 m with the mean value of 15.32±3.4 m; 7.4 to 21.6 m with the mean of 16.08±5.88 m; 5.8–16.01 m with the mean value of 9.92±3.57 m; and 7.7 to 13.0 m with the mean value of 10.43±1.52 m in Site 1, Site 2, Site 3 and Site 4 respectively (Table 1). The maximum value was recorded in July and the minimum in January (Figure 6). Comparatively lower water depth was measured in the Tetulia River near the Lalmohon site in Bhola, although several submerged islands or sand bars were found in the lower Meghna, Tetulia and Andhermanik Rivers that change river ecology by blocking the migratory routes, which might affect the spawning and feeding migration of hilsa. No significant difference ($p>0.05$) was found between Site 1 and Site 2 and between Site 3 and Site 4, but significant differences ($p< 0.05$) were found when comparing Sites 1 and 2, and Sites 3 and 4.

3.2 Chemical and biological assessment

3.2.1 Chemical assessment

pH

As part of the chemical parameters of water quality, the pH of water is the most important factor for species distribution. The pH was found to be slightly alkaline and it ranged from 7.16 to 8.69 with the mean value of 8.02±0.45[b], 7.82 to 8.34 with the mean value of 8.08±0.15, 7.95 to 8.35 with the mean value of 8.16±0.1 and 7.32 to 8.19 with the mean value of 7.78±0.27 in Site 1, Site 2, Site 3 and Site 4 respectively over the study period (Table 2). The maximum value was found in January at all the sites, but the minimum value was recorded in August, November, and July in site 1, site 2, 3 and site 4 respectively (Figure 10). Similar findings were reported by Ahmed and Rahman (2000) and Ahmed at *el.* 2005. The standard value of water pH for fish ranges from 6.5–8.5 (ECR 1997). Water with a pH of less than 6.5 or more than 9–9.5 for a long period is harmful to the reproduction and growth of fish (Boyd 1979). The water pH in the Meghna River was found to be neutral to alkaline (7.0–8.0) at all the sampling stations (Ahmed *et al.* 2005). Bhaumik and Sharma (2012) stated that the permissible range of pH was between 6.4 and 8.5. The value is similar to the present findings, which is why we can say that there were acceptable ranges of the pH of water for the fish. The pH values showed significant differences ($p < 0.05$) between Site 4 and other three sites, but no significant difference ($p > 0.05$) was found among the three sites (Site 1, Site 2 and Site 3).

Alkalinity

Total alkalinity ranged from 48 to 98 mgl^{-1}, 64 to 92 mgl^{-1}, 62 to 104 mgl^{-1}, and 80 to 106 mgl^{-1}, with the mean values of 74.61±11.37 mgl^{-1}, 76.11±7.7 mgl^{-1}, 76.44±10.27 mgl^{-1}, and 86.53±3.03 mgl^{-1} respectively (Table 2). The highest alkalinity was found in Site 4. From a monthly perspective, the highest alkalinity was found in January at three sites except Site 4, where the highest value was found in May, whereas the lowest alkalinity was recorded in August (in Site 1), September (in Site 2 and 3) and July (Site 4) (Figures 7 and 10). No significant difference ($p > 0.05$) was found between the three sites (Site 1, Site 2 and Site 3), but differences were found between Site 4 and the other three sites. Moyle (1946) described the total alkalinity of medium and highly productive water as ranging from 40.0 to 90.0 ppm and above 90.0 ppm, whereas Boyd and Lichtkoppler (1979) suggested that water with total alkalinities of 20 to 150 mg L^{-1} contain the right quantities of carbon dioxide to permit plankton production, and Bhuiyan (1970) stated that the total alkalinity of medium productive water ranged from 25

Figure 7. Monthly variations of total alkalinity and pH in Meghna River, Chandpur

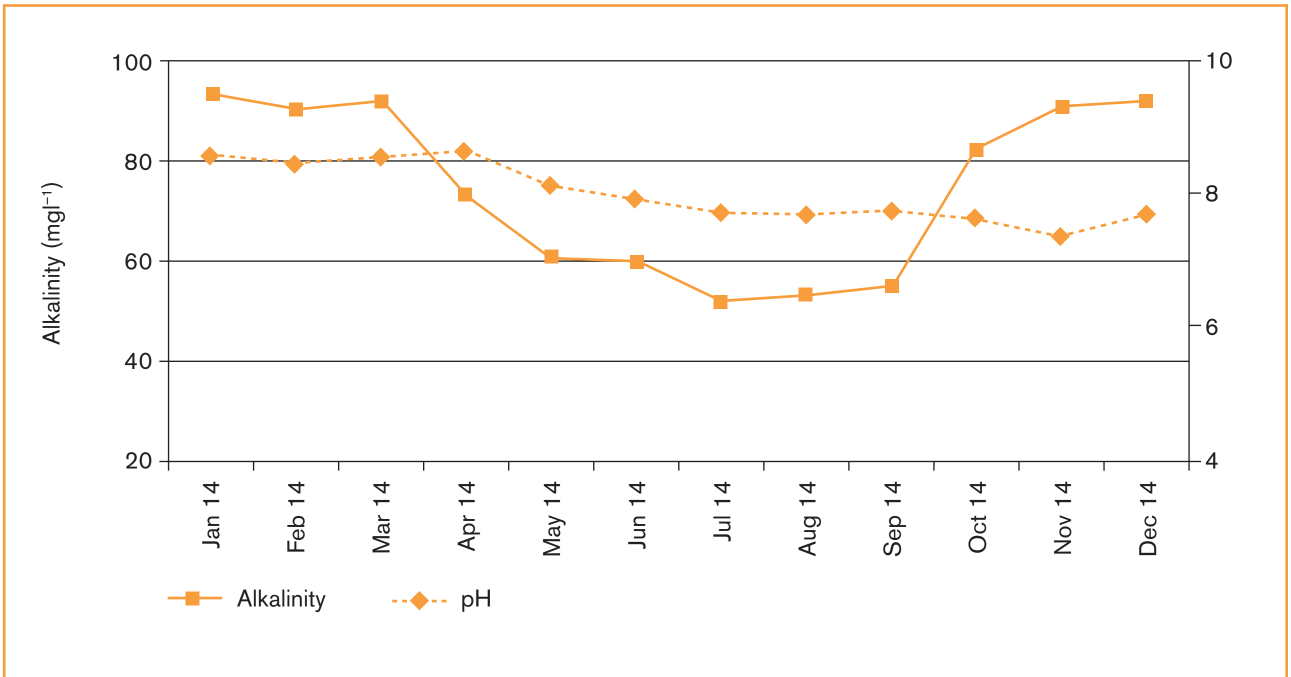


Table 2. Chemical parameters of water quality in the four sites in the major hilsa fishery areas

PARAMETERS	MEGHNA RIVER, CHANDPUR (SITE 1)	MEGHNA RIVER, DAULATKHNA, BHOLA (SITE 2)	TETULIA RIVER, LALMOHON, BHOLA (SITE 3)	ANDHERMANIK RIVER, KALAPARA, PATUAKHALI (SITE 4)
pH	8.02±0.45^{a} (7.16–8.69)	8.08±0.15^{a} (7.82–8.34)	8.16±0.1^{a} (7.95–8.35)	**7.78±0.27^{b} (7.32–8.19)**
Alkalinity (mgl^{-1})	74.61±11.37^{b} (48–98)	76.11±7.7^{b} (64–92)	76.44±10.27b^{b} (62–104)	**86.53±3.03^{a} (80–106)**
Dissolved oxygen (mgl^{-1})	7.24±1.03 (5.91–9.50)	7.25±0.44 (6.72–8.4)	7.49±0.44 (6.8–8.26)	**7.46±0.4 (7.01–8.33)**
Salinity (ppt)	0.08±0.03^{b} (0.04–0.12)	0.77±1.41^{b} (0.05–4.09)	0.11±0.09^{b} (0–0.24)	**18.49±3.53^{a} (11.7–23.7)**
NO_3-N (mgl^{-1})	0.026±0.013^{a} (0.01–0.05)	0.015±0.007^{b} (0–0.03)	0.024±0.011^{a} (0–0.05)	**0.019±0.007^{b} (0.01–0.03)**
NO_2-N (mgl^{-1})	0.006±0.003^{b} (0.002–0.016)	0.007±0.003^{ab} (0–0.01)	0.008±0.004^{ab} (0.003–0.02)	**0.009±0.006^{a} (0.001–0.02)**
NH_3-N (mgl^{-1})	0.11±0.16^{b} (0.01–0.63	0.05±0.02^{b} (0.02–0.1)	0.07±0.05^{b} (0.01–0.16)	**0.78±0.32^{a} (0. 46–1.62)**
PO_4-P (mgl^{-1})	0.18±0.11 (0.05–0.51)	0.19±0.09 (0.06–0.34)	0.16±0.08 (0.04–0.29)	**0.18±0.07 (0.08–0.3**
Chlorophyll-*a* (µgl^{-1})	9.01±5.15^{a} (2.86–19.52)	8.88±5.38^{a} (3.25–19.99)	8.71±4.53^{a} (3.08–17.14)	3.59±1.32^{b} (1.9–6.19)

All the values were reported as mean with standard deviation. Figures in the same superscripts are not significantly different ($p>0.05$), and those with different superscripts are significantly different ($p<0.05$). Values in parentheses indicate the range of parameter.

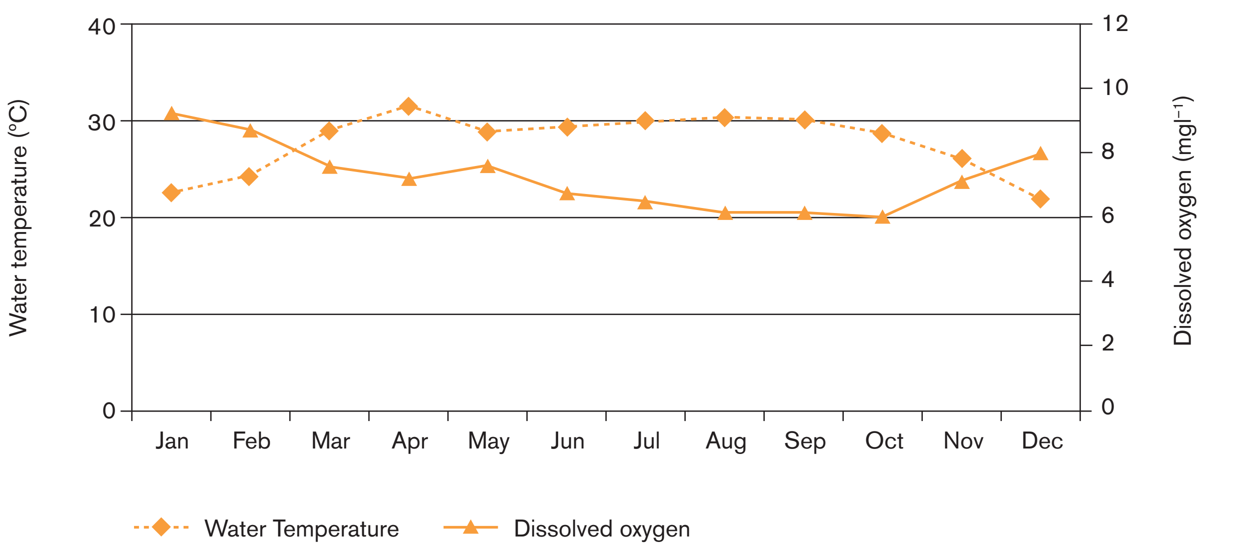
to 100 mg/l. This indicates that the range of alkalinity found in the present study is acceptable for planktonic organisms and fish.

Dissolved oxygen (DO)

Dissolved oxygen (DO) concentration is a major factor that triggers species distribution in bodies of natural water. DO generally promotes the survival of fish, especially juvenile and fry. Maes *et al.* (2004) mentioned dissolved oxygen as one of the most important factors for fish abundance and distribution. Dissolved oxygen (DO) concentrations from different sites showed a wide range of variation, ranging from 5.91 to 9.50 mgl^{-1}, 6.72 to 8.4 mgl^{-1}, 6.8 to 8.26 mgl^{-1} and 7.01 to 8.33 mgl^{-1}, with the mean values of 7.24±1.03 mgl^{-1}, 7.23±0.44 mgl^{-1}, 7.49±0.44 mgl^{-1} and 7.46±0.4 mgl^{-1} in Site 1, Site 2, Site 3 and Site 4 respectively during the study period (Table 2). The highest DO was measured in January at the four sites, when the water temperature was comparatively lower (Figure 8). DO levels fell from March to August when the water temperature rose, and the minimum was recorded in August when the water temperature was higher (Figure 8).

Higher DO was recorded in the upper stretches of the Meghna river basin than in the lower stretches. Higher DO values indicate higher productivity which might play an important role for the migration of hilsa. The result was more or less similar to the findings reported

Figure 8. Monthly variations of DO in relation to water temperature in Meghna River, Chandpur



by Ahmed *et al.* (2005) and they recorded the mean value of DO as 6.7 ± 0.81 mgl^{-1} in the Meghna River and also showed that DO concentration was found to decrease gradually from the upper to the lower stretches of the river system. DO concentration in the Meghna river estuary was found to range from 4.6 and 5.8 mg/L (Hossain et *al.* 2012), and almost the same result was reported by Ahammad (2004) where the values ranged from 3.63 - 6.83 mg/l, which differs from the present findings. According to Bhatnagar and Singh (2010) and Bhatnagar *et al.* (2004) DO level >5ppm is essential to support good fish production. Chacko and Krishnamurthy (1949) estimated >5 mgl^{-1} DO was preferable and from 4–5 mgl^{-1} upwards was moderately suitable, but <4 mgl^{-1} DO was not suitable for the juvenile hilsa. This indicates that the range of DO found in the present study is suitable for the fish especially the juvenile hilsa. In the case of DO concentrations, no significant difference was found between the sites.

Salinity

Salinity showed a wide range of variation in different sites and ranged from 0.04 to 0.12 ppt, 0.05 to 4.09 ppt, 0 to 0.24 ppt and 11.7 to 23.7 ppt, with the mean values of 0.08±0.03 ppt, 0.77±1.41 ppt. 0.11±0.09 ppt and 18.49±3.53 ppt in Site 1, Site 2, Site 3 and Site 4 respectively (Table 2). Salinity was found at zero or close to zero in two sites (Site 1 and Site 3) over the period. This might be due to a huge fresh water discharge from the surrounding land, fresh water supply from the upstream river and the long distance from the downstream coastal water. Hossain *et al.* (2012) reported almost zero salinity in the Meghna River throughout the study period of their work. However McErlean *et al.* (1973) stated that the salinity of an estuary ranged from 0.50 ppt to 35 ppt, and Ahammad (2004) reported the salinity ranged from 14.43 ppt to 25.92 ppt in the Moheskhali channel estuary.

The hilsa fish has a very strong osmoregulatory mechanism and can tolerate a wide range of salinity; it also has different preferences of salinity range at different stages of its life cycle (Rahman 2001 & 2006, Milton and Chenery 2001 & 2003). For the breeding and nursing of the juveniles, it prefers fresh water, the young (pre-adult) needs estuarine and coastal water and at maturation it needs high saline marine water. In the present study, the higher concentration of salinity (12.2 to 23.4 ppt) was recorded in Andhermanik River in all seasons; this might be due to the close proximity to the Bay of Bengal and also to the tidal influence. Mitra and Devasvndarm (1954) stated that salinity levels ranging from 0 to 0.5 ppt. and from 0.05 to 0.1 ppt were most suitable, and moderately suitable for the juvenile hilsa, but salinity above 1.0 ppt was not suitable for juvenile hilsa, whereas Bhaumik *et al.* (2011) estimated the ideal salinity as <0.1 for the breeding and nursery activities of hilsa in the Hooghly-Bhagirathi river system. Following the discussion above, it can be said that salinity found in the Meghna-Tetulia river basin during the study period was the most suitable for breeding and nursery activities. No significant difference ($p>0.05$) was found between the three sites (Site 1, Site 2 and Site 3), but differences were found between Site 4 and the other three sites.

Nitrogenous compounds (NO_3-N, NO_2-N and NH_3-N)

Nitrogenous compounds (NO_3-N, NO_2-N, NH_3-N) and phosphatic compounds (PO_4-P) are important parameters of the water quality which trigger biological production in water bodies. Nitrogenous compounds (NO_3-N, NO_2-N, NH_3-N) found in waters at the different sites are shown in Table 4, and monthly variations of NO_3-N, NO_2-

N and NH_3-N are shown in Figure 9 (for the Meghna River). Nitrogenous compounds (NO_3-N, NO_2-N) were found at minimum levels (almost zero or close to zero) - except ammonia-nitrogen (NH_3-N) - in all the sites (Figure 10). According to Bhatnagar *et al.* (2004), NO_2-N <0.02 ppm is acceptable for fish, whereas Santhosh and Singh (2007) recommended that nitrite concentration in water should not exceed 0.5 mgl^{-1}. OATA (2008) recommended that it should not exceed 0.2 mgl^{-1} in fresh water, and 0.125 mgl^{-1} in sea water.

The findings of the current observation showed that NO_2-N concentration was found at an acceptable range, and that NH_3-N ranged from 0.01–0.63 mgl^{-1}, 0.02–0.1 mgl^{-1} and 0.01–0.16 mgl^{-1} with the mean values of 0.11±0.16 mgl^{-1}, 0.05±0.02 mgl^{-1} and 0.07±0.05 mgl^{-1} in Site 1, Site 2 and Site 3 respectively. More or less similar findings were observed by Ahmed *et al* (2005) who reported that ammonia concentration was found to be elevated and ranged from 0.1 to 0.6 mgl^{-1}, and showed a gradual decreasing trend from the upward to the downward stretches in the Meghna river systems. However, a higher concentration of NH_3-N (0.46 to 1.62 mgl^{-1}) was found in Site 4 (Andemanik River). The maximum limit of ammonia concentration for aquatic organisms is 0.1 mgl^{-1} (Meade, 1985). Santhosh and Singh, 2007 and Bhatnagar *et al.* (2004) suggested >0.4 ppm to be lethal and <0.05 ppm as safe for many tropical fish species. The finding of the present study showed that NH_3-N concentration is at the acceptable range for fish in all the stations except in Site 4. Nitogenous compounds varied significantly among the sites.

Phosphatic compounds (PO_4-P)

Phosphate-phosphorus (PO_4-P) ranged from 0.05 to 0.51 mgl^{-1} with the mean value of 0.18±0.11 mgl^{-1}; 0.06 to 0.34 mgl^{-1} with the mean value of 0.19±0.09 mgl^{-1}; 0.04 to 0.29 mgl^{-1} with the mean value of 0.16±0.08 mgl^{-1}, and 0.08 to 0.3 mgl^{-1} with the mean value of 0.18±0.07 mgl^{-1} in Site 1, Site 2, Site 3 and Site 4 respectively over the study period (Table 2). No significant difference was found among the sites. Bhatnagar *et al.* (2004) suggested that 0.05–0.07 ppm is optimum and productive; 1.0 ppm is good for plankton production, which supports evidence that the ecosystems were productive and favourable for aquatic organisms.

Figure 9. Monthly variations of nutrients in the waters of Meghna River, Chandpur

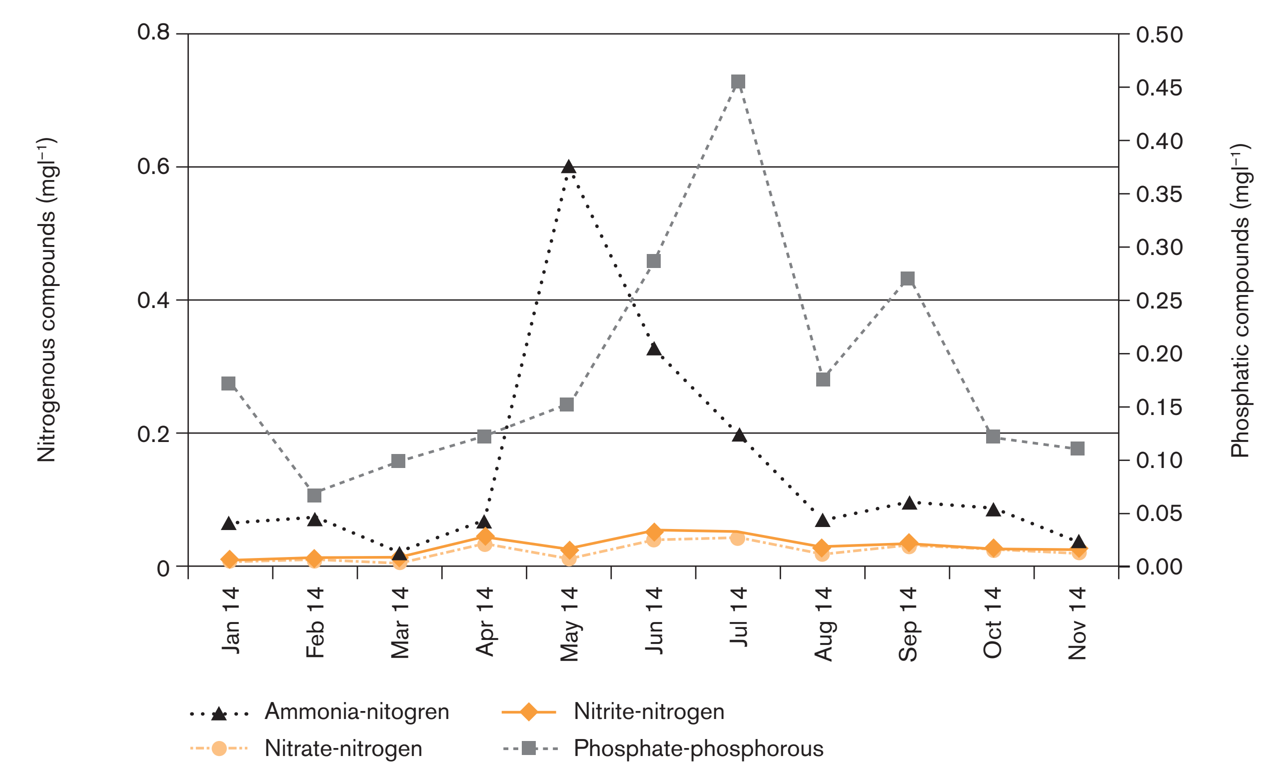
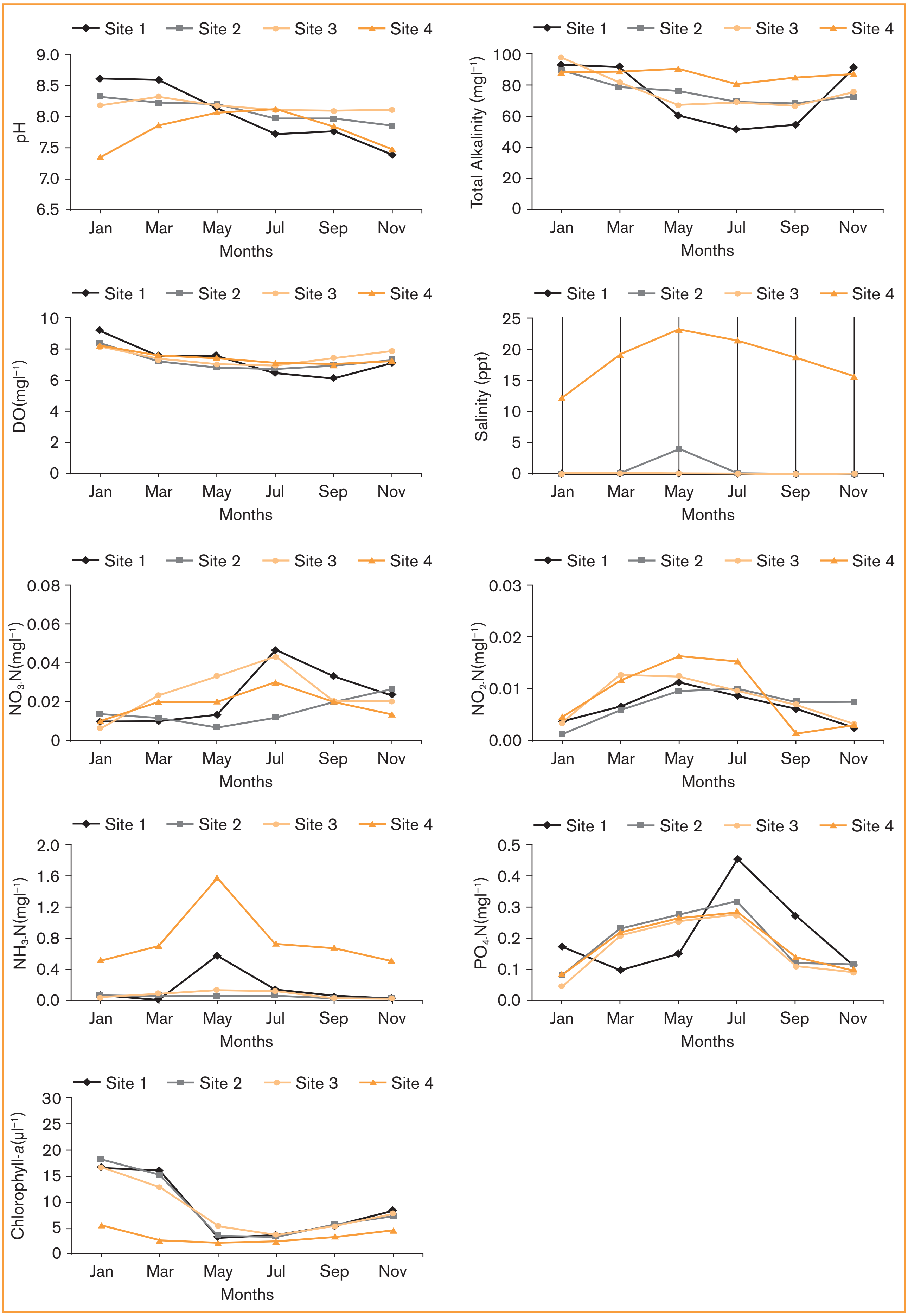


Figure 10. Bi-monthly variations of chemical water quality parameters in different sites



Chlorophyll-*a*

Chlorophyll-*a* concentrations ranged from 2.86 to 19.52 mgl^{-1}, 3.25 to 19.99 mgl^{-1}, 3.08 to 17.14 mgl^{-1} and 1.9 to 6.19 mgl^{-1} with the mean of 9.01±5.15 mgl^{-1}, 8.88±5.38 mgl^{-1},8.71±4.53 mgl^{-1} and of 3.59±1.32 mgl^{-1} in site 1, site 2 site 3 and site 4 respectively (Table 2). Comparatively higher chlorophyll-*a* was found from January to April and lower during the rest of the year (Figure 10). Among the four sites, comparatively minimum chlorophyll-*a* was found in the Andhermanik River. Chlorophyll-*a* value is an indicator of productivity in the water body, which shows an inverse relationship with water transparency (Ahmed 1993). Chlorophyll-*a* varied significantly ($p< 0.05$) between Site 4 and the other three sites.

3.2.2 Biological Assessment

Plankton population in the river

Six groups (families) of phytoplankton,namely Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae, Dinophyceae, and Xanthophyceae comprising 58 genera and zooplankton including Copepoda, Cladocera, Rotifera, and Protozoa having 18 genera were identified at Site 1 (Meghna River, Chandpur) whereas, five families of phytoplankton (such as Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dinophyceae, Euglenophyceae and Xanthophyceae) comprising 44 genera and zooplankton including Copepoda, Cladocera, Rotifera and Protozoa with 17 genera were identified at Site 2 (Meghna River, Daulatkhan, Bhola) (Table 4). Five groups of phytoplankton comprising 43 genera and four groups of zooplankton with 17 genera were identified at Site 3 (Tetulia River). Plankton composition at Site 4 (Andhermanik River) was to some extent different from the other three sites of the Meghna river basin and Tetulia River.

There were four groups of phytoplankton comprising 25 genera and three groups of zooplankton with seven genera. Chlorophyceae was the dominant group and *Ulothrix* was the dominant genus among the phytoplankton, however Rotifera was the dominant group and *Keratella* was the dominant genus in zooplankton in three sites (Site 1, Site 2 and Site 3), whereas Bacillariophyceae was the most abundant group and *Coscinodiscuss* was the dominant genus among phytoplankton and Copepoda was the dominant group in zooplankton in Site 4 (Table 4). Ahsan *et al.* (2012) reported the occurrence of 58 taxa of which 19 were of phytoplankton and 39 were of zooplankton. A relatively lower abundance of plankton including 41 genera of phytoplankton and 13 genera of zooplankton were recorded (Ahmed *et al.* 2005). It was observed from the present study that the number of plankton varied from 6,096 to 96,604 cells L^{-1}, 5,925 to 97,765 cells L^{-1}, 6,023 to 85,733 cells L^{-1}, and 2,210 to 5,769 cells L^{-1}, where phyplankton varied from 5,277 to 92,655 cells L^{-1}, 5,462 to 93,619 cells L^{-1}, 5,297 to 81,457 cells L^{-1}, 1,530 to 5,145 cells L^{-1} and zooplankton ranged from 716 to 5,211 cells L^{-1}, 463 to 4,147 cells L^{-1}, 727 to 4,276 cells L^{-1}, 405 to 1,208 cells L^{-1} in Site 1, Site 2, Site 3, Site 4 respectively. The mean plankton abundance were 36,996 cells L^{-1}, 35,929 cells L^{-1}, 32,556 cells L^{-1}, 4,020 cells L^{-1}, where, phytoplankton abundance were 34,795 cells L^{-1}, 34,142 cells L^{-1}, 30,612 cells L^{-1}, 3,225 cells L^{-1}, and zooplankton were 2,201 cells L^{-1}, 1,787 cells L^{-1}, 1,943 cells L^{-1}, 795 cells L^{-1} in Site 1, Site 2, Site 3, Site 4 respectively (Table 3). But Ahmed *et al.* (2005) observed the mean plankton abundance as 23,031±9,555 cells L^{-1}, with phytoplankton and zooplankton as 23,525±9,254 cells L^{-1} and 494±332 cells L^{-1} respectively. Very minimum plankton abundance (194.05±82.58 individuals/l) was found in the Ganga-Meghna river system (Ahsan *et al.* 2012), which differs from the present findings. In the present study, a higher percentage of phytoplankton (94.05 per cent, 94.84 per cent, 94.04 per cent, 80.22 per cent in Sites 1, 2, 3 and 4 respectively), and a lower percentage of zooplankton (5.95 per cent, 5.16 per cent, 5.96 per cent, 19.78 per cent in Sites 1, 2, 3 and 4 respectively) were observed. The variations among different groups of plankton are shown in Figure 11 and Figure 12.

Similar results were found by other researchers (Ahmed *et al.* 2003; 2005 and Ahsan *et al.* 2012). In the Ganga-Meghna river system, phytoplankton formed 90 per cent of the total plankton abundance (Ahsan *et al.* 2012). Shafi *et al.* (1978) reported a higher percentage of phytoplankton (76.0–93.6 per cent) from the Meghna River, whereas Ahmed *et al.* (2005) reported that the plankton biomass was relatively lower in the Meghna River comprising 96.74 per cent phytoplankton and 3.26 per cent zooplankton of the total planktonic organisms, which is similar to the present findings.

In the current study, Chlorophyceae was the dominant group and *Ulothrix* was the dominant genus among phytoplankton; however, Rotifera was the dominant group and *Keratella* was the dominant genus in zooplankton in all the sites except in the Andhermanik River (Site 4). Bacillariophyceae and copepoda were dominant in that site (Figure 11 and Figure 12). Bacillriophyceae and Rotifera were found second in position according to the abundance in the Meghna and

Figure 11. Phytoplankton composition in four sites

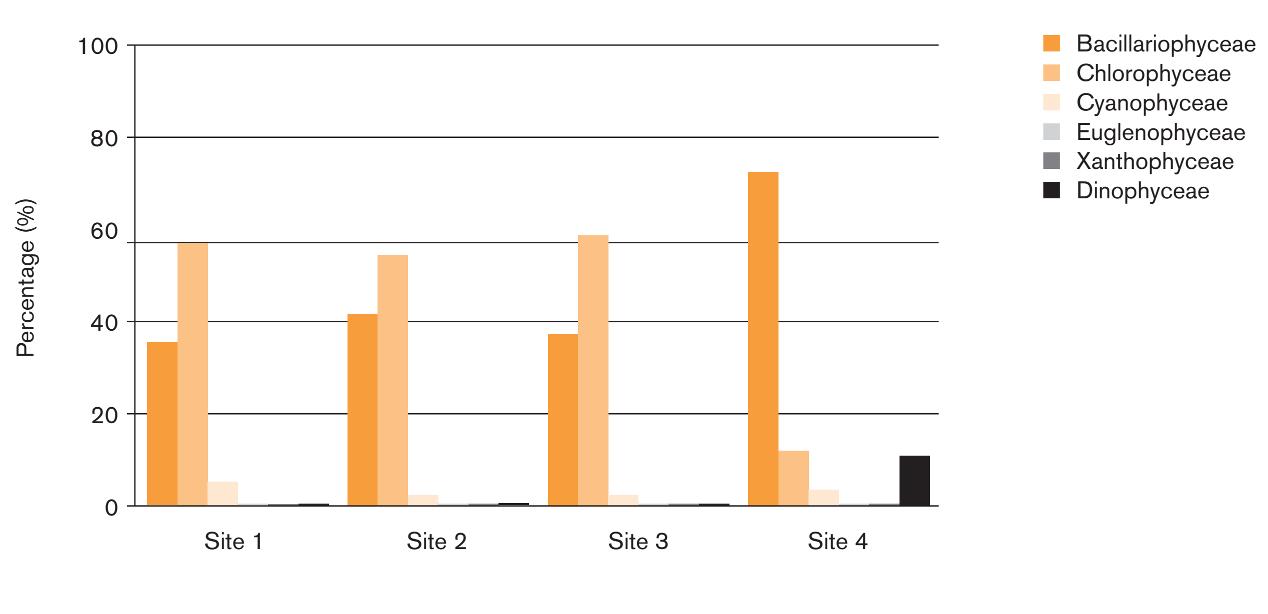
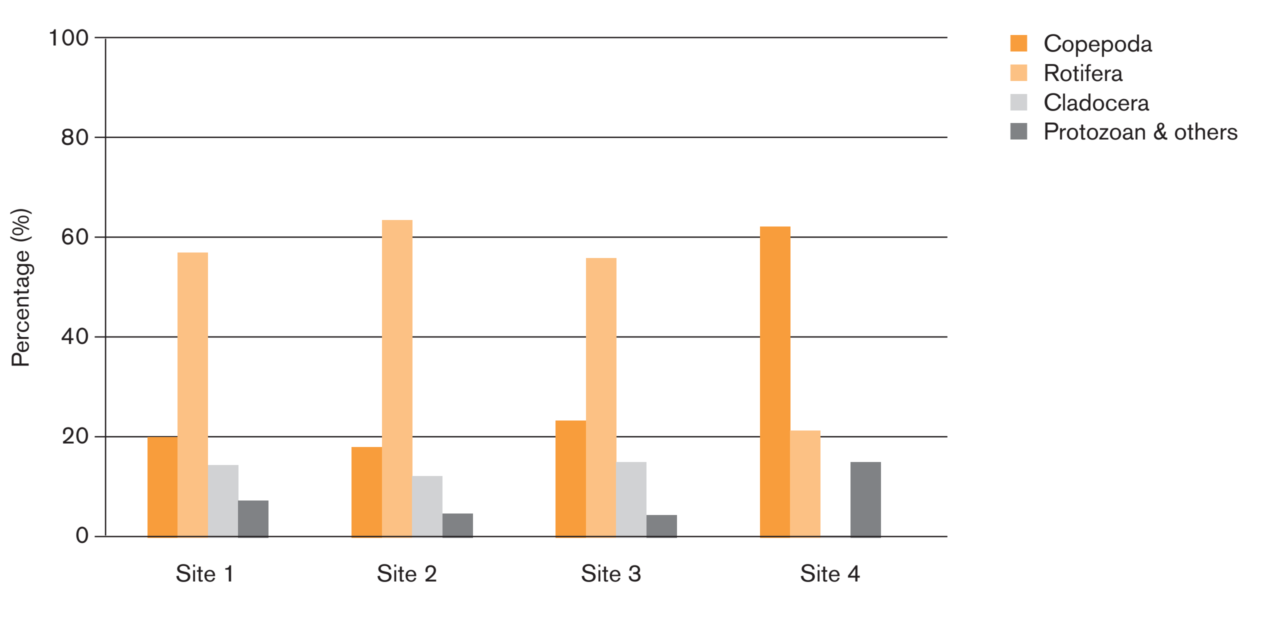


Figure 12



Tetulia river basin, while Chllorophyceae and Rotifera occupied the second position in accordance with abundance at the Andhermanik River. Similar findings were observed by Mahmud *et al.* (2007). The plankton abundance in quantity and genus composition is not similar in the major hilsa fishery areas of the Meghna, Tetulia and Andhermanik river basins. Maximum plankton abundance, both in number and texa, was observed in the Meghan and Tetulia Rivers. So, preferred food organisms for hilsa were available in the sanctuary areas, but the availability in terms of quality and quantity, was higher in the Meghna River basins (Daulatkhan and Chandpur sites) and Tetulia River compared to Andhermanik River (Kalapara, Patuakhali site).

Table 3. Plankton abundance in different rivers of the hilsa fishery areas

MEAN, RANGE OF PLANKTON (CELLS L^{-1}) IN FOUR SITES				
GROUP	MEGHNA RIVER, CHANDPUR (SITE 1)	MEGHNA RIVER, DAULATKHAN BHOLA (SITE 2)	TETULIA RIVER, LALMOHON BHOLA (SITE 3)	ANDHERMANIK RIVER, KALAPARA, PATUAKHALI (SITE 4)
Phytoplankton	**34795 (5277–92655)**	**34142 (5462–93619)**	**30612 (5297–81457)**	**3225 (1530–5145)**
Bacillariophyceae	12545 (1221–35317)	14165 (2449–38987)	11707 (2419–31707)	2353 (1166–3694)
Chlorophyceae	20007 (2799–52543)	18839 (2370–54048)	17929 (2425–47760)	397 (148–706)
Cyanophyceae	1964 (423–5744)	914 (493–1635)	840 (211–1724)	120 (24–228)
Euglenophyceae	83 (0–277)	82 (33–200)	79 (28–180)	0
Xanthophyceae	62 (0–277)	0	0	0
Dinophyceae	134 (0–653)	142 (0–443)	57 (0–167)	355 (192–537)
Zooplankton	**2201 (716–5211)**	**1787 (463–4147)**	**1943 (727–4276)**	**795 (405–1208)**
Copepoda	448 (155–1319)	327 (103–563)	530 (167–1026)	499 (253–740)
Rotifera	1260 (156–2965)	1136 (80–3184)	1017 (92–3017)	174 (91–229)
Cladocera	322 (0–884)	225 (90–443)	308 (64–1391)	0
Protozoa & others	163 (0–431)	99 (27–200)	88 (27–251)	122 (0–274)
Total plankton	**36996 (6096–96604)**	**35929 (5925–97765)**	**32556 (6023–85733)**	**4020 (2210–5769)**

Values are means of 12 sampling dates and three locations (n=36). Ranges are given in parentheses.

Table 4. Plankton observed in different rivers (Meghna-Tetulia-Adhermanik Rivers)

GROUP	GENUS
Phytoplankton	
Bacillariophyceae	*Amphora, Asterinella, Bacillaria, Biddulphia, Chaetoceros, Cosmorium, Cyclotella, Coscinodiscus, Diatoma, Fragilaria, Gomphonema, Gyrosigma, Melosira, Navicula, Nitzschia, Pleorosigma, Pinullaria, Rhizosolenia, Surirella, Synedra, Tabellaria, Triceratium* and *Thallassionema*
Chlorophyceae	*Actinastrum, Ankistrodesmus, Botryococcus, Chlorella, Closterium, Coelastrum, Closteridium, Microspora, Micractinium, Muogeotia, Oedogonium, Oocystis, Pediastrum, Scenedesmus, Selenestrum, Spirogyra, Staurastrum, Stichococcus, Tetraedron, Ulothrix, Uroglena, Volvox* and *Zygnema*
Cyanophyceae	*Anabaena, Aphanizomenon, Aphanocapsa, Chroococcus, Gomphosphaeria, Merismopedium, Microcystis, Nostoc, Oscillatoria* and *Spirulina.*
Euglenophyceae	*Euglena* and *Phacus*
Xanthophyceae	*Botrydium*
Dinophyceae	*Ceratium, Peridinium* and *Protoperidinium*
Zooplankton	
Copepoda	*Cyclops, Diaptomus, Naupleus* and *Mesocyclops*
Cladocera	*Bosmina, Daphnia, Diaphanosoma, Moina* and *Sida*
Rotifera	*Asplanchna, Brachionus, Filinia, Hexarthra, Keratilla, Poliarthra* and *Trichocerca*
Protozoa	*Difflugia* and *Favella*

4

Conclusions and policy recommendations

This assessment of the physical, hydrological, chemical and biological profile of the environment of the hilsa fishery areas in Bangladeshi waters provides information which is essential to the updating of the hilsa fisheries management action plan and to the sustainable management of hilsa fishery more broadly.

The outcomes of the study show that water quality parameters, such as water pH, DO, alkalinity, water nutrients (NO_3-N, NO_2-N, PO_4-P) are within the ranges 'suitable' for fish in all the sites, except in the Andermanik River, where comperatively higher levels of ammonia-nitrogen were found. The largest quantity of plankton as a natural food (both in number and texa) was found in the Meghna river basin compared to the other rivers. The study also found that water quality was not the same in all the sites throughout the year, and this is likely to influence the migration of hilsa upsteam, as well as their feeding and spawning.

We conclude that, from the ecological view point, the hilsa sanctuaries are characterised by 'optimal' or 'acceptable' level of water quality. However, in some areas (particularly the Andermanik River) it was found to be unsuitable for hilsa fish. Therefore, efforts must be made to enforce existing pollution control policies – particularly pollution from industrial effluents.

Several sub-merged islands or sand bars were found in the lower Meghna, Tetulia and Andhermanik Rivers which may disrupt the migration patterns of hilsa. Therefore, drastic efforts should be made to dredge the rivers and restore water flow and depth which is critical for hilsa migration and feeding. Efforts must be made to minimize, or where possible, eliminate non-fishing related stresses and integrate these recommendations in the overall hilsa management action plan.

References

Ahammad, F (2004) Catch Composition of Estuarine Set Bag Net (ESBN) in the Moheshkhali Channel of the Bay of Bengal, Bangladesh. MSc Thesis, Institute of Marine Sciences, University of Chittagong, Bangladesh.

Ahmed, KKU, Ahmed, SU, Hossain, MRA, Ahmed, T and Rahman, S (2003) Quantitative and qualitative assessment of plankton: some ecological aspect and water quality parameters of the river Meghna, Bangladesh. Bangladesh J. Fish Res. **7**(2): 131–140.

Ahmed, KKU, Ahmed, SU, Haldar, GC, Hossain, MRA and Ahmed, T (2005) Primary Production and Fish Yield Estimation in the Meghna River System, Bangladesh. *Asian Fisheries Science* 18 (2005): 95–105 Asian Fisheries Society, Manila, Philippines.

Ahmed, MF and Rahman, MM (2000) Water Supply and Sanitation. ITN-Bangladesh, Centre for Water Supply and Waste Management, BUET, Dhaka, Bangladesh.

Ahmed, ZF, Wahab, MA, Miah, MAH and Azim ME (2000) Investigation of Water Quality Parameters in Carp Nursery under Two Different ponds Conditions. Pakistan Journal of Biological Sciences 3 (8): 1349–1351.

Ahmed, ZF (1993) Electivity index and dietary overlap of *Catla catla* (Hamilton) in fertilized ponds of Bangladesh. M.S. dissertation, Dept. of Fisheries Biology and Limnology, Bangladesh Agricultural University, Mymensingh, 163 p.

Ahsan, DA, Kabir AKMN, Rahman, MM, Mahabub, S, Yesmin, R, md. Faruque, H and Naser, MN (2012) Plankton composition, abundance and diversity in hilsa (*tenualosa ilisha*) migratory rivers of Bangladesh during spawning season. Dhaka Univ. J. Biol. Sci. **21**(2): 177–189, 2012 (July).

Ahsanullah, M (1964) Population dynamics of hilsa in East Pakistan. *Agriculture Pakistan.* 15, 351–365.

APHA (1992) *Standard methods for the examination of water and waste water.* American Public Health Association, Washington DC.

Belcher, H and Swale, S (1976) A beginner's guide to freshwater algae. Institute of Terrestrial Ecology, Natural Environmental Research Council, London. 47 pp.

Bellinger, EG (1992) A Key to Common Algae, Freshwater and Some Coastal Species, 4th edition. Institute of Water and Environmental Management, London.

BFRI/RS (1994) Bangladesh Fisheries Research Institute, Riverine Station. Hilsa Fisheries Development and Management. *Annual Rep.BFRI/RS 94*. 21 pp.

Bhatnagar, A and Singh, G (2010) Culture fisheries in village ponds: a multilocation study in Haryana, India. *Agriculture and Biology Journal of North America*, 1(5), pp 961–968.

Bhatnagar, A, Jana, SN, Garg, SK, Patra, BC, Singh, G and Barman, UK (2004) Water quality management in aquaculture, In: Course Manual of summerschool on development of sustainable aquaculture technology in fresh and saline waters, CCS Haryana Agricultural, Hisar (India), pp 203–210.

Bhaumik, U and Sharma, AP (2012) Present status of hilsa in Hooghly-Bhagirathi river. *CIFRI Bulletin* No.179.

Bhaumik, U, Srivastava, NP, Satpathy, BB, Mukhopadhyay, MK and Sharma, AP (2011) Impact of hydro-ecology on fish migration in selected east coast estuaries. *J. Inland Fish. Soc.* 43(1):1–9.

Bhuiyan, BR (1970) Physico-chemical qualities of water of some ancient tanks in Sibsagar. Assam, *Environ. Health,* **12:** 129–134.

Blaber, SJM (2000) Tropical Estuarine Fishes: Ecology, Exploitation and Conservation. Blackwell Science, Oxford, 372p.

Boyd, CE and Lichtkoppler, F (1979) Water Quality Management in Fish Ponds. Research and Development Series No. 22, International Centre for Aquaculture (JCAA) Experimental Station Auburn University, Alabama, pp 45–47.

Boyd, CE (1979) Water quality in warm water fish ponds. Auburn University, Craftmaster Printers, Opelika, Alabama, 359 p.

Chacko, PI and Krishnamurthy, B (1949) Hermaphroditism in the Indian shad, *Hilsa ilisha* (Ham.), *North Am. J. Fish. Manage.*, vol. 36, no. 3, pp. 167.

Curray, JR and Moore, DD (1971) Growth of Bengal Deep Sea Fan and Denudation in the Himalayas. In: Submarine canyons and deep sea fans (ed. J.H.M. Whitaker). Hutchinson and Ross, Inc., Pennsylvania, USA, pp. 236–245.

ECR (1997) The Environment Conservation Rules. Government of the People's Republic of Bangladesh. Ministry of Environment and Forest. pp. 205–207

Haldar, GC, Rahman, M and Haroon, AKY (1992) Hilsa, *Tenualosa ilisha* (Ham.), fishery of Feni River with reference to the impacts of the flood control structures. *J. Zool.*, **7**, 51–56.

Holemen, JN (1986) The sediment field of major rivers of the world, Water Resources Research, 4/4: 737–747.

Hossain, MS, Das NG, Subrata S and Rahaman, MZ (2013) Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. National Institute of Oceanography and Fisheries. *Egyptian Journal of Aquatic Research* (2012) 38, 213–226.

Jafri, SIH (1988) Biology and fishery of river Shad (Palla) – a review. Pak. J. Agric.Res. 9 (2), 252–263.

Maes, J, Van Damme, S, Meire, P and Ollevier, F (2004) Statistical modeling of seasonal and environmental influences on the population dynamics of an estuarine fish community. Marine Biology 145, 103342.

Mahmud MM, Khan AN, Kamal D, Rahman MA and Hossain MA (2007) Abundance and distribution of phytoplankton in Mouri river. Bangladesh. J. Asiat. Soc. Bangladesh. Sci. **33**(2): 161–168.

McErlean, AJ, O'Connor, SG, Mihursky, JA and Gibson, CI (1973) Abundance, diversity and seasonal patterns of estuarine fish populations. Estuarine, Coastal and Marine Science 1, 1936.

Meade, JW (1985) Allowable ammonia for fish culture, Progressive Fish culture, 47, pp 135–145.

Milton, DA and Chenery, SR (2001) Can otolith chemistry detect the population structure of the shad hilsa, *Tenualosa ilisha*? Comparison with the results of genetic and morphological studies. Mar. Ecol. Prog. Ser 222: 239–251.

Milton, DA and Chenery, SR (2003) Movement patterns of the tropical shad, hilsa (*Tenualosa ilisha*) inferred from transects of 87Sr/86Sr isotope ratios in their otoliths Can. J. Fish. Aquat. Sci. 60(11): 1376–1385

Mitra, GN and Devasundaram, MP (1954) On the Hilsa of the Chilka Lake with a note on the occurrence of Hilsa in Orissa, *J. Asiat. Soc. (Sci.)*, vol. 20, no. 1, pp. 33–40.

Mohammed, EY and Wahab, MA (2013) *Direct Economic Incentives for Sustainable Fisheries Management: The Case of Hilsa Conservation in Bangladesh*, IIED, London. http://pubs.iied.org/pdfs/16527IIED.pdf.

Moses, BS (1983) Introduction to Tropical Fisheries, Ibadan University Press, UNESCO/ICSU, Part, pp: 102–105.

Moyle, JB (1946) Some indices of lake productivity, Transactions of the American Fisheries Society, 76, pp 322–334.

Ornamental Aquatic Trade Association (OATA) (2008) Water Quality Criteria. Version 2.0, March 2008. www.ornamentalfish.org/wp-content/uploads/2012/08/Water-Quality-Criteria.pdf [Last accessed 21 April 2015].

Pillay, TVR (1958) Biology of the Hilsa, *Hilsa ilisha* (Hamilton) of the River Hooghly, *Int. J. Geogr. Inform. Syst.,* vol. 5, pp. 201–257.

Prescott, GW (1962) Algae of the Western Great Lakes Area. Wm. C. Brown Co., Dubuque, Iowa. 977 pp.

Quereshi, MR (1968) Hilsa fishery in East Pakistan. *Pakistan Journal of Scientific and Industrial Research,* 11, 95–103.

Rahman MJ (2006) Recent advances in the biology and management of Indian shad (*Tenualosa ilisha* Ham.). *SAARC Journal of Agriculture,* 4: 67–90.

Rahman, M (1997) Studies on population structure of shad in Bangladesh waters with emphasis on population genetics of hilsa shad (*Tenualosa ilisha*). Ph D thesis, Department of Fisheries & Marine Biology, University of Bergen, Norway.

Rahman, MM, Nagelkerke, LAJ, Verdegem, MCJ, Wahab MA, Verreth JAJ (2008) Relationships among water quality, food resources, fish diet and fish growth in polyculture ponds: A multivariate approach. Aquaculture 275 (2008) 108–115.

Rahman, MA, Emran, M and Islam, MS (2010) Hilsa fisheries management in Bangladesh. *Regional Consultation on Preparation of Management Plan for Hilsa Fisheries.* The Bay of Bengal Programme Inter-Governmental Organization (BOBP-IGO) BOBP-IGO/RC-HF2/5, 7–8 February 2010, Chittagong, Bangladesh, pp. 16.

Rahman, MA, Alam, MA, Hasan, SJ and Jaher, M (2012) Hilsa fishery management in Bangladesh in Anon (ed.) *Hilsa: Status of Fishery and Potential for Aquaculture, Proceedings of the Regional Workshop held in Dhaka, 16–17 September 2012*, The WorldFish, Bangladesh and South Asia Office, Dhaka, pp. 40–60.

Rahman, MJ (2001) Population biology and management of the hilsa shad (*Tenualosa ilisha*) in Bangladesh. Ph.D. Thesis. The University of Hull, England. 253pp.

Raja, BTA (1985) A review of the biology and fisheries of *Hilsa ilisha* in the upper Bay of Bengal. Proceedings of the Marine Fisheries Resourse Management. Bay of Bengal, Colombo, Sri Lanka. *FAO/UNDP BOBP/WP/37*, 66 pp.

Santhosh, B and Singh, NP (2007) Guidelines for water quality management for fish culture in Tripura, ICAR Research Complex for NEH Region, Tripura Center, Publication no.29.

Shafi M, Quddus, MMA and Islam, N (1978) Studies on the limnology of the river Meghna. Bangladesh J. Fish. 1(2): 85–97.

Stirling, HP (1985) Chemical and Biological Methods of Water Analysis for Aquaculturists, Institute of Aquaculture, University of Stirling. Scotland. 117pp.

Varshney, RK, Ujjania NC, Kumar V and Halwai BK (2004) Water quality parameters: Guidelines for fish farmers. *Fishing Chimes* 24 (4): 43–45.

Wahab, MA, Bergheim A and Braaten B (2003) Water quality and partial mass budget in extensive shrimp ponds in Bangladesh. Aquaculture 218: 413–423.

Ward, HB and Whipple, GC (1959) Freshwater Biology. John Wiley and Sons, New York. 1248 pp.

Whitefield, AK (1999) Ichthyofaunal assemblages in estuaries: a South African case study. Reviews in Fish Biology and Fisheries 9: 151–186.

The common Indian shad 'hilsa' (*Tenualosa ilisha*) is the most important anadromous fish species of Bangladesh that migrates through the Padma-Meghna River systems. A study was carried out between January and December 2014 to assess the physical, chemical, and biological parameters of the habitat of the hilsa fishery areas. While the parameters were found to be at 'acceptable' levels, some measures are needed to improve the quality of water to ensure successful migration and reproduction of the hilsa fish. Efforts must be made to minimize, or where possible, eliminate non-fishing related stresses such as siltation and pollution and integrate them into the overall hilsa fisheries management action plan.

iied

International Institute for Environment and Development
80-86 Gray's Inn Road, London WC1X 8NH, UK
Tel: +44 (0)20 3463 7399
Fax: +44 (0)20 3514 9055
email: info@iied.org
www.iied.org

Knowledge Products

Funded by:

UKaid from the British people

DARWIN INITIATIVE

This research was funded by UK aid from the UK Government, however the views expressed do not necessarily reflect the views of the UK Government.