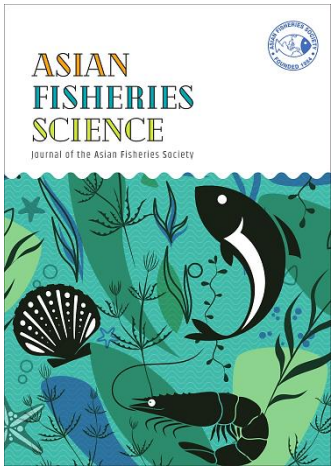

Diversity of Biological Communities Along the Major Rivers of Sundarbans in Bangladesh

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Abstract

Despite recent unexpected and irreversible changes in the environment brought on by global climate change, the largest mangrove forest of Sundarbans is still considered a biodiversity hotspot in Bangladesh. This study aimed to assess the abundance, diversity indices and richness of plankton and fisheries resources of the four major rivers (Pasur, Sela, Sibsa, and Kapotakkho) in Sundarbans. During the study period (July 2017 to November 2018), the range of pH, temperature, salinity and dissolved oxygen values were from 7.1 to 8.7, 25 °C to 32.8 °C, 1.5 ‰ to 23 ‰ and 4.3 mg.L^{-1} to 7.7 mg.L^{-1}, respectively. Phytoplankton and zooplankton communities were represented by 29 and 18 species, respectively. The number of plankton per litre was highest in the Pasur River during both pre-monsoon and post-monsoon season. A total of 186 species of fish and crustaceans were recorded in the rivers of Sundarbans. The plankton, fish and crustacean diversity indices were as follows: Shannon-Wiener diversity (1.22 ± 0.27 to 3.48 ± 0.22), Margalef's richness (1.29 ± 0.33 to 4.56 ± 0.45) and Pielou's evenness (0.94 ± 0.04 to 1.02 ± 0.04). The results of the present study underscore new insight on riverine biological communities of the Sundarbans and emphasise the need for long-term monitoring in this ecologically fragile ecosystem.

Keywords: mangrove forest, biodiversity, richness, evenness, fisheries resources

Introduction

The Sundarbans (21°30′ to 22°40′ N, 88°05′ to 89°55′ E) are the only contiguous and largest mangrove forest system in the world with a total area of over 10,000 km^2 (Gopal and Chauhan, 2006). About 60 % of the Sundarbans is under the Bangladesh territory and located on the northern limits of the Bay of Bengal and the old Ganges delta (Agarwala et al., 2003). The size, abundance of tidal rivers, flora and fauna, productivity and significance in the ecological balance make the Sundarbans a unique ecological site (Mamun et al., 2009) hence was designated under the World Heritage site in 1999.

The highly interwoven river system and large trucks of wetlands are also known for their rich aquatic biodiversity, which includes 250 fish species and numerous species of phytoplankton, zooplankton, invertebrates and molluscs (Gopal and Chauhan, 2006). Aziz et al. (2012) listed 36 species of phytoplankton belonging to the families Chlorophyceae, Euglenophyceae, Bacillariophyceae and Xanthophyceae. Eleven (11) major taxa of zooplankton occurred in the Sundarbans estuarine system of Bangladesh (Mamun et al., 2009), while 56 taxa were identified from the Matla River in the Sundarbans estuarine system, India (Nandy and Mandal, 2020).

The Sundarbans are abundant with vast biological resources and an important breeding ground for marine fish species such as *Tenualosa ilisha* (Hamilton, 1822), *Lates calcarifer* (Bloch, 1790), *Liza parsia* (Hamilton, 1822) and *Platanista gangetica* (Lebeck, 1801) and *Orcaella brevirostris* (Owen in Gray, 1866) (GoB, 2010). In the current era of global change, human influences climate, food web structure, water

quality and habitat availability which eventually affect species abundance, altering their productivity, survival, reproductive success, interaction with other species, geographic distribution and behaviour (Barange et al., 2018). Qiu and Zhu (2015) found that the rise in sea level will likely have significant ecosystem consequences via saltwater intrusion and degree of stratification. They estimated 28 % to 48 % changes in freshwater volume by 2100 in the riverine estuary. Similarly, the biodiversity of mangrove forests has also been increasing with greater interest because of global climate change.

Many species prefer the Sundarbans nursery habitats, and the continued decline of intertidal areas will likely reduce the recruitment of these species with harmful effects on both the small-scale and the semi-industrial fisheries (Lugendo, 2015). However, low fisheries compliance, widespread migratory fishing and extreme weather events that reduced fish diversity and biomass in the mangroves resulted in negative impacts on life-history characteristics and emphasised the need for increased management restrictions and compliance to sustain these climate-adaptive centres. Therefore, it is crucial to assess the present status of productivity and fisheries diversity of the largest diversified mangrove forest of the Sundarbans, which serve as important nursery and breeding grounds for fish and other biological communities. The objective of the study was to understand the seasonal fluctuation of water quality parameters and assess the diversity of plankton, fish and crustacean communities in the major rivers of the Sundarbans, Bangladesh.

Materials and Methods

Sampling stations

This study focuses on the Sundarbans in Bangladesh (Fig. 1). The study was carried out in Khulna Sadar, Bagerhat Sadar, Mongla, Digrajbazar, Shatkhira, Shemnagar, Koira, Paikgacha, Garuikhali, and Mongla port along with four major rivers (Pasur, Sela, Sibsa, Kapotakkho) of the Sundarbans area from July 2017 to November 2018.

Water quality parameter analysis

Basic water qualities of the study area such as pH (pHep tester-98107, Hanna Instruments, Romania), salinity (Refractometer-96801, Hanna Instruments, Romania), DO (Meter-5509, China) and temperature (Celsius thermometer) of water were determined *in situ* with the help of respective instruments.

Collection and identification of plankton

Plankton samples were collected from four main rivers of the Sundarbans (Fig. 1). Each stream was divided into three stations. Phytoplankton and zooplankton samples were collected from 12 stations using a simple conical tow-net oblique mesh size of 40 µm. The samples were preserved in 4 % formalin in a plastic container for both qualitative and quantitative analysis. Both phytoplankton and zooplankton cells were enumerated under a light microscope using Sedgewick Rafter cell. A series of pencil and ink drawing on postcards of the species were prepared to identify the organisms. Phytoplankton identification was done according to Bellinger (1992). Zooplanktons were identified following keys given by Bhouyain and Asmat (1992).

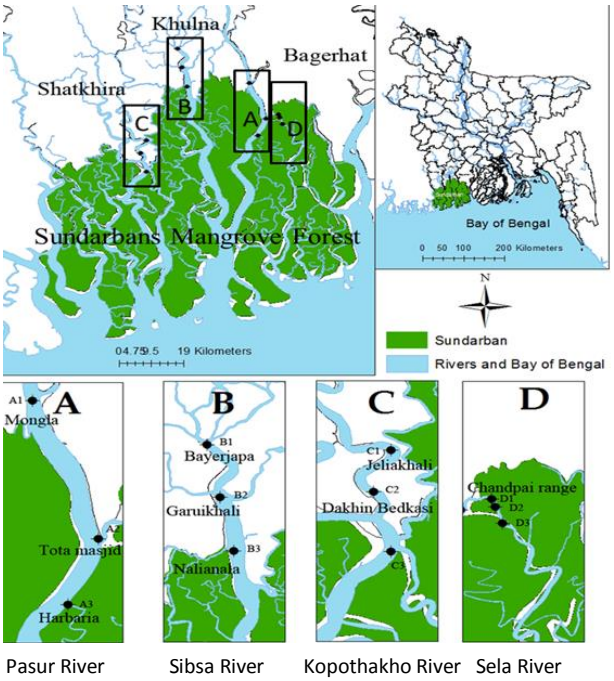

Fig. 1. Sampling stations for the diversity of biological communities in the major rivers of Sundarbans. (A) Pasur; (B) Sibsa; (C) Kapotakkho; (D) Sela.

Counting of plankton

For phytoplankton counting, the Sedgwick-Rafter (S-R) cell was used which is 50 mm long, 20 mm wide and 1 mm deep. The number of phytoplankton in the S-R cell was derived from the following formula:

$$\text{No. mL}^{-1} = \frac{\text{C} \times 1000}{\text{L} \times \text{D} \times \text{W} \times \text{S}}$$

where,
C = Number of organisms (phytoplankton and zooplankton) counted.
L = Length of each strip (S-R cell length) in mm.
D = Depth of a strip (Whipple grid image width) in mm.
S = Number of strips counted.
W = Width of the strip (Whipple grid image width) in mm.

The number of cells per mm was multiplied by a correction factor to adjust the number of organisms

per litre.

Data collection of fisheries resources

Data of fisheries resources of Sundarbans were collected by monthly routine investigations. The investigations were made by monitoring the local fish markets, fishery ghat and fishers' boats where fishes were captured and the boat landing sites.

Identification of fisheries resources

Fish samples were brought to the laboratory for double confirmation to identify the fish species. The samples were confirmed based on the morphometric and meristic appearances according to Talwar and Jhingran (1992), Rahman (2005) and Rahman et al. (2009).

Calculation of diversity indices

In this study Shannon-Wiener diversity index (H'), Margalef's richness index (D) and Pielou's evenness index (e) were calculated to obtain an estimation of species diversity, species richness and species evenness, respectively, using the following formulae:

Shannon-Wiener diversity index:

$$H' = -\sum_{i}^{S}(ni/N) \times \ln(ni/N)$$

Margalef's richness index: $D = (S-1)/\ln N$

Pielou's evenness index: $e = H'/\ln S$

Here, H' is the diversity index, n*i* is the density of *i*th species, N is the total density and S is the total number of species found at one sampling date, ln is natural logarithm and Σ is the sum of the calculations.

Results

Water quality parameters

In this study, water quality parameters of four rivers were analysed and the average values of temperature, pH, salinity and DO are shown in Figure 2.

Quantitative analysis of plankton in major rivers of Sundarbans

The occurrence of phytoplankton (cells.L^{-1}) and zooplankton (individuals.L^{-1}) of the major rivers of Sundarbans are given in Table 1. In this study, phytoplankton cells were recorded highest in the Pasur River during the monsoon season and the lowest were in Kapothakkho River during all seasons. The abundance of zooplankton showed the same trend as the phytoplankton, with the lowest occurrence in the monsoon season and the highest in post-monsoon. In Kapotakkho River, zooplankton (individuals.L^{-1}) was low during all seasons.

Qualitative analysis of plankton

A total of 29 species of phytoplankton and 18 species of zooplankton were identified (Table 2) from the four major river system of Sundarbans. Among the phytoplankton, Bacillariophyceae was recorded with the highest number of species (16), while Xanthophyceae had the lowest (1). Among zooplankton, Hexanauplia was represented by 11 species which is the highest number. Branchiopoda and Malacostraca were represented by 3 species and 2 species, respectively. Only one species was recorded from both Ostracoda and Monogononta class.

Fish and crustacean abundance in Sundarbans

The abundance of fish and crustaceans are presented

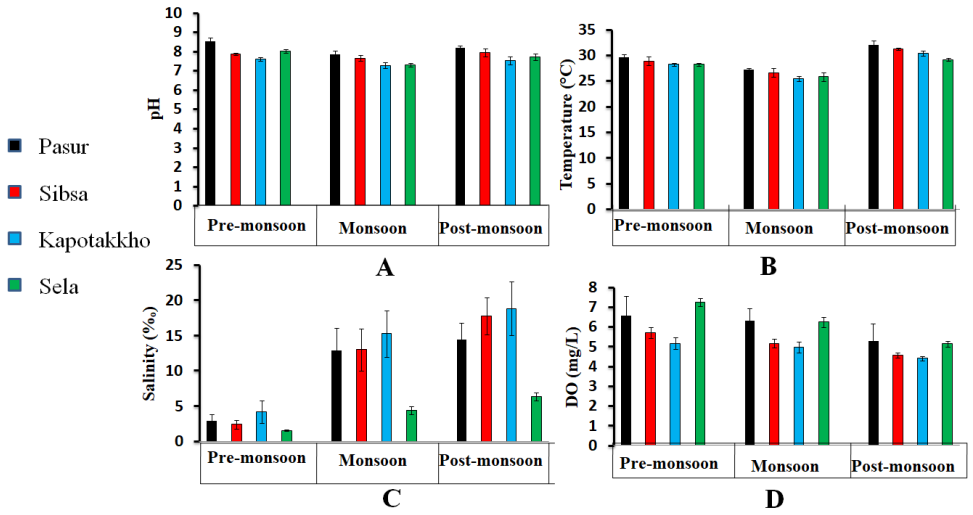

Fig. 2. Seasonal variation of water quality parameters assessed from Pasur, Sibsa, Kapothakkho and Sela rivers of the Sundarbans. (A) pH; (B) Temperature; (C) Salinity; (D) Dissolved oxygen (DO).

Table 1. Phytoplankton (cells.L^{-1}) and zooplankton (individuals.L^{-1}) abundance in different seasons in the major rivers of Sundarbans.

Major rivers	Sampling area	Pre-monsoon		Monsoon		Post-monsoon	
		Phyto-plankton	Zoo-plankton	Phyto-plankton	Zoo-plankton	Phyto-plankton	Zoo-plankton
Pasur	22°27′56″N 89°35′21″E	6297 ± 478	2168 ± 167	5085 ± 445	1993 ± 240	6544 ± 629	2659 ± 335
Sibsa	22°34′25″N 89°23′59″E	3281 ± 635	1810 ± 276	3722 ± 616	1396 ± 246	4728 ± 768	2503 ± 199
Kapotakkho	22°17′01″N 89°19′06″E	639 ± 40	290 ± 90	363 ± 50	168 ± 36	599 ± 77	367 ± 89
Sela	22°21′57″N 89°39′59″E	3981 ± 278	1178 ± 408	1929 ± 316	1052 ± 110	3100 ± 368	2541 ± 281

Values are represented as mean ± SD.

Table 2. List of phytoplankton and zooplankton found in Pasur, Sibsa, Kapothakkho and Sela rivers of the Sundarbans.

Phytoplankton			Zooplankton		
Class	Species	No.	Class	Species	No.
Chlorophyceae	*Oocystis pusilla* var. maior Skuja, 1949 *Uronema* sp. *Echinosphaerella limnetica* Smith, 1920	3	Malacostraca	*Lucifer* sp. *Scylla serrata* (Forsskål, 1755)	2
			Ostracoda	*Pseudocandona* sp.	1
Euglenophyceae	*Astasia cylindrical* Pringsheim, nom. Illeg., 1942 *Euglena spathirhyncha* Skuja, 1948	2	Monogononta	*Brachionus* sp.	1
Bacillariophyceae	*Bacteriastrum delicatulum* Cleve, 1897 *Chaetoceros pendulus* Karsten, 1905 *Chaetoceros socialis* Lauder, 1864 *Coscinodiscus excentricus* var. punctifera Grunow, 1884 *Coscinodiscus lineatus* Ehrenberg, 1840 *Coscinodiscus granii* Gough, 1905 *Coscinodiscus marginatus* Ehrenberg, 1843 *Coscinodiscus jonesianus* (Greville) Ostenfeld, 1915 *Cyclotella comta* Kützing, 1849 *Humidophila brekkaensis* (Petersen) Lowe, 2014 *Thalassionema nitzschioides* (Grunow) Mereschkowsky, 1902 *Lioloma delicatulum* (Cupp) Hasle, 1996 *Skeletonema costatum* (Greville) Cleve, 1873 *Nitzschia acicularis* (Kützing) Smith, 1853 *Nitzschia sigma* (Kützing) Smith, 1853 *Proboscia* sp.	16	Hexanauplia	*Acartia* sp. *Mesocyclops* sp. *Centropages* sp. *Mysidella* sp. *Diaptomus* sp. *Calanus* sp. *Cyclops* sp. *Oithona* sp. *Paracalanus* sp. *Pseudocalanus* sp. *Paracartia* sp.	11
Cyanophyceae	*Microcystis aeruginosa* Kützing, 1846 *Microcystis elongate* Desikachary, 1959 *Microcystis argentea* Schiller, 1954 *Gloeotrichia pisum* Thuret ex Bornet & Flahault, 1886 *Chroococcus disperses* (Keissler) Lemmermann, 1904	5	Branchiopoda	*Bosmina* sp. *Praunus* sp. *Daphnia* sp.	
Zygnematophyceae	*Gonatozygon aculeatum* Hastings, 1892 *Gonatozygon brebissonii* De Bary, 1858	2			
Xanthophyceae	*Centritractus belanophorus* (Schmidle) Lemmermann, 1900	1			

Source: www.algaebase.org; www.marinespecies.org

in Table 3 and Table 4, respectively. Fish, shrimp, prawn, crab and lobster species were recorded as 164, 11, 5, 5 and 1 species in number, respectively, during the study period. Eight species of shark and ray belonging to 4 families and 156 species of teleost fish belonging to 58 families were also recorded (Table 3). Among the 164 fish species, seven vulnerable and six endangered species were identified according to IUCN red list (IUCN, 2015). Under the order Decapoda, a total of 22 species were also recorded under 8 families (Table 4) with one endangered species.

Diversity indices of plankton, fish and crustaceans in Sundarbans

The temporal and monthly variation of plankton, fish and crustacean diversity indices during the study period are given in Table 5. Phytoplankton community showed marked variation in Shannon-Wiener diversity index (H') from 2.06 (October) to 2.53 (July), Margalef's richness (D) from 1.58 (October) to 3.1 (July) and Pielou's evenness (e) from 0.94 (March) to 1.05 (December). In zooplankton, the recorded minimum

Table 3. List of fish species found in Pasur, Sibsa, Kapothakkho and Sela rivers of the Sundarbans.

Order	Family	Species	Common name	IUCN status	No.
Lamniformes	Carcharhinidae	*Scoliodon sorrakowah* Müller & Henle, 1838	Dog fish shark	NT	3
		Carcharhinus melanopterus (Quoy & Gaimard, 1824)	Black tip reef shark	NT	
	Sphyrnidae	*Sphyrna blochii* (Cuvier, 1816)	Hammer headed shark	NT	
Rajiformes	Rhinobatidae	*Rhynchobatus djiddensis* (Forsskål, 1775)	Giant guitarfish	VU	4
	Dasyatidae	*Himantura uarnak* (Gmelin, 1789)	Honeycomb stingray	VU	
		Himantura walga (Müller & Henle, 1841)	Scaly whipray	NT	
		Dasyatis zugei (Müller & Henle, 1841)	Pale-edged stingray	NT	
Osteoglossiformes	Notopteridae	*Chitala chitala* (Hamilton 1822)	Indian featherback	EN	2
		Notopterus notopterus (Pallas, 1769)	Bronze featherback	VU	
Elopiformes	Elopidae	*Elops machnata* (Forsskål, 1775)	Tarpon	LC	1
Anguiliformes	Muraenesocidae	*Muraenesox cinereus* (Forsskål, 1775)	Dagger tooth Pike Conger	NE	2
		Congresox talabonides (Bleeker, 1853)	Eel	NE	
Clupeiformes	Engraulidae	*Coilia ramcarati* (Hamilton, 1822)	Ramcarat Grenadier Anchovy	NE	24
		Coilia neglecta Whitehead, 1967	Neglected Grenadier Anchovy	LC	
		Coilia dussumieri Valenciennes, 1848	Gold spotted Grenadier Anchovy	LC	
		Setipinna phasa (Hamilton, 1822)	Gangetic Hairfin Anchovy	LC	
		Setipinna taty (Valenciennes, 1848)	Scaly Hairfin Anchovy	LC	
		Stolephorus tri (Bleeker, 1852)	Spined Anchovy	LC	
		Thryssa dussumieri (Valenciennes, 1848)	Anchovy	LC	
		Thryssa hamiltoni Gray, 1835	Hamilton's Thryssa	LC	
	Clupeidae	*Gudusia chapra* (Hamilton, 1822)	Indian River Shad	LC	
		Escualosa thoracata (Valenciennes, 1847)	White Sardine	NE	
		Sardinella gibbosa (Bleeker, 1849)	Gold Stripe Sardine	NE	
		Sardinella melanura (Cuvier, 1829)	Blacktip Sardinella	NE	
		Sardinella fimbriata (Valenciennes, 1847)	Sardine	NE	
		Anodontostoma chacunda (Hamilton, 1822)	Chacunda Gizzard Shad, Shortnose Gizard Shad	NE	
		Dussumieria acuta Valenciennes, 1847	Rainbow sardine	LC	
		Raconda russeliana Gray, 1831	Smooth Back Herring	LC	
		Tenualosa ilisha (Hamilton, 1822)	River Shad, Hilsa Shad	LC	
		Tenualosa toli (Valenciennes, 1847)	Toli Shad, Shad	NE	
		Hilsha kelee (Cuvier, 1829)	Kelee Shad	NE	
	Pristigasteridae	*Pellona ditchela* Valenciennes, 1847	Indian Pellona Herring	LC	
	Chirocentridae	*Chirocentrus dorab* (Forsskål, 1775)	Dorab Wolf-Herring	NE	
		Chirocentrus nudus Swainson, 1839	Wolf herring	LC	
Cypriniformes	Cyprinidae	*Esomus danricus* (Hamilton, 1822)	Flying barb	LC	10
		Amblypharyngodon mola (Hamilton, 1822)	Mola carplet	LC	
		Osteobrama cotio (Hamilton, 1822)	Cotio	LC	
		Labeo calbasu (Hamilton, 1822)	Black rohu	LC	
		Labeo rohita (Hamilton, 1822)	Rohu	LC	
		Labeo bata (Hamilton, 1822)	Bata labeo	LC	
		Cirrhinus cirrhosus (Bloch, 1795)	Curvey white carp	LC	
		Puntius sophore (Hamilton, 1822)	Spotfin swamp barb	LC	
		Puntius ticto (Hamilton, 1822)	Ticto barb	VU	
		Catla catla (Hamilton, 1822)	Catla	LC	

Table 3. Continued.

Order	Family	Species	Common name	IUCN status	No.
Siluriformes	Siluridae	*Wallago attu* (Bloch & Schneider, 1801)	Boal	VU	20
		Ompok bimaculatus (Bloch, 1794)	Butter Catfish	EN	
	Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)	Stinging catfish	LC	
	Plotosidae	*Plotosus canius* (Hamilton, 1822)	Gray eel-catfish	NT	
	Chacidae	*Chaca chaca* (Hamilton, 1822)	Squarehead catfish	EN	
	Pangasidae	*Pangasius hypophthalmus* (Sauvage, 1878)	Iridescent shark	LC	
		Pangasius pangasius (Hamilton, 1822)	Pungas catfish	EN	
	Schilbeidae	*Silonia silondia* (Hamilton, 1822)	Silond catfish	LC	
	Bagridae	*Rita rita* (Hamilton, 1822)	Rita	EN	
		Sperata aor (Hamilton, 1822)	Long-whiskered catfish	VU	
		Mystus tengara (Hamilton, 1822)	Tengara mystus	LC	
		Mystus gulio (Hamilton, 1822)	Long whiskers catfish	NT	
	Ariidae	*Osteogeneiosus militaris* (Linnaeus, 1758)	Soldier catfish	LC	
		Arius gagora (Hamilton, 1822)	Gagora catfish	NT	
		Arius sona (Hamilton, 1822)	Sona sea catfish	NE	
		Arius thalassinus (Rüppell, 1837)	Giant catfish	NE	
		Arius buchanani Day, 1877	Threadfin sea catfish	NE	
		Arius dussumieri Valenciennes, 1840	Blacktip sea catfish	LC	
		Arius nenga (Hamilton, 1822)	Engraved catfish	NE	
		Arius maculatus (Thunberg, 1792)	Spotted sea catfish	NE	
Aulopiformes	Harpadontidae	*Harpadon nehereus* (Hamilton, 1822)	Bombay duck	NE	1
Cyprinodontiformes	Hemirhamphidae	*Hyporhamphus limbatus* (Valenciennes, 1847)	Congaturi halfbeak	LC	1
Syngnathiformes	Syngnathidae	*Hippocampus kuda* Bleeker, 1852	Yellow seahorse	VU	1
Synbranchiformes	Synbranchidae	*Monopterus cuchia* (Hamilton, 1822)	Gangetic mud eel	LC	1
Scorpaeniformes	Platycephalidae	*Coxiella crocodiles* (Cuvier, 1829)	Flat head	NE	3
		Platycephalus scaber (Linnaeus, 1758)	Flat head	NE	
		Rogadius asper (Cuvier, 1829)	Olive tail flat head	LC	
Perciformes	Mastacembelidae	*Macrognathus aculeatus* (Bloch, 1786)	Lesser spiny eel	NT	80
		Mastacembelus armatus (Lacepède, 1800)	Zig-zag eel	EN	
	Stromateidae	*Pampus chinensis* (Euphrasen, 1788)	Chinese silver pomfret	NE	
		Pampus argenteus (Euphrasen, 1788)	Silver pomfret	NE	
	Polynemidae	*Polynemus paradiseus* Linnaeus, 1758	Paradise threadfin	NE	
		Polynemus indicus Shaw, 1804	Threadfin fish	NE	
		Eleutheronema tetradactylum (Shaw, 1804)	Four finger threadfin	LC	
		Polydactylus indicus (Shaw, 1804)	Indian threadfin	NE	
	Mugilidae	*Rhinomugil corsula* (Hamilton, 1822)	Corsula	LC	
		Mugil corsula (Hamilton, 1822)	Corsula mullet	LC	
		Mugil cephalus Linnaeus, 1758	Flathead grey mullet	LC	
		Liza parsia (Hamilton, 1822)	Gold-spot mullet	LC	
		Liza subviridis (Valenciennes, 1836)	Green-back mullet	LC	
	Anabantidae	*Colisa fasciatus* (Bloch & Schneider, 1801)	Giant gourami	LC	
		Anabas testudineus (Bloch, 1792)	Climbing perch	DD	
	Eleotridae	*Butis melanostigma* (Bleeker, 1849)	Black-spotted gudgeon	LC	
	Gobiidae	*Pseudapocryptes elongatus* (Cuvier, 1816)	Hidden goby	LC	
		Pseudapocryptes lanceolatus (Cuvier, 1816)	Pointed-tailed goby	LC	
		Apocryptes bato (Hamilton, 1822)	Mud skipper	LC	
		Periophthalmus koelreuteri (Pallas, 1770)	Atlantic mudskipper	LC	
		Periophthalmodon schlosseri (Pallas, 1770)	Giant mudskipper	LC	
		Boleopthalmus boddarti (Pallas, 1770)	Boddarts goggle-eyed goby	LC	
		Glossogobius giuris (Hamilton, 1822)	Gangetic tank goby	LC	
		Parapocryptes batoides (Day, 1876)	Pacific ocean goby	LC	
		Scartelaos viridis (Hamilton, 1822)	Mud skipper	LC	
		Stigmatogobius sadanundio (Hamilton, 1822)	South Asian goby	LC	
	Trichiuridae	*Eupleurogrammus muticus* (Gray, 1831)	Small head hair tail	LC	
		Lepturacanthus savala (Cuvier, 1829)	Savalai hair tail	LC	
		Trichiurus lepturus Linnaeus, 1758	Large head hair tail	LC	
	Gobioididae	*Odontamblyopus rubicundus* (Hamilton, 1822)	Rubicusduseel goby	NE	

Table 3. Continued.

Order	Family	Species	Common name	IUCN status	No.
	Uranoscopidae	*Uranoscopus guttatus* (Cuvier, 1829)	Dollfus' star grazer	NE	
	Drepanidae	*Drepane longimana* (Bloch & Schneider, 1801)	Concertina fish	NE	
		Drepane punctata (Linnaeus, 1758)	Spotted sicklefish	NE	
	Ephippidae	*Ephippus orbis* (Bloch, 1787)	Orbfish	NE	
	Pomoadasyidae	*Pomadasys maculatus* (Bloch, 1793)	Saddle grunt	LC	
	Lethrinidae	*Lethrinus ornatus* Valenciennes, 1830	Ornate emperor	LC	
	Platycephalidae	*Platycephalus indicus* (Linnaeus, 1758)	Bartail flathead	NE	
	Sillaginidae	*Sillaginopsis panijus* (Hamilton, 1822)	Gangetic whiting	LC	
		Sillago domina Cuvier, 1829	Gangetic sillago	LC	
	Nandidae	*Nandus nandus* (Hamilton, 1822)	Gangetic leaffish	NT	
	Scatophagidae	*Scatophagus argus* (Linnaeus, 1766)	Spotted scat	LC	
	Lobotidae	*Lobotes surinamensis* (Bloch, 1790)	Atlantic black grunt	LC	
	Sparidae	*Acanthopagrus berda* (Forsskål, 1775)	Goldsilk sea bream	LC	
		Argyrops spinifer (Forsskål, 1775)	King soldier bream	NE	
	Sciaenidae	*Otolithoides pama* (Hamilton, 1822)	Long-finned croaker	LC	
		Pterotolithus maculatus (Cuvier, 1830)	Blotched tiger-toothed croaker	LC	
		Macrospinosa cuja (Hamilton, 1822)	Gangetic bola	NT	
		Johnius coitor (Hamilton, 1822)	Coitor croaker	LC	
		Johnius argentatus (Houttuyn, 1782)	Silver jew fish	NE	
		Panna microdon (Bleeker, 1849)	Panna croaker	NE	
		Pennahia macrophthalmus (Bleeker, 1849)	Bloch's Croaker	NE	
	Carangidae	*Alepes melanoptera* (Swainson, 1839)	Short finned trevally	LC	
		Megalaspis cordyla (Linnaeus, 1758)	Torpedo scad	LC	
		Selar boops (Cuvier, 1833)	Oxeye scad	LC	
	Gerreidae	*Pentaprion longimanus* (Cantor, 1849)	Longfin mojarra	LC	
	Menidae	*Mene maculata* (Bloch & Schneider, 1801)	Moonfish	NE	
	Formionidae	*Formio niger* (Bloch, 1795)	Black pomfret	NE	
	Leiognathidae	*Gazza minuta* (Bloch, 1795)	Tooth pony	NE	
		Leiognathus fasciatus (Lacepède, 1803)	Banded ponyfish	LC	
		Leiognathus bindus (Valenciennes, 1835)	Splendid pony fish	NE	
		Secutor ruconius (Hamilton, 1822)	Deep pugnose pony fish	NE	
		Secutor insidiator (Bloch, 1787)	Pugnose pony fish	NE	
	Centropomidae	*Lates calcarifer* (Bloch, 1790)	Asian sea bass	LC	
	Ambassidae	*Pseudambassis ranga* (Hamilton, 1822)	Indian glassy fish	LC	
		Chanda nama (Hamilton, 1822)	Elongate glass-perchlet	LC	
		Chanda ranga (Hamilton, 1822)	Indian glassy fish	LC	
		Chanda baculis (Hamilton, 1822)	Deep pugnose ponyfish	LC	
		Pseudambassis baculis (Hamilton, 1822)	Himalayan glassy perchlet	LC	
	Serranidae	*Cephalopholis miniata* (Forsskål, 1775)	Coral hind	LC	
		Epinephelus fasciatus (Forsskål, 1775)	Black tip grouper	LC	
		Epinephelus tauvina (Forsskål, 1775)	Greasy grouper	DD	
	Scombridae	*Euthynnus affinis* (Cantor, 1849)	Mackerel tuna	LC	
		Rastrelliger brachysoma (Bleeker, 1851)	Short mackerel	DD	
	Channidae	*Channa striata* (Bloch, 1793)	Striped snakehead	LC	
		Channa marulius (Hamilton, 1822)	Giant snakehead	EN	
		Channa punctata (Bloch, 1793)	Green snakehead	LC	
		Channa orientalis Bloch & Schneider, 1801	Walking snakehead	LC	
	Toxotidae	*Toxotes chatareus* (Hamilton, 1822)	Spotted archerfish	NE	
	Teraponidae	*Terapon jarbua* (Forsskål, 1775)	Tiger perch	LC	
		Terapon theraps Cuvier, 1829	Large scaled terapon	LC	
Pleuronectiformes	Bothidae	*Pseudorhombus arsius* (Hamilton, 1822)	Large tooth flounder	NE	9
		Pseudorhombus elevatus Ogilby, 1912	Deep flounder	NE	
		Pseudorhombus malayanus (Bleeker, 1865)	Malayan flounder	NE	
	Soleidae	*Synaptura pan* (Hamilton, 1822)	Pan sole	NT	
		Synaptura orientalis (Bloch & Schneider, 1801)	Oriental sole	NT	
	Cynoglossidae	*Cynoglossus bilineatus* (Lacepède, 1802)	Four lined tongue sole	LC	
		Cynoglossus lingua (Hamilton, 1822)	Long tongue sole	LC	
		Cynoglossus cynoglossus (Hamilton, 1822)	Bengal tonguesole	LC	
		Cynoglossus kopsii (Bleeker, 1851)	Tongue sole	LC	
Tetraodontiformes	Tetraodontidae	*Chelonodon patoca* (Hamilton, 1822)	Milk spotted puffer	DD	2
		Chelonodon fluviatilis (Hamilton, 1822)	Green pufferfish	NE	

NE = Not evaluated; DD = Data deficient; LC = Least concern; NT = Near threatened; VU = Vulnerable; EN = Endangered.

Source: www.fishbase.org; www.marinespecies.org

Table 4.List of crustacean species found in Pasur, Sibsa, Kapothakkho and Sela rivers of the Sundarbans.

Order	Family	Species	Common name	IUCN status	No.
Decapoda	Penaeidae	*Penaeus monodon* Fabricius, 1798	Black tiger shrimp	NE	9
		Penaeus indicus Milne Edwards, 1837	Indian white prawn	NE	
		Penaeus merguiensis De Man, 1888	Banana shrimp	NE	
		Metapenaeus monoceros (Fabricius, 1798)	Speckled shrimp	NE	
		Metapenaeus brevicornis Milne Edwards, 1837	Yellow shrimp	NE	
		Metapenaeus spinulatus Kubo, 1949	Yellow shrimp	NE	
		Parapenaeopsis sculptilis (Heller, 1862)	Rainbow shrimp	NE	
		Parapenaeopsis stylifera (Milne Edwards, 1837)	Kiddi shrimp	NE	
		Parapenaeopsis uncta Alcock, 1905	Uncta Shrimp	NE	
	Solenoceridae	*Solenocera subnuda* Kubo, 1949	Coastal mud shrimp	NE	1
	Sergestidae	*Acetes indicus* Milne Edwards, 1830	Jawla paste shrimp	NE	1
	Palaemonidae	*Macrobrachium rosenbergii* (de Man, 1879)	Giant river prawn	NE	5
		Macrobrachium villosimanus (Tiwari, 1949)	Dimua river prawn	LC	
		Macrobrachium gangeticum Bate, 1868	Freshwater prawn	NE	
		Macrobrachium lamarrei (Milne Edwards, 1837)	Indian whisker prawn	EN	
		Palaemon styliferus Milne Edwards, 1840	Roshna prawn	NE	
	Portunidae	*Scylla serrata* (Forsskål, 1755)	Mud crab or mangrove crab	NE	1
	Grapsidae	*Sesarma mederi* (De Man, 1888)	Vinegar crab	NE	3
		Metaplax elegans De Man, 1888	Orange signaller crab	LC	
		Metaplax crenulata (Gerstaecker, 1856)	Mudflat varunid crab	LC	
	Macrophthalmidae	*Macrophthalmus brevis* (Herbst, 1804)	Marine crab	NE	1
	Scyllaridae	*Thenus orientalis* (Lund, 1793)	Flathead lobster	LC	1

NE = Not evaluated; LC = Least concern, EN = Endangered.

Source: www.marinespecies.org

Table 5. Diversity indices of fish, plankton and crustaceans with respective values of Shannon-Wiener diversity (H'), Margalef's richness (D) and Pielou's measure of evenness (e) in each sampling month.

Sampling month	Fish			Phytoplankton			Zooplankton			Crustaceans		
	H'	D	e	H'	D	E	H'	D	e	H'	D	e
Jul/2017	3.61	4.84	1.04	2.53	3.10	0.96	2.09	2.49	0.95	1.24	1.25	0.89
Aug/17	3.67	4.98	1.05	2.35	2.51	0.98	1.76	2.26	0.85	1.41	1.56	0.88
Sept/17	3.81	5.10	1.08	2.43	2.52	0.98	2.12	2.82	0.96	0.99	1.03	0.91
Oct/17	3.36	4.84	0.97	2.14	1.97	0.97	1.88	2.08	0.97	1.28	1.54	0.92
Nov/17	3.45	4.05	1.05	2.15	1.92	0.98	1.75	1.60	0.98	1.01	1.12	0.92
Dec/17	3.34	4.09	1.01	2.18	1.70	1.05	1.85	1.91	0.95	1.08	0.96	0.99
Jan/2018	3.42	4.00	1.05	2.14	2.02	0.98	1.96	2.17	0.94	1.01	1.12	0.92
Feb/18	3.15	3.89	0.98	2.18	2.36	0.95	1.75	1.73	0.98	1.31	1.37	0.95
Mar/18	3.18	4.07	0.96	2.40	2.90	0.94	1.80	2.08	0.92	1.37	1.30	0.99
Apr/18	3.29	4.50	0.97	2.44	2.52	0.98	2.23	2.65	0.97	1.71	1.89	0.95
May/18	3.56	4.81	1.03	2.52	2.85	0.98	2.13	2.49	0.97	1.04	0.96	0.95
Jun/18	3.75	5.02	1.07	2.27	2.64	0.95	2.01	2.26	0.96	1.67	1.85	0.93
Jul/18	3.63	4.80	1.05	2.42	2.69	0.97	2.01	2.38	0.97	1.31	1.37	0.95
Aug/18	3.74	5.08	1.06	2.20	2.36	0.96	2.11	2.67	0.96	1.01	1.03	0.91
Sept/18	3.65	4.97	1.04	2.35	2.56	0.98	1.89	2.12	0.97	1.56	1.74	0.97
Oct/18	3.42	4.41	1.02	2.06	1.58	0.99	1.92	2.42	0.92	1.01	1.12	0.92
Nov/18	3.12	3.99	0.96	2.16	1.90	0.98	1.84	2.04	0.94	0.69	0.72	1.01
Mean ± SD	3.48 ± 0.22	4.56 ± 0.45	1.02 ± 0.04	2.29 ± 0.15	2.36 ± 0.44	0.98 ± 0.02	1.95 ± 0.15	2.25 ± 0.33	0.95 ± 0.03	1.22 ± 0.27	1.29 ± 0.33	0.94 ± 0.04

and maximum value of diversity (H'), richness (D) and evenness (e) were 1.75 (February) and 2.23 (April), 1.6 (November) and 2.82 (September) and 0.85 (August) and 0.98 (November), respectively. During the study period, temporal fluctuations were also found in H' (Shannon-Wiener diversity) from 3.12 (November) to 3.81 (September), D (Margalef's richness) from 3.89 (February) to 5.1 (September) and e (Pielou's evenness) from 0.96 (November) to 1.08 (September) for fish species in Sundarbans. In the case of crustaceans, the indices value of H ranged from 0.69 (November) to 1.71 (April), D from 0.72 (November) to1.89 (April) and e from 0.88 (August) to 0.99 (March).

Discussion

Water quality parameters

Physico-chemical parameters of water play a significant role in primary production which ultimately influences the diversity of zooplankton, fish, crustaceans and other aquatic organisms in the wetland ecosystem (Uddin et al., 2018). Among the water quality parameters, adverse pH value is very detrimental for the ecosystems, and the recommended pH level of river water is around 7.4 as it controls the growth of the green algae (Shaikh and Yeragi, 2003). In the present study, the highest average pH (8.5) was in Pasur River, while the lowest average pH (7.3) was recorded in the Kopothakho River. Rahman et al. (2003) observed that pH of the water of Sundarbans seasonally varies from 7.0 to 8.4, which is very similar to the present study. In this study, the mean average pH value also indicated that the river water was slightly alkaline, which may be influenced by the local discharges that comprise alkaline effluents from industries and mills situated in the Rupsa-Pasur belt (Hoq et al., 2006). During the study period, the average temperature varied from 25 °C to 32.8 °C in the major rivers of the Sundarbans, with the highest average temperature during the monsoon season in Pasur River. Present observation is similar to the seasonal fluctuation in temperature studied in estuarine (Uddin et al., 2018) and riverine ecosystem (Hossain et al., 2018) in Bangladesh. A previous study conducted by Hoq et al. (2002) found the maximum DO 7.1 $mg.L^{-1}$ in the monsoon period and the minimum DO 4.9 $mg.L^{-1}$ in the pre-monsoon period in the rivers of Sundarbans. The present study was also evident with more or less similar (7.4 $mg.L^{-1}$ to 4.4 $mg.L^{-1}$) data with an exception in the minimum point (4.4 $mg.L^{-1}$) observed in Kopothakho River during pre-monsoon season. It may be because during pre-monsoon season a large portion of organic waste flows down the rivers of the Sundarbans result in reduced average DO concentrations, as seen in this study. In the present study, Pasur and Sibsa rivers were found as mesohaline (5–18 ‰) zones, while Kopothakho River was found as polyhaline (18–30 ‰) zone during pre-monsoon season. According to Hoq et al. (2006), the salinity of the Sundarbans increase steadily and reaching its maximum in the pre-monsoon season (March). The reduced flow rate of the river has increased high saline sea water in rivers of Sundarbans (Furumai et al., 2007).

Primary and secondary productivity of the Sundarbans

Mangrove estuaries are the most productive transitional ecotones, characterised by marked gradients of physical, chemical and biological components (Nandy et al., 2018). In the present study, total 29 species of phytoplankton, including 12 common and 7 abundant species belonging to 8 major classes were recorded from the rivers of Sundarbans. Bacillariophyceae was the dominant class with the highest number (16) of species. Diatoms including *Coscinodicus* spp., *Navicula brekkaensis* Petersen, 1928, *Thalassionema nitzschioides* (Grunow) Mereschkowsky, 1902, *Cyclotella comta* Kützing, 1849 in addition with *Microcystis* spp. and *Oocystis pusilla* var. maior Skuja, 1949 were the common occurrences. In previous studies, a total of 36 species of phytoplankton have been recorded in the Sundarbans region of Bangladesh (Aziz et al., 2012; Choudhury and Bhadury, 2014). Analysing the previous studies, it is clear that most of the freshwater phytoplankton diversity in the rivers of Sundarbans had slightly reduced due to increased salinity intrusion of recent years (2005: 14.1667 ‰, 2010: 15.1000 ‰, 2015: 16.4333 ‰). Furthermore, fresh water flow decreased from upstream which is similar to the previous findings of Mitra and Banerjee (2018). A total of 18 zooplankton species, including 6 abundant species, were found in different rivers of Sundarbans. Among them, Hexanauplia was represented by the highest number (11) of genera and species. The most dominant species were *Mesocyclops* sp., *Bosmina* sp., *Praunus* sp., *Diaptomus* sp., *Daphnia* sp., and *Brachionus* sp. in the rivers during the post-monsoon season. According to Nandy et al. (2018), 56 taxa of zooplankton were identified from the Sundarbans estuarine system of India, which is much higher than the present study. The variation in the number of species could be due to various reasons and the differences in identification methods. However, Mamun et al. (2009) have recorded 11 genera of a different group of zooplankton from the rivers of Sundarbans. The abundance of both phytoplankton and zooplankton was high in Pasur River, followed by Sibsa, Sela and Koapothakkho rivers, respectively. The abundance of zooplankton was significantly less in Kapothakkho River than the other three rivers, where the average salinity (3 ‰ to 23 ‰) and DO (4.02 to 5.2 $mg.L^{-1}$) was recorded as the lowest.

Abundance of fisheries resources in the Sundarbans

The fisheries resources in Sundarbans are characterised by a very high degree of abundance and diversity, with a higher number of fish and crustaceans than adjacent fresh water and the marine ecosystem in Bangladesh (Islam and Haque, 2004; Hoq, 2007). In the present study, a total of 164 fish species were recorded. During the study period, highly saline areas (18 ‰ to 30 ‰) were dominant with *Thryssa* spp., *Harpodon nehereus* (Hamilton, 1822), *Arius* spp., *Trichiurus savala* Cuvier, 1829, *Setipinna* spp., *Lethrinus* spp., *Pseudorhombus* spp., *Pampus* spp., *Sillago* spp., *Sardinella* spp. The moderate saline zones (5 ‰ to 17 ‰) were dominated by *T. ilisha* , *Pomadasys hasta* (Bloch, 1790) , *Plotosus* spp., *Polynemus* spp., *Mugil* spp., *Liza* spp., *Coilia* spp., *Pseudapocryptes* spp., *Drepane* spp., *Otolithoides pama* (Hamilton, 1822), *Johnius* spp. The low saline zones (1.5 ‰ to 4 ‰) were dominated by *Chelondon*

spp., *Cynoglossus* spp., *Synaptura* spp., *Epinephelus* spp., *Glossogobius giuris* (Hamilton, 1822), *Apocryptes bato* (Hamilton, 1822) , *Periophthalmus* spp., *Butis melanostigma* (Bleeker, 1849), *Platycephalus* spp. and diadromous species such as *Pangasius pangasius* (Hamilton, 1822), *T. ilisha and L. calcarifer* were also available. The Sundarbans mangroves also support many crustacean species of very high commercial values. In the present study, only five species of prawn belonging to two families, 11 species of shrimp belonging to three families, five species of crab belonging to three families and one species of lobster were recorded. According to Rahman and Asaduzzaman (2013) there were 20 species of shrimps, eight species of lobsters, seven species of crabs, 42 species of molluscs and 225 species of fish among which 120 species of commercially important fishes are available in the Sundarbans. The number of recorded fish and crustacean species in the present study was considerably less than in previous studies. Most of these species were not available in the market. The reduction in species might be caused by negative natural and anthropogenic impacts and overexploitation of natural resources have caused severe damage to the ecosystem (Rahman et al., 2010).

Diversity indices of plankton, fish and crustacean communities in Sundarbans

The ecological status of this mangrove system can be described by several diversity indices used for the last four decades (Cardoso et al., 2012). A well-defined measure of the diversity of planktons was found to play a role in the productivity of the Sundarbans with an average Shannon-Wiener index, H (2.29 ± 0.15) and Margalef's richness, D (2.36 ± 0.44) in phytoplankton and 1.95 ± 0.15 (H) and 2.25 ± 0.33 (D) in zooplankton, respectively. A similar study has found with the Shannon-Weiner index and Margalef's richness of phytoplankton with a range of 2.730 to 2.939 and 3.121 to 3.774, respectively, in the wetland systems of Sundarbans (Gogoi et al., 2019). Zooplankton diversity indices were found to fluctuate from 3.13 ± 0.58 to 1.63 ± 0.12 during wet and dry seasons in the haor region of Bangladesh (Islam et al., 2020). In this study, Pielou's evenness index value, e ($P > 0.95$) of both phytoplankton and zooplankton, indicated an even distribution of plankton community in the major rivers of the Sundarbans. This even distribution of planktons had made the Sundarbans ecosystem rich in fisheries resources. The fish diversity index describes the richness of fish which depends on the variation in the number of individuals of each species. In this study, mangrove had moderate fish diversity indices with an average value of Shannon's index, H′ (3.48 ± 0.22), Margalef's richness, D (4.56 ± 0.45) and Pielou's evenness, e (1.02 ± 0.04). Islam et al. (2016) have studied fish species diversity of the Sundarbans and found Shannon's diversity value ranging from 3.30 to 3.91. A similar study has also been carried out in the southern part of Bangladesh to demonstrate the species diversity, richness and evenness of fish with their overall values 3.54–3.70, 7.48–8.67 and 0.95–0.96, respectively (Hanif et al., 2015). In crustaceans, a temporal fluctuation was found in the Sundarbans during the present study. Analysing the previous studies, shows that the mangrove ecosystem has moderately diversified indices with slightly reduced abundance in fisheries resources. Despite having some negative natural and anthropogenic impacts (Rahman et al., 2010), the complex mangrove ecosystem provides a better habitat for a greater variety of plankton, fish and crustaceans to thrive.

Conclusion

The present study mainly focuses on the documentation of the biological communities in the four major rivers (Pasur, Sela, Sibsa, and Kapotakkho) of the Sundarbans, Bangladesh. The total number of fish species recorded during the study period showed a good indication of a rich diversity of fish in these rivers. However, the threatened fish species recorded from the studied mangrove ecosystem indicates the alarming threat to the present conservation status of fishes in Bangladesh. The temperature, DO and pH were favourable, but the salinity level is increasing day by day due to the decreasing flow rate of the river and other anthropogenic impacts. However, efforts to reduce these barriers and synthesise learning from continued research will be critical to improving or preserve adaptive capacity for the future sustainability of the overall fisheries resources of the Sundarbans.

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