Fish diversity, assemblage pattern along with the environmental variables in tidal fresh water stretch in the Hooghly estuary of Gangetic delta, West Bengal, India

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Abstract

The greatest estuary created by the Gangetic delta in India is the Hooghly estuary. Despite their importance to the estuarine biodiversity, the tidal freshwater areas of this estuary have gained little interest from ecologists. Present study aims to explore the fish diversity with its assemblage pattern and their relationship with physico-chemical parameters from June 2020 to May 2021. There have been identified 118 species in total, from 14 orders and 47 families, with seven (7) being near threatened, fifteen (15) vulnerable, four (4) endangered, and eight (8) not evaluated. Perciformes (29.66%), Cypriniformes (22.88%), and Siluriformes (21.18%) accounted for 73.72% of the overall species count. Station-1 has significantly higher species richness, rarefied richness, and abundance. Station-3 and station-2 followed station-1 respectively. The composition of fish species changed significantly among the stations, as shown by cluster analysis, nMDS (nonmetric multidimensional scaling), ANOSIM (analysis of similarities), and SIMPER (similarity percentage analysis) ($p < 0.05$). The canonical correspondence analysis revealed that alkalinity, conductivity, phosphate, and total carbon dioxide of the water were the key environmental parameters. In addition to defining a sustainable management method for the fish resources in the Hooghly estuary, this effort will act as a baseline study for further investigation.

Introduction

Estuarine environment are distinguished by an abundance of nutrients and primary producers, making this system one of the most productive in the world (Roshith et al. 2013). Many fish species depend on estuaries for crucial life processes, such as spawning, migration, nursing, and feeding. Climate change, anthropogenic pressures, presence of exotic species, and use of uncontrolled fishing gears pose threat to the fresh water fishes that inhabit in the river (Dudgeon et al. 2006; Mas- Marti et al. 2010; Vass et al. 2011; Das et al. 2012; Shamsuzzaman et al. 2017; Hussain 2010). The diversity of fish populations in an aquatic habitat has been changed by a variety of physicochemical parameters and climatic elements like rainfall and temperature (Shahnawaz et al. 2010; Brander 2007). Fish species in large number become vulnerable, endangered, or severely endangered as a result of the deterioration of the riverine ecology (Alam et al. 2013). Freshwater fishes are extreme sensitivity to changes in aquatic habitats which makes them the most endangered taxonomic groups (Laffaille et al. 2005; Kang et al. 2009; Sarkar et al. 2008). Estuaries are among the most altered and susceptible habitats on the planet (Blaber et al. 2000).

With an estimated 2,200 fish species, India is ranked third in Asia in the total number of freshwater fish (Sarkar et al. 2008). The diverse estuary systems in India, which cover over 300,000 ha, are an essential part of the fishing resources and have a big impact on productivity (Sugunan and Sinha 2001). The Hooghly estuary, which stretches for around 295 km from the sea mouth of Bay of Bengal to Nabadwip of Nadia district of West Bengal, is the largest estuary in the India (Roshith et al. 2013). This estuary, which makes up around 14.05% of the length of the Ganga River, is mixohaline in nature. In this estuarine system, freshwater tidal zones generate a distinct biotope with a unique community structure. The biota in this region is affected by the tides without being affected by salinity (Roshith et al. 2013). Prior to 1975, the Ganga discharged all of its water into the Padma River, which empties into Bangladesh, so the water supply to the Hooghly estuary was low. Heavy siltation, and saline water ingression during high tide, extends the distribution of estuarine and marine fish species towards the upper stretch by displacing the freshwater fish species, which cannot acclimatize to the changed ecological condition. Farraka Barrage was built in 1975 in between two districts Malda and Murshidabad of West Bengal to increase the flow of freshwater to the Hooghly estuary. The Hooghly estuary's freshwater zone is extended by the increased discharge of freshwater, which forces the saltwater zone towards the mouth of the estuary. Numerous freshwater fish species started to appear in this tidal freshwater zone (Sinha et al. 1996).

The majority of the Hooghly estuary is covered by this freshwater tidal zone, which greatly enhances fish diversity and production (Roshith et al. 2013). This estuary offers livelihood and nutritional security to the surrounding people, but unfortunately, this particular stretch of the estuary has received less urgency from a conservational and management point of view. Understanding the reason and processes of long-term fluctuations in biodiversity is important because sustainable development is linked to the conservation of fish assemblage. The variations, which are of worldwide relevance, should be thoroughly considered in the management techniques utilized in programmes aiming at preserving biodiversity and sustainable fisheries (Shan et al. 2013). Fluvial Hooghly estuarine zone is subjected to the anthropogenic stresses as it is in proximity to the Kolkata port, Kolkata Metropolitan Zone, and huge industrial establishments (including those producing pesticides, chemicals, plastics, paper, leather, jute, textiles etc.). As a result, massive amount of treated and untreated waste from domestic, industrial as well as agricultural sources are introduced daily to this stretch of the Hooghly estuary (Roshith et al. 2013).

Numerous investigations were made on the fish diversity in the Ganga River and the highly salinized area of the Hooghly Estuary (Das et al. 2013; Sarkar et al. 2012; Das et al. 2023). The tidal freshwater zone of this estuary has received relatively little attention from ecological study, despite a few studies being conducted. (Roshith et al. 2013; Nath and Patra 2015; Ghosh 2008). Complete information is not yet available on the species diversity, pattern of fish assemblages, different water parameters and their relation with fish diversity. In this context this study was designed to address the followings:

1. Exploration of the fish diversity status.

2. Analyze the spatial variation in fish assemblages.
3. Determination of the environmental factors which affect these assemblages.

Materials and methods

Study area

The Hooghly estuary (Fig. 1), lies between $21^0 31'$-$23^0\ 30'$ North latitude and $87^0 45'$- $88^0\ 45'$ East longitudes is the lower stretch of the river Ganga in India. It is subject to tides because it has funnel-shaped sea front. The other extreme part, opposite to sea front of the Hooghly estuary is the region around Nabadwip, which is approximately 295 kilometres from the estuarine mouth and experiences tidal influence. Present study was covered 210 km (71% of the estuary's overall length). From upstream to downstream three sampling stations were taken viz. Nabadwip ($23^0\ 24'$ N and $88^0\ 22'$ E, upstream, station-1), Bagbazar (22^0 12' N and 88^0 48'E, midstream, station-2) and Raichak (22^0 12' N and $88^0 07'$ E, Downstream, station-3) by considering the fishing grounds and accessibility.

Data collection

Samples were collected from June 2020 to May 2021 according to the lunar periodicity in every month. The use of various fishing practices according to different locations and seasons is the main barrier in fish sampling in the estuary of the tropical region. In the present study, it was difficult to implement a uniform sample strategy across all sampling locations. Sample were collected from the three sampling station in the consecutive three days of the full moon and new moon period. We examined the catch samples from non-selective fishing gears used at the various sampling stations, including bag nets, seine nets, cast nets, and set barriers. In-situ counting and probable listing of collected fish samples were attempted. Following sorting and counting, all individuals from around 10% of the total capture were kept in 10% formalin for taxonomical study in the laboratory following Talwar and Jhingran (1991) and Jayaram (2010). Following identification, the fishes were classified following Nelson 2006. Conservation status of the fishes were assessed following NBFGR (Lakra et al. 2010a, b), and the IUCN Red List (IUCN 2020).

Physico chemical parameters like dissolved oxygen (DO), alkalinity, hardness, and total carbon dioxide (TCo_2), were analysed on the bank of the estuary between 9:00 AM to 12:00 noon following the standards method (APHA 2005). Total dissolved solids (TDS) and conductivity were measured by a PTTestr 35 waterproof multi-parameter portable meter.

Data analysis

The following formula was used to assess the relative abundance of fish species among various sampling sites:

Relative abundance (RA): $\frac{Number\ of\ sample\ of\ a\ particular\ species*100}{Total\ number\ of\ sample}$

Univariate analysis of alpha diversity of fish assemblages was measured by different diversity indices viz. Margalef's species richness index (D), Shannon-Weiner diversity (H'), Evenness (e), and Dominance indices in the spatial spectrum. The following equations were followed.

Margalef's species richness index: $D = \frac{(S-1)}{\ln N}$ (Margalef 1968)

Shannon-Wiener diversity index: $H' = -\Sigma P_i \ln P_i$ (Shannon and Wiener 1963)

Pielou evenness index: $e = \frac{H'}{\ln S}$ (Pielou 1966)

Dominance index= $\Sigma(\frac{Ni}{N})^2$ (Harper 1999)

Where N represent the total number of individuals in the sample, S is the number of species. Pi is the ratio of Ni to N, Ni is the individual number of species i, and H is the Shannon-Wiener diversity index.

Quantifying and calculating species richness involves a number of typical mistakes. In order to overcome these errors, species richness was assessed using three estimating techniques viz., Chao1 (Chao et al. 2005), Jack (Chazdon 1998), and Bootstrap to check the differences (Gotelli and Colwell 2001). EstimateS (version 8.0) was used to calculate these estimators (Colwell, 2006). Expected Species accumulation curves (sample-based rarefaction curve) were generated and compared these randomized communities ('pseudo-communities') (Pianka 1986) with the real data matrix. Expected species richness and the sampling effectiveness of getting representative samples of species numbers at each sampling station were evaluated by species accumulation curve followed by the rarefaction method (Gotelli and Colwell 2001). The primary trends among the environmental variables as well as the pattern on a spatial scale were explored using principal component analysis (PCA) and cluster plot with a confidence ellipse from PCA. Prior to analysis, log(x + 1) transformation of the initial environmental data was performed. PCA analysis was performed in R 3.1.1 with "FactoMineR" (Sebastien et al. 2008) and "factoextra" (Kassambara and Mundt 2017)

packages. For assessing mean differences of, environmental factors and diversity indices among the stations a one-way ANOVA with post hoc Tukey HSD test ($p < 0.05$) was used (Spjotvoll and Stoline 1973).

Using the Bray-Curtis index, a dendrogram was generated using hierarchical clustering in order to examine similarities between the sites. A 2-D ordination plot (nMDS) with 999 permutations was used to graphically depict the similarity in fish assemblages between the sites (Clarke and Warwick 1994). Bray-Curtis distance was used to determine similarity from the species composition data because it is resistant to bias brought on by variations in sampling effort (Faith et al. 1987). On the nMDS plot, sites that shared a similar species composition were the closest to one another. It was determined by a 'stress coefficient'. The degree and importance of the nMDS were assessed using ANOSIM (Analysis of Similarity) (Paramo et al. 2012). The R statistic is a measure of how well the groups are divided, with values ranging from 0 (indistinguishable) to 1 (extremely separated). To calculate the degree to which the stations are similar, a similarity percentages analysis (SIMPER) (Clarke and Warwick 1994) was used. Additionally, this methodology calculated the proportion of important contributing species between the stations. PAST software was used to calculate diversity indices, rarefaction analysis, nMDS, ANOSIM, and SIMPER (Hammer et al. 2001).

Canonical Correspondence Analysis (CCA) was used to predict the probable correlation between fish assemblage and environmental variables (Ter Braak 1986). CANOCO (version 4.5) software was used to carry out the CCA. Data on fish abundance and environmental factors (aside from pH) were processed, respectively, using the square root and logarithmic $\log(x + 1)$ methods, to lessen the variation. The Monte Carlo permutation test was used to assess the statistical significance of environmental factors and fish abundance (number of permutations = 999) (TerBraak and Smilauer 2002). The environmental factors were ranked using a forward selection technique (TerBraak and Verdonschot 1995).

Result

Faunistic composition

The study enumerated 33,647 individual fishes, representing 118 species under 47 families and 14 orders (Table 1). The most prevalent order was Perciformes (29.66%), followed by Cypriniformes (22.88%), Siluriformes (21.18%), and Clupeiformes (9.32%) (Fig. 2a). The most species abundant families were Clupeidae (25 species), Gobiidae (9 species), and Bagridae (7 species), while Sisoridae, Schilbeidae, Clupeidae, and Engraulidae each contributed five species. The maximum number of species was found at station 1 (species-78, individuals-5224), followed by station 3 (species-58, individuals-18185), and the lowest number was found at station 2 (species-36, individuals-10238) among the sample stations. Table 1 displays the relative abundance of all collected species. Small native freshwater fish species dominated Station 1 such as *Puntius sophore* (13.3%), *Corica soborna* (11.7%), *Gudusia chapra* (9.91%), *Esomus danricus* (9.6%), *Amblypharyngodon mola* (5.88%), *Puntius conchonius* (2.23%), *Chanda nama* (1.23%), *Xenentodon cancila* (1.17%), *Glossogobius giuris* (1.11%), *Pisodonophis boro* (1.38%), *Labeo bata* (1.42%), *Systoma sarana* (7.7%). The relative abundance of the dominating species at Station 2 were *Gudusia chapra* (12.77%), *Corica soborna* (15.05%), *Setipinna phasa* (10.54%), *Rita gogra* (3%) *Polynemus paradiseus* (17.87%), *Odontamblyopus rubicandus* (15.15%), *Otolithoides biauritus* (12.03%), *Pseudapocryptes elongates* (6.32%), *Cynoglossus cynoglossus* (1.21%), and *Rhinomugil corsula* (1.42%). Assemblages with the dominance of estuarine species characterized station 3. The dominant species, according to their relative abundance (RA) were *Coilia dussumieri* (51.36%), *Setipinna phasa* (11.15%), *Harpadon nehereus* (8.21%), *Otolithoides biauritus* (6.67%), *Polynemus paradiseus* (5.58%), *Odontamblyopus rubicandus* (3.08%), *Pseudapocryptes elongates* (3.11%), *Rita gogra* (1.68%), *Gudusia chapra* (1.20%), *Cynoglossus cynoglossus* (2.86%), *Corica soborna* (1.57%).Conservation status showed that 65.25% Least Concern (LC), 6.78% Not Evaluated (NE), 5.93% Near Threatened (NT), 5.93% Data Deficit (DD), 3.39% Endangered and rest 12.71% species were under Vulnerable (VU) status (Fig. 2b).

Table 1
List of fish species collected with their relative abundance (RA) and conservational status in the Hooghly estuary. + means presence of any species, present, -means absence of any species, Stn station, LC least concern, VU vulnerable, DD data deficient, EN endangered, NT near threatened, NE near endangered

Order	Family	Species	Code	Stn 1	Stn 2	Stn 3	RA	CS
Cypriniformes	Cyprinidae	*Labeo calbasu* (Hamilton, 1822)	C1	+	-	-	0.012	LC
		Cirrhinus reba (Hamilton, 1822)	C2	+	-	-	0.101	LC
		Chirrhinus mrigala (Hamilton, 1822)	C3	+	-	-	0.024	LC
		Labeo bata (Hamilton, 1822)	C4	+	+	+	0.238	LC
		Labeo rohita (Hamilton, 1822)	C5	+	-	+	0.139	LC
		Puntius sophore (Hamilton, 1822)	C6	+	-	-	1.899	LC
		Puntius conchonius (Hamilton, 1822)	C7	+	-	-	0.345	LC
		Systomus sarana (Hamilton, 1822)	C8	+	-	-	1.192	VU
		Chagunius chagunio (Hamilton, 1822)	C9	+	-	-	0.009	EN
		Osteobrama cotio (Hamilton, 1822)	C10	+	-	-	0.053	LC
		Gibelion catla (Hamilton, 1822)	C11	+	-	-	0.081	LC
		Crossocheilus latius (Hamilton, 1822)	C12	+	-	-	0.009	VU
		Cabdio morar (Hamilton, 1822)	C13	+	-	-	0.029	LC
		Esomus danrica (Hamilton, 1822)	C14	+	-	-	1.486	LC
		Securicula gora (Hamilton, 1822)	C15	+	+	-	0.033	LC
		Salmostoma phulo (Hamilton, 1822)	C16	+	-	+	0.012	LC
		Salmophasia bacaila (Hamilton, 1822)	C17	+	+	+	0.312	LC
		Amblypharyngodon mola (Hamilton, 1822)	C18	+	-	-	0.909	LC
		Aspidoparia jaya (Hamilton, 1822)	C19	+	-	-	0.015	LC
		Laubuka laubuca (Hamilton, 1822)	C20	+	-	-	0.009	LC
		Devario devario (Hamilton, 1822)	C21	+	-	-	0.009	LC
		Hypophthalmichthys nobilis (Richardson, 1845)	C22	+	-	-	0.012	DD
		Hypophthalmichthys molitrix (Valenciennes, 1844)	C23	+	-	-	0.012	NT
		Botia dario (Hamilton, 1822)	C24	+	-	-	0.021	VU
		Acanthocobitis botia (Hamilton, 1822)	C25	+	-	-	0.003	LC
	Cobitidae	*Lepidocephalichthys guntea* (Hamilton, 1822)	C26	+	-	-	0.045	LC
		Canthophrys gongota (Hamilton, 1822)	C27	+	-	-	0.015	LC
Siluriformes	Bagridae	*Mystus vittatus* (Bloch, 1794)	C28	+	-	-	0.074	LC
		Mystus tengara (Hamilton, 1822)	C29	+	-	-	0.036	LC
		Mystus cavasius (Hamilton, 1822)	C30	+	-	-	0.029	LC
		Rita rita (Hamilton, 1822)	C31	+	+	+	0.077	LC
		Rita gogra (Sykes, 1839)	C32	-	+	+	2.039	EN
		Sperata aor (Hamilton, 1822)	C33	+	+	-	0.045	VU
		Sperata seenghala (Sykes, 1839)	C34	+	-	-	0.009	LC
	Siluridae	*Ompok pabda* (Hamilton, 1822)	C35	+	-	-	0.021	VU
		Ompok pabo (Hamilton, 1822)	C36	+	-	-	0.006	EN

Order	Family	Species	Code	Stn 1	Stn 2	Stn 3	RA	CS
		Wallago attu (Bloch & Schneider, 1801)	C37	+	-	-	0.015	VU
	Erethistidae	*Erethistes pusillus* (Müller & Troschel, 1849)	C38	+	-	-	0.009	LC
	Sisoridae	*Gagata gagata* (Hamilton, 1822)	C39	-	+	+	0.039	LC
		Gagata cenia (Hamilton, 1822)	C40	-	+	+	0.003	LC
		Gagata sexualis (Tilak, 1970)	C41	+	+	-	0.012	LC
		Glyptothrax telchitta (Hamilton, 1822)	C42	-	+	-	0.012	VU
		Bagarius bagarius (Hamilton, 1822)	C43	+	+	-	0.024	VU
	Schilbeidae	*Pachypterus atherinoides* (Bloch, 1794)	C44	+	-	-	0.009	LC
		Silonia silondia (Hamilton, 1822)	C45	+	-	-	0.012	VU
		Ailia colia (Hamilton, 1822)	C46	+	+	-	0.191	NT
		Clupisoma garua (Hamilton, 1822)	C47	+	+	+	0.089	LC
		Eutropicthys vacha (Hamilton, 1822)	C48	+	+	+	0.086	VU
	Ariidae	*Arius gagora* (Hamilton, 1822)	C49	-	+	+	0.535	NT
	Pangasiidae	*Pangasius pangasius* (Hamilton, 1822)	C50	+	+	+	0.081	VU
	Heteropneustidae	*Heteropneustis fossilis* (Bloch, 1794)	C51	+	+	-	0.021	VU
	Clariidae	*Clarias batrachus* (Linnaeus, 1758)	C52	+	-	-	0.006	LC
Perciformes	Gobiidae	*Odontamblyopus rubicundus* (Hamilton, 1822)	C53	-	+	+	6.384	LC
		Glossogobius giuris (Hamilton, 1822)	C54	+	+	-	0.211	LC
		Stigmatogobius sadanundio (Hamilton, 1822)	C55	-	-	+	0.009	NE
		Trypauchen vagina (Bloch & Schneider, 1801)	C56	-	-	+	0.015	LC
		Oxyurichthys ophthalmonema	C57	-	-	+	0.015	LC
		Pseudapocryptes elongatus (Cuvier, 1816)	C58	-	+	+	3.715	LC
		Apocryptes bato (Hamilton, 1822)	C59	-	+	+	0.172	LC
		Boleopthalmus boddarti (Pallas, 1770)	C60	-	-	+	0.015	LC
		Periophthalmus novemradiatus (Hamilton, 1822)	C61	-	-	+	0.015	DD
	Eleotridae	*Eleotris fusca* (Forster, 1801)	C62	+	+	+	0.056	LC
		Butis humeralis (Valenciennes, 1837)	C63	-	-	+	0.006	NE
	Channidae	*Channa striata* (Bloch, 1793)	C64	+	+	-	0.009	LC
		Channa punctata (Bloch, 1793)	C65	+	+	-	0.015	LC
		Channa gachua (Hamilton, 1822)	C66	+	-	-	0.015	LC
	Osphronemidae	*Trichogaster lalius* (Hamilton, 1822)	C67	+	-	-	0.015	LC
		Trichogaster fasciatus (Bloch & Schneider, 1801)	C68	+	-	-	0.045	LC
	Nandidae	*Badis badis* (Hamilton, 1822)	C69	+	-	-	0.024	VU
		Nandus nandus (Hamilton, 1822)	C70	+	-	-	0.024	LC
	Anabantidae	*Anabas testudineus* (Bloch, 1792)	C71	+	-	-	0.006	LC
	Sciaenidae	*Johnius gangeticus* (Talwar, 1991)	C72	+	+	+	0.042	DD
		Otolithoides biauritus (Cantor, 1849)	C73	-	+	+	4.613	DD
		Johnius coitor (Hamilton, 1822)	C74	-	-	+	0.009	LC

Order	Family	Species	Code	Stn 1	Stn 2	Stn 3	RA	CS
	Sillaginidae	*Sillanginopsis panijus* (Hamilton, 1822)	C75	-	+	+	0.089	NE
	Sparidae	*Calamus cervigoni* (Randall & Caldwell, 1966)	C76	-	-	+	0.009	NE
	Polynemidae	*Polynemus paradiseus*(Linnaeus, 1758)	C77	-	+	+	8.658	LC
		Eleutheronema tetradactylum (Shaw, 1804)	C78	-	-	+	0.065	NE
	Latidae	*Lates calcarifer* (Bloch, 1790)	C79	-	-	+	0.015	LC
	Ambassidae	*Pseudambasis ranga* (Hamilton, 1822)	C80	+	+	+	2.957	LC
		Chanda nama(Hamilton, 1822)	C81	+	-	-	0.191	LC
		Parambassis lala (Hamilton, 1822)	C82	+	-	-	0.208	NT
	Scatophagidae	*Scatophagus argus* (Linnaeus, 1766)	C83	-	-	+	0.018	LC
	Leiognathidae	*Nuchequula gerreoides* (Bleeker, 1851)	C84	-	-	+	0.015	NE
	Trichiuridae	*Trichiurus lepturus* (Linnaeus, 1758)	C85	-	-	+	0.021	LC
	Terapontidae	*Terapon theraps* (Cuvier, 1829)	C86	-	-	+	0.024	LC
	Platycephalidae	*Platycephalus indicus* (Linnaeus, 1758)	C87	-	-	+	0.027	DD
	Siganidae	*Siganus canaliculatus* (Park, 1797)	C88	-	-	+	0.006	LC
Beloniformes	Belonidae	*Xenentodon cancila* (Hamilton, 1822)	C89	+	-	-	0.181	LC
	Hemiramphidae	*Hyporhamphus limbatus* (Valenciennes, 1847)	C90	+	-	+	0.024	LC
Clupeiformes	Clupeidae	*Gudusia chapra* (Hamilton, 1822)	C91	+	+	+	6.111	LC
		Corica soborna (Hamilton, 1822)	C92	+	+	+	7.302	LC
		Tenualosa lisha (Hamilton, 1822)	C93	+	+	+	0.249	LC
		Gonialosa manmina (Hamilton, 1822)	C94	+	+	-	0.015	VU
		Esculosa thoracota (Valenciennes, 1847)	C95	-	-	+	0.009	LC
	Engraulidae	*Stolephorus commersonii* (Lacepède, 1803)	C96	-	-	+	0.045	LC
		Coilia ramcarati (Hamilton, 1822)	C97	-	-	+	0.018	LC
		Thryssa hamiltonii (Gray, 1835)	C98	-	-	+	0.015	LC
		Setipinna phasa (Hamilton, 1822)	C99	-	+	+	9.629	LC
		Coilia dussumieri (Valenciennes, 1848)	C100	-	-	+	29.59	LC
	Pristigasteridae	*Ilisha megaloptera* (Swainson, 1838)	C101	-	-	+	0.012	EN
Pleuronectiformes	Cynoglossidae	*Cynoglossus cynoglossus* (Hamilton, 1822)	C102	-	+	+	2.027	LC
		Cynoglossus punticeps (Richardson, 1846)	C103	-	-	+	0.033	LC
	Soleidae	*Brachirus orientalis* (Bloch & Schneider, 1801)	C104	-	+	+	0.285	LC
Mugiliformes	Mugilidae	*Rhinomugil corsula* (Hamilton, 1822)	C105	+	+	+	0.981	LC
		Liza Persia (Hamilton, 1822)	C106	-	+	+	0.158	NE
		Minimugil cascasia (Hamilton, 1822)	C107	+	-	-	0.018	VU
Anguilliformes	Ophichthidae	*Pisodonophis boro* (Hamilton, 1822)	C108	+	-	+	0.259	LC
	Anguillidae	*Anguilla bengalensis* (Gray, 1831)	C109	+	+	+	0.053	NT
Synbranchiformes	Mastacembelidae	*Macrognathus aral* (Bloch & Schneider, 1801)	C110	+	-	-	0.122	LC
	Mastacembelidae	*Macrognathus pancalus* Hamilton, 1822	C111	+	-	-	0.018	LC
	Mastacembelidae	*Mastacembelus armatus* (Lacepède, 1800)	C112	+	-	-	0.015	LC

Order	Family	Species	Code	Stn 1	Stn 2	Stn 3	RA	CS
	Synbranchidae	*Monopterus cuchia* (Hamilton, 1822)	C113	+	-	+	0.015	LC
Osteoglossiformes	Notopteridae	*Notopterus notopterus* (Pallas, 1769)	C114	+	-	-	0.042	NT
Tetraodontiformes	Tetraodontidae	*Leiodon cutcutia* (Hamilton, 1822)	C115	+	-	-	0.012	NT
Gadiformes	Bregmacerotidae	*Bregmaceros mcclellandi* (Thompson, 1840)	C116	-	-	+	0.009	NE
Elopiformes	Megalopidae	*Megalops cyprinoide* (Broussonet, 1782)	C117	-	-	+	0.012	DD
Aulopiformes	Synodontidae	*Harpadon nehereus* (Hamilton, 1822)	C118	-	-	+	4.515	NT

Environmental variables

Table 1 lists the environmental factors noted throughout the study period in different stations. Spatial impacts significantly altered the ecological state of the Hooghly River. Parameters like salinity, alkalinity and total dissolved solids exhibited significant differences ($p < 0.001$) among the stations (Table 2). Other physicochemical parameters showing spatial changes included phosphate, hardness, and total carbon dioxide ($p < 0.05$). Dissolve Oxygen concentrations did not differ significantly among the sampling stations..

Table 2
Mean and standard deviation values of environmental variables with significance level according to ANOVA, HSD, $P < 0.05$ of Hooghly estuary.

Water parameters	Stn 1	Stn 2	Stn 3	*F* value	*P* value
Salinity (mg/l)	24.58 ± 7.40	25.83 ± 7.27	208 ± 106.48	35.029	< 0.001
Phosphate (mg/l)	0.17 ± 0.09	0.15 ± 0.09	0.30 ± 0.16	5.7741	< 0.05
Dissolved oxygen (mg/l)	7.91 ± 0.66	7.63 ± 0.72	7.29 ± 0.54	2.7377	> 0.05
Alkalinity (mg/l)	198.73 ± 101.21	161.73 ± 46.89	278.75 ± 66.57	7.6336	< 0.001
Hardness (mg/l)	128.75 ± 54.18	121.58 ± 33.50	232.5 ± 125.49	7.0034	< 0.05
Conductivity (mhos/cm)	195.08 ± 74.03	288.9 ± 40.98	721.85 ± 422.09	15.338	< 0.001
Total dissolved solids (mg/l)	148 ± 29.65	198.02 ± 33.81	508.99 ± 307.51	14.259	< 0.001
Total carbon dioxide (mg/l)	91.83 ± 40.39	125.71 ± 31.98	158.47 ± 90.33	3.6963	< 0.05

Figure 3 depicts the relationships and spatial variations of environmental variables. Conductivity, salinity, total dissolved solids, phosphate, and hardness were highly correlated and positively linked to axis 1, explaining 63.59% of the total variance. The association of these parameters with dissolved oxygen were negative. Axis 1 showed a negative relationship with Alkalinity and total carbon dioxide. Alkalinity and total carbon were linked to axis 2, and contributing 16.32% of the total variance (Fig. 3a). Cluster plots with confidence ellipses using PCA explained spatial differences in environmental parameters, and for interpretation, the first two axes were considered which explained 65.67% of data variability (Fig. 3b). It was found that physicochemical parameters of stn1 and stn-2 were very much similar. Still, stn-3 was quite different from these two stations.

Community structure

Figure 4 depicts the station-wise values of the Margalef's richness, Shannon-Wiener index, dominance index, and evenness indices. The maximum Margalef's richness value was recorded 8.89 at stn-1, followed by 6.12, 3.9 at stn-3 and stn-2 respectively. The mean Margalef's richness value differed significantly amongst the stations ($P < 0.0001$). Stn-1 had the highest Shannon-Weiner diversity index (2.7), followed by Stn-3 (2.54), and Stn-2 (2.28). A substantial difference ($P < 0.0001$) in the mean Shannon-Wiener index was seen among the station. The maximum dominance index was found at stn-2 (0.11) followed by stn-1 and stn-3 (0.09 each). The mean dominance index for each of the three sampling stations showed no appreciable variation. The highest evenness index was 0.24 at Stn-1, followed by Stn-3 and Stn-2, respectively, with 0.21 and 0.18. The mean evenness index among the stations showed a significant difference ($P < 0.05$).

Analysis of species diversity using rarefaction revealed that stn-1 (Fig. 5a) had the highest species richness, followed by stn-3 (Fig. 5c) and stn-2 (Fig. 5b) (which had the fewest species overall). The levels of significance were calculated using 95% confidence intervals. Because the confidence intervals finally stopped overlapping as each curve neared an asymptote, the curves also imply that the richness at each height is significantly different. Evaluation of species richness using rarefaction method of the observed species often underestimates the true richness

since it ignores the rare species, underrepresented species in the sample. Three non-parametric approaches were employed to evaluate the overall species richness at each station in order to assist rarefaction method

The predicted species richness for the three sampling stations was determined using the three non-parametric approaches (Fig. 6). A total of 78 species were counted from stn-1. Simultaneously, the Jackknife 1 estimator estimated 87 species, Chao1 78 species, and the Bootstrap approach 83 species (Fig. 6a). From stn-2, 36 species were enumerated, but 37, 36 and 37 species were estimated by Jackknife 1, chao 1 and bootstrap estimation method respectively (Fig. 6b). In case of stn-3, 58 species were collected. In contrast, the Jackknife 1 estimator gives an estimate of 64, Chao1 58 species and the Bootstrap method 62 species (Fig. 6c).

Cluster analysis based on species assemblage structure revealed that stn-1 was differed from stn-2 and stn-3 where as stn-2 and stn-3 showed overlapping structure (Fig. 7a). 2-D nMDS plot (using Bray–Curtis's similarity index) showed, fish faunal composition differed among the three sampling stations. The fish samples of stn-1 were well-separated from the stn- 2 and stn-3 at the stress of 0.160 (Fig. 7b). The stn-2 and stn-3 were close to each other but were not identical in the ordination diagram. Furthermore, analysis of similarities (ANOSIM) revealed the difference in the distribution of fish species among the stations ($R = 0.49$; $p = 0.0001$ Fig. 7c). The inter-group differences (mean rank between-364.2) in fish community structure among the stations were greater than the intra-group differences (mean rank within-209.2), and the composition difference was significant ($p < 0.05$). Table 3 lists the results of the SIMPER analysis, including the proportion of dissimilarity between the stations and the contributing species.

Table 3
Results of ANOSIM and SIMPER showing the Global R, significance level (*P*), overall dissimilarity among the station as well as contribution of major discriminating fish species (> 5%)

ANOSIM (Global R = 0.49; P = 0.001)					
SIMPHER					
Station	P	Overall dissimilarity (%)	Major discriminating species	Contribution %	Cumulative %
Stn1 vs stn 2	0.001	94.44	*Corica soborna*	15.12	15.12
			Gudusia chapra	9.713	24.83
			Odontamblyopus rubicundus	9.227	34.05
			Setipinna phasa	8.521	42.58
			Pseudambasis ranga	7.634	50.21
			Puntius sophore	6.222	56.43
			Amblypharyngodon mola	5.629	62.06
Stn 1 vs stn 3	0.001	98.03	*Coilia dussumieri*	24.79	24.79
			Harpadon nehereus	11.76	36.56
			Setipinna phasa	7.451	44.01
			Polynemus paradiseus	5.736	49.75
			Pseudambasis ranga	5.676	55.42
Stn 2 vs stn 3	0.032	89.7	*Coilia dussumieri*	25.13	25.13
			Harpadon nehereus	11.95	37.09
			Setipinna phasa	10.4	47.49
			Corica soborna	10.07	57.56
			Polynemus paradiseus	9.261	66.82
			Odontamblyopus rubicundus	7.97	74.79
			Gudusia chapra	6.226	81.02

The Canonical Correspondence Analysis (CCA) has shown how different environmental parameters affect fish assemblage (Fig. 8). Almost all of the environmental factors (Table 2) in the Hooghly estuary were in a range that was favorable for the fish population. Axes I (eigen value: 0.263) and II (eigen value: 0.168), which together account for 61.3% of the total variance, were used in the interpretation. Stepwise forward selection (using permutation tests) of CCA revealed conductivity, alkalinity, total caron dioxide, and phosphate were the four most significant

environmental factors affecting fish abundance. At the 0.05 level, the permutation test (999 random permutations) supported the significance of the CCA model.

Discussion

The present study (118 species) documented 18 species more than Ghosh (2008) and 31 species more than Nath and Patra (2015), which could be due to covering the limited area in the previous work. The diversity found in the present study was 37 species lower than that found in a recent study (Roshith et al. 2013), in which nine sample locations were selected. Perciformes (29.66%) was the most dominant order, as observed by Nath and Patra (2015). The highest richness, diversity, and evenness indices revealed that stn-1 had greater fish diversity which might be attributed to slow water, less tidal influence, less anthropogenic interference, deep pool (meeting point with another river Jalangi), and presence of enriched macrophytes (Grown et al. 2003; Raghavan et al. 2008). As expected, a diverse assemblage of cyprinids, notopterids, and silurids was found from stn-1, which is supported by Lakra et al. (2010). From stn-2, the least number of species was recorded. The data analysis demonstrated that reduced richness, diversity, and dominance indices in stn-2 were related to high anthropogenic activities since it is close to the Kolkata urban region and Kolkata port. Huge amount of untreated effluent, domestic sewage, and different inland transporting activities continuously degraded the habitat. In contrast, stn-3 had the most tidal influence and served as a favourable feeding as well as breeding site for many anadromous fish species. Fish population of stn-3 was dominated by gobiids like *Odontamblyopus rubicandus*, *Pseudapocryptes elongates* and anadromus fish species such as *Coilia dussumieri, Harpadon nehereus, Polynemus paradiseus, and Tenualosa ilisha.*

Rarefaction curves showed that stn-1 had the highest species richness (α-diversity), and further sampling was expected to find additional species (Fig. 5). The growing tendency of the rarefaction curve suggested that more fish species could be found if more samplings were done than what was actually found (Seid and Santini 2017). This implied that stn-1 could have more than 78 fish species if more sampling were done. In contrast, the rarefaction curves for stn-2 and stn-3 initially climbed and subsequently assumed a platue-like form as the counting of number of individuals increased. Estimating species richness with the Jackknife-1 estimator (Fig. 5) revealed that stn-1 may have 11 more unrecorded species. As a result, 89 fish species might potentially be found at stn-1. Contrarily, even if more sampling were conducted during the study at stn-2 and stn-3, the chance of finding 1 and 6 more new (rare) fish species respectively (Fig. 6). For the present study, the actual species richness appeared to have a safe upper limit provided by the Jacknife-1 estimation approach and corresponds with the study of Das et al. 2013.

Notable spatial differences in physic-chemical parameters of water were observed. These findings concur with those of Islam et al. (2017). Fish population is significantly affected by the structure as well as water quality of a habitat (Bio et al. 2011). Changes in the water quality factors have an impact on distribution, survival, and fish assemblage structure in a habitat (Cendejas et al. 2013). According to Hossain et al. 2012, variations in the hydrological conditions cause the variance in species abundance.

The most popular technique for determining and recognizing patterns of similarity and dissimilarity among different sites is clustering (Backer, 1995; Ripley, 1996). The cluster analysis results in this investigation showed that stn-1 was separate from the other two stations. Overlapping of species distribution was seen at stn-2 and stn-3; to some extent, these two stations were similar but not identical. Natural sample groupings, such as species assemblages, are generally identified using cluster analysis (Hossain et al. 2012). In order to facilitate understanding and highlight correlations between and within sampling sites, nMDS produced a graphical spatial illustration of the species abundance. The nMDS plot likewise showed the same categories of species as were discovered in the cluster, indicating once more how species composition and abundance vary according to the locations under study. Furthermore, ANOSIM analysis revealed substantial variations in community organization among the sites (R = 0.49, P 0.05). Similar findings were made by Murugesan and Purusothaman (2011) and Ajmal Khan et al. (2008). The species predominantly accountable for the disparity in abundance across the sample stations was identified by SIMPER analysis. The overall dissimilarity between stn-1 and 2 was 94.44%, between stn-1 and 3 was 98.03%, and between stn-2 and 3 was 89.7% respectively.

Environmental factors can have a direct or indirect impact on a variety of fish behaviors, including feeding, growing, breeding, and survival (Dubey et al. 2012; Karnatak et al. 2018). The majority of the environmental variables were favourable for fish growth in the study area. Conductivity, alkalinity, phosphate, and total carbon dioxide were the main environmental factors affecting fish assemblage. This outcome is in line with the outcomes of several earlier investigations (Brysiewicz et al. 2022; Lianthuamluaia et al. 2019; Pokharel et al. 2018). Chemical composition of the river water was more significant than physical qualities (Tongnunui and Beamish 2016; Suvarnaraksha et al. (2012). Water conductivity is related to alkalinity, which is related to productivity as well as prevention of ammonia excretion in some fish (Wilkie & Wood 1991). Phosphorus is a key component that regulates the biological productivity of water (Schindler et al. 2008) and has an impact on fish population and density (Griffiths 2006) since phytoplankton is a primary food source for many fish species.

Conclusion

Measures of fish community structure are valuable for examining long-term changes in faunal composition and assessing the effects of disturbances on estuarine ecosystems. The current study provides baseline data about fish distribution pattern, varieties, and their relationship with limnological factors that may be useful for future evaluation of the biological integrity of the Hooghly River. Significant variation of fish abundance and environmental parameters were observed in spatial scale. The environmental variables were observed to be within a reasonable range for fisheries. Alkalinity, conductivity, phosphate, and total carbon dioxide were the environmental factors that significantly influenced the fish distribution pattern in the Hooghly estuary. Due to growing anthropogenic influences, including poor wastewater management and deterioration of estuarine nursery habitats, management measure will need to be intensified. The current study identified 118 fish species, of which seven have been classified as near threatened (NT), fifteen as vulnerable (VU), four as endangered (EN), and eight as not yet evaluated (NE). This suggests the significance of this fluvial estuarine zone as an important habitat because of its high fish diversity as well as fostering many larval and juvenile fishes. This research accentuates the significance of performing extensive study on the fluvial estuarine areas of various estuarine systems in India. This will help in formulate the better conservation strategies for this crucial habitat.

Declarations

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Ethical Approval

No live samples were collected for this investigation, and no habitat modifications were made. The sample was collected from the local fishers, which were dead but fresh in condition. As a result, no permission is required from the authorizing committees. Prior to beginning fieldwork, we notified the Central Marine Fisheries Research Institute (CMFRI) and ICAR-Central Institute of Brackishwater Aquaculture (CIBA) authorities because this is necessary in order to complete the fieldwork.

Consent to participate

This is not applicable

Consent to Publish

This is not applicable

Author Contributions

The study's inception and design involved input from all authors. [Bhuban Mohan Majhi] collected the data, carried out the analysis, and prepared the materials. [Bhuban Mohan Majhi] wrote the initial draught of the manuscript. [Ashim Kumar Nath] and [Chiranjeeb Dey] investigate all the steps of the research work. All contributors provided feedback on an earlier draught and approved the final manuscript.

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The author certifies that they have no known competing financial or personal interests that may have influenced the work described in this paper.

Availability of data and materials

Data will be provided upon request.

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Figures

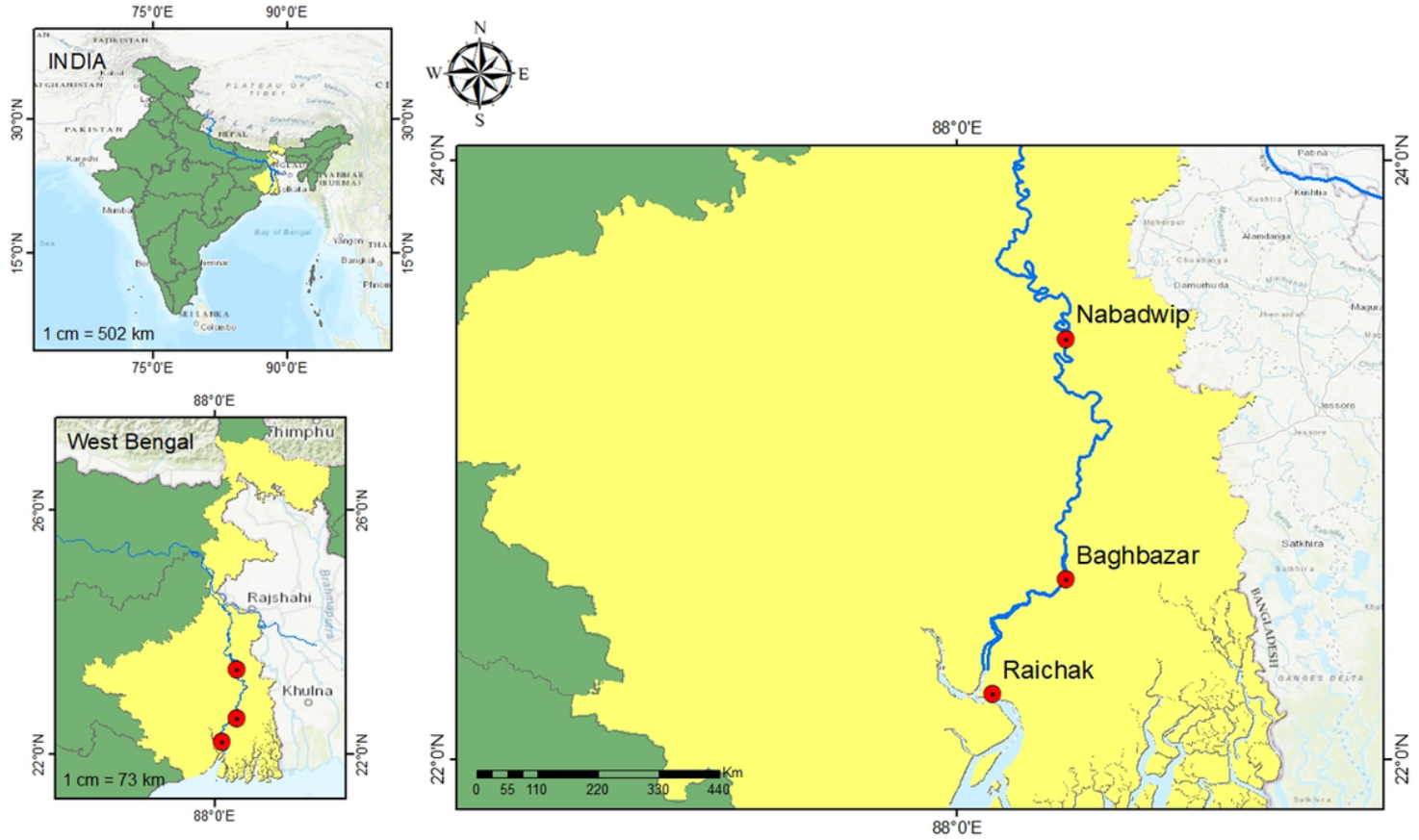

Figure 1

Map of Hooghly estuary showing sampling stations: Nabadwip (upstream, stn-1), Bagbazar (mid stream, stn- 2), Raichak (downstream, stn-3)

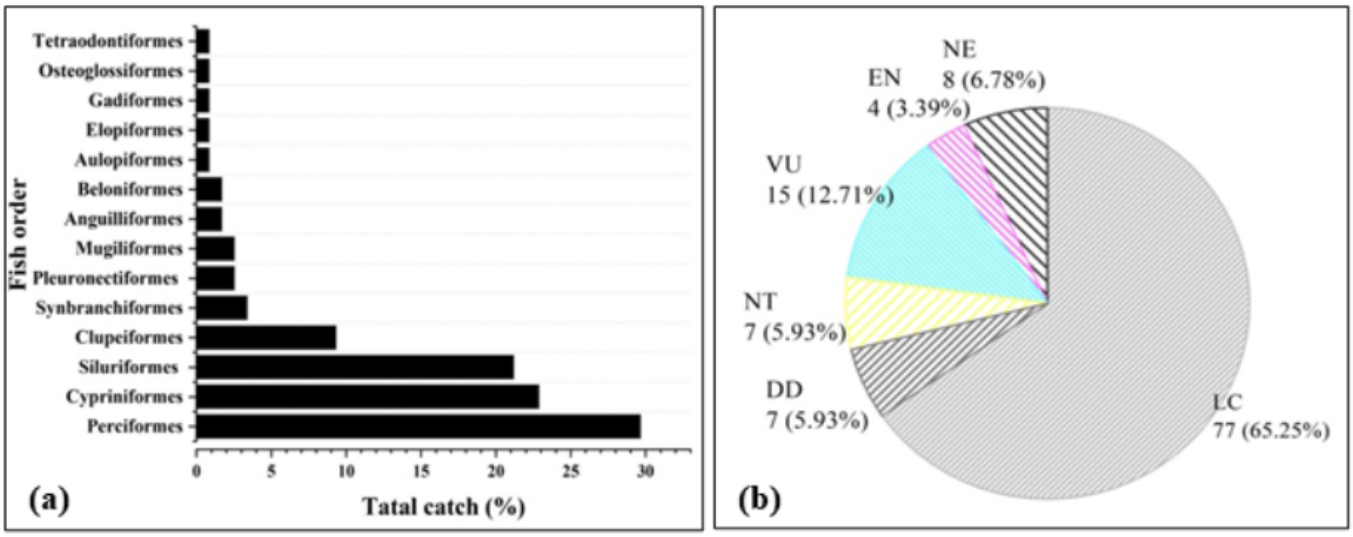

Figure 2

Order-wise percent composition of fishes collected from Hooghly estuary (a), conservation status of collected fish species (b) (LC-Least concern, DD-Data deficient, NT-Near threatened, VU-Vulnerable, EN-Endangered, and NE-Not evaluated)

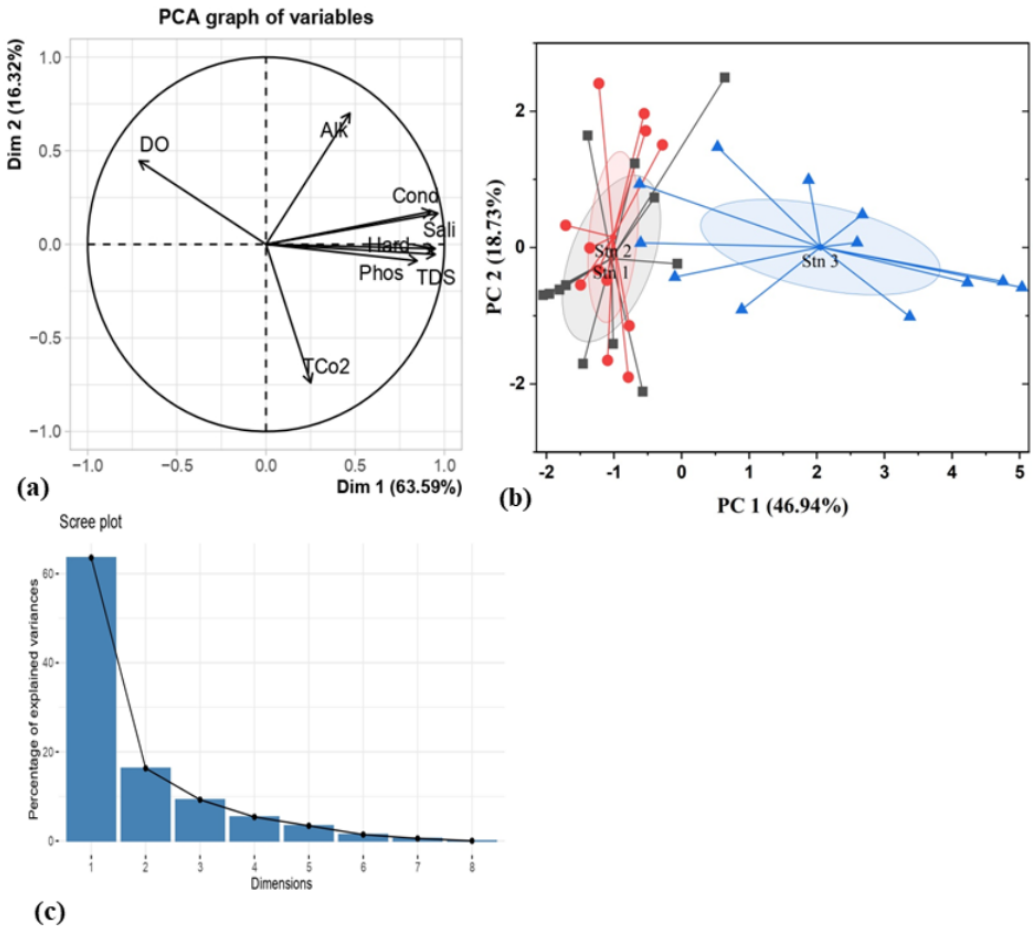

Figure 3

Principal component analysis (PCA) plots for the environmental variables. Correlations of the environmental variables (a), eigen values (c), multivariate analyses of the environmental variables through a scatter diagram of different station (b) (DO-Dissolved oxygen, Alk-Alkalinity, Cond-Conductivity, Sali-Salinity, Hard-Hardness, TDS-Total Dissolved Solids, Phos-Phosphate, and TCo2-Total Carbon dioxide)

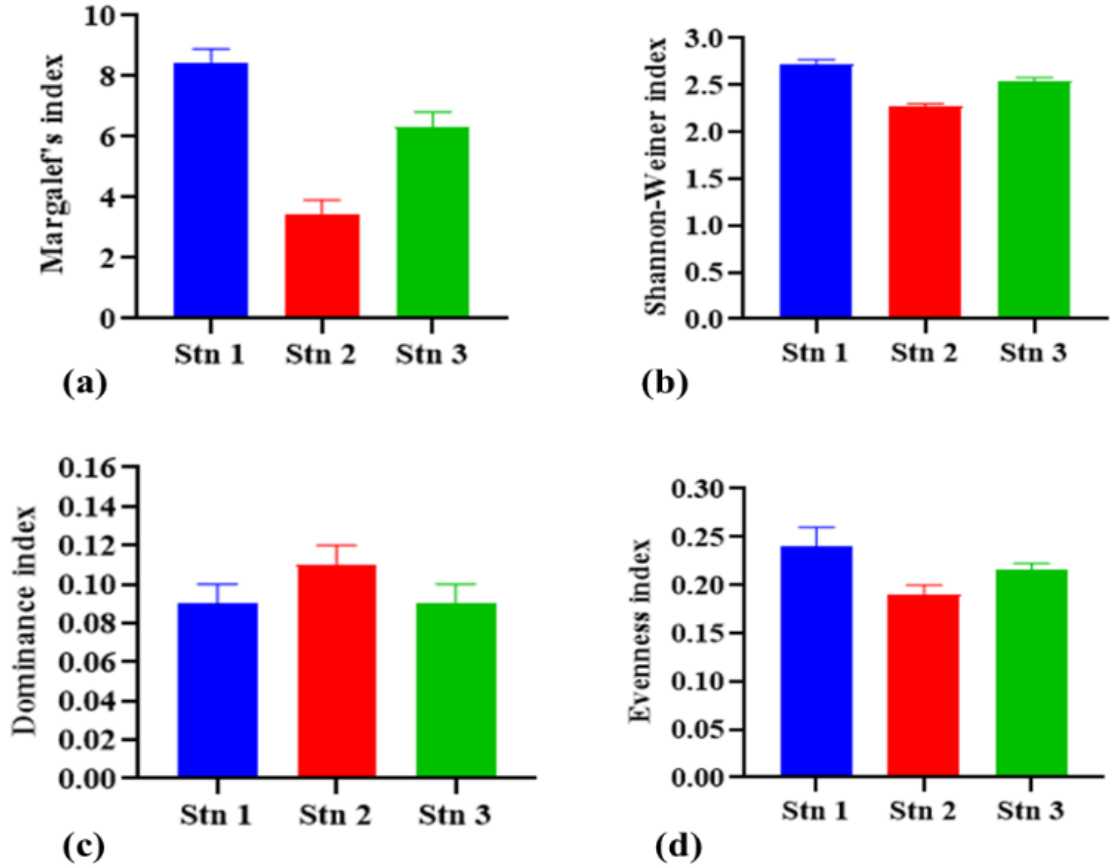

Figure 4

Different diversity indices (a-d) at different sampling station of Hooghly estuary

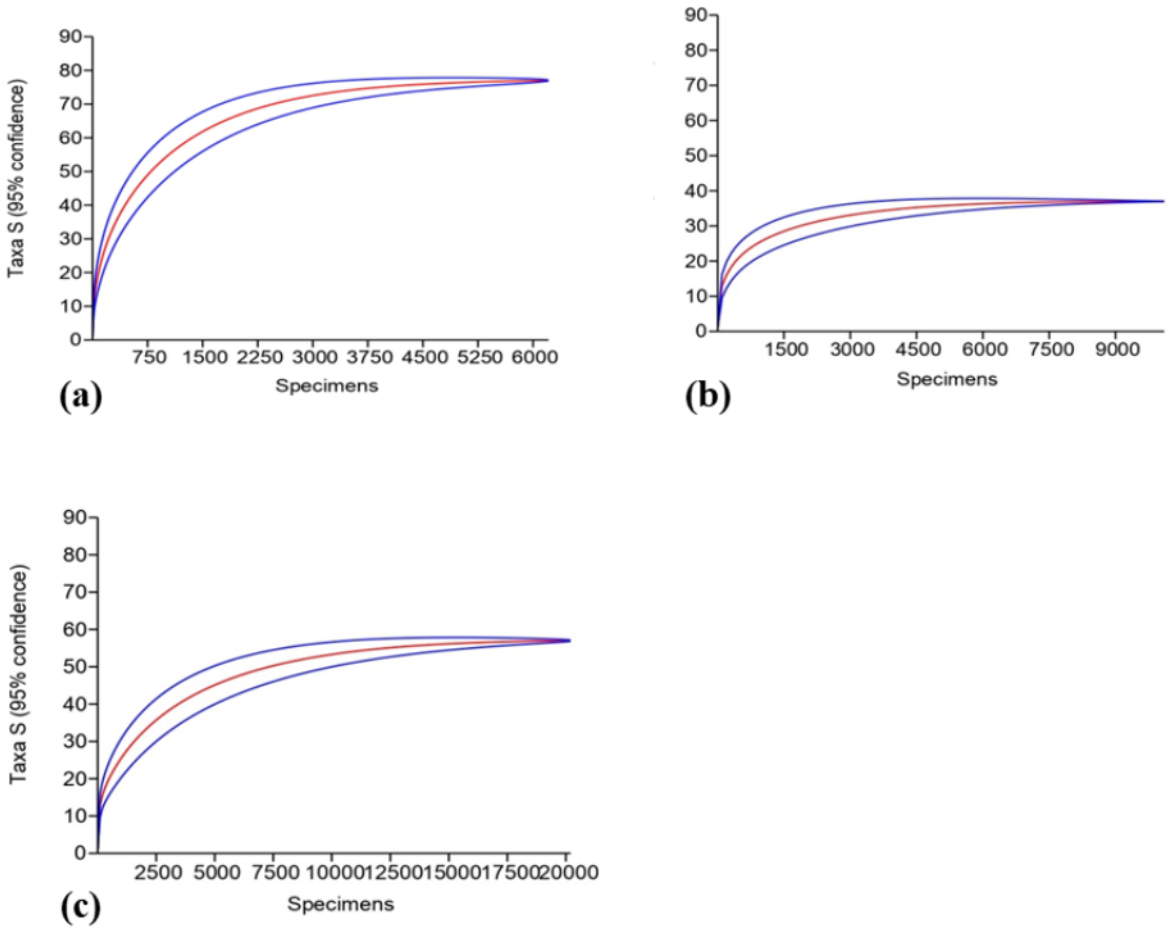

Figure 5

Rarefaction curves of cumulative increase of species richness (at 95% confidence) as the function of individual fish species counts across the sampling sites. (a) stn-1, (b) stn-2, (c) stn-3

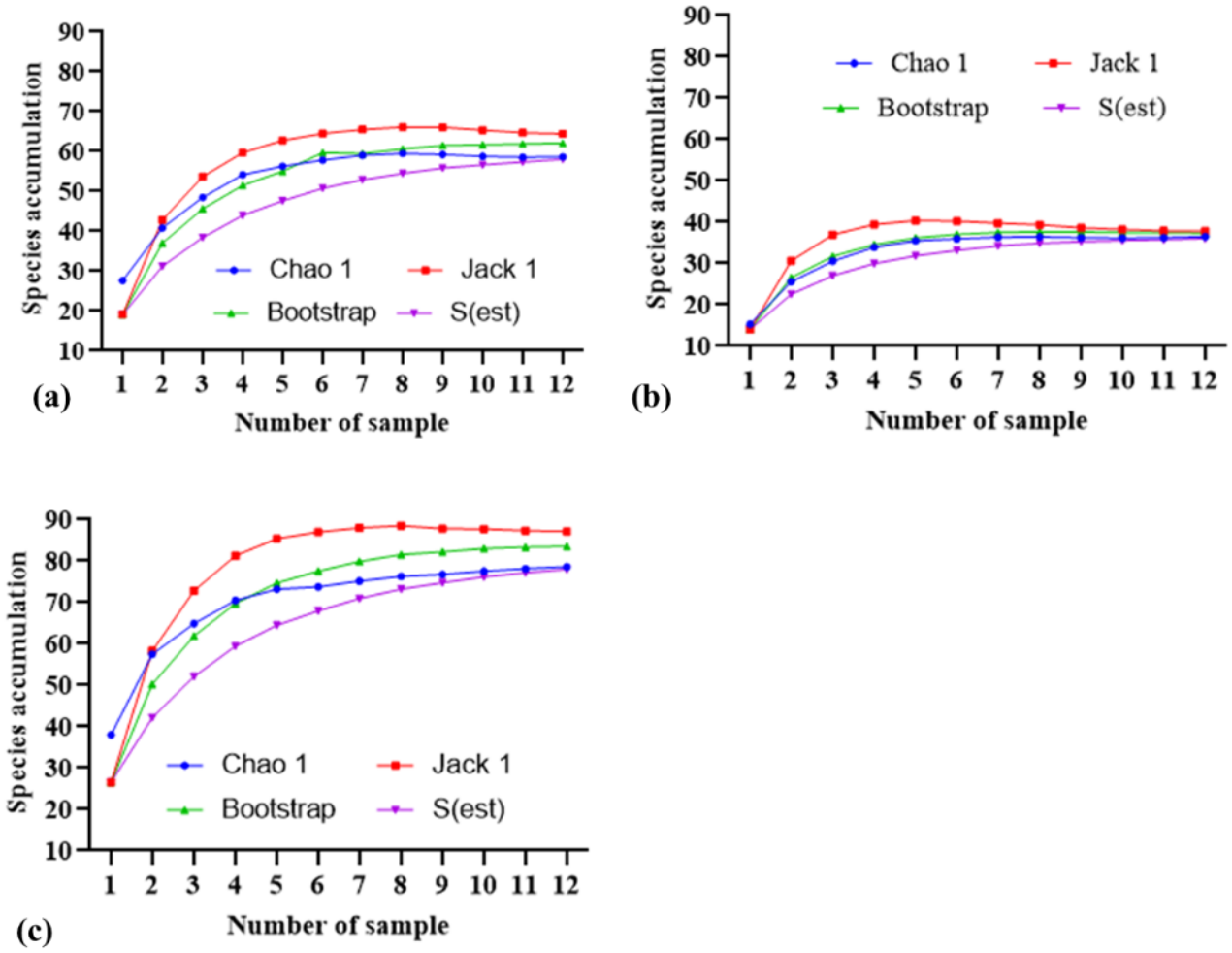

Figure 6

Comparison of projected species accumulation curves derived by various species richness estimators to actual data estimated at three sampling station of Hooghly estuary. (a) stn-1, (b) stn-2, (c) stn-3

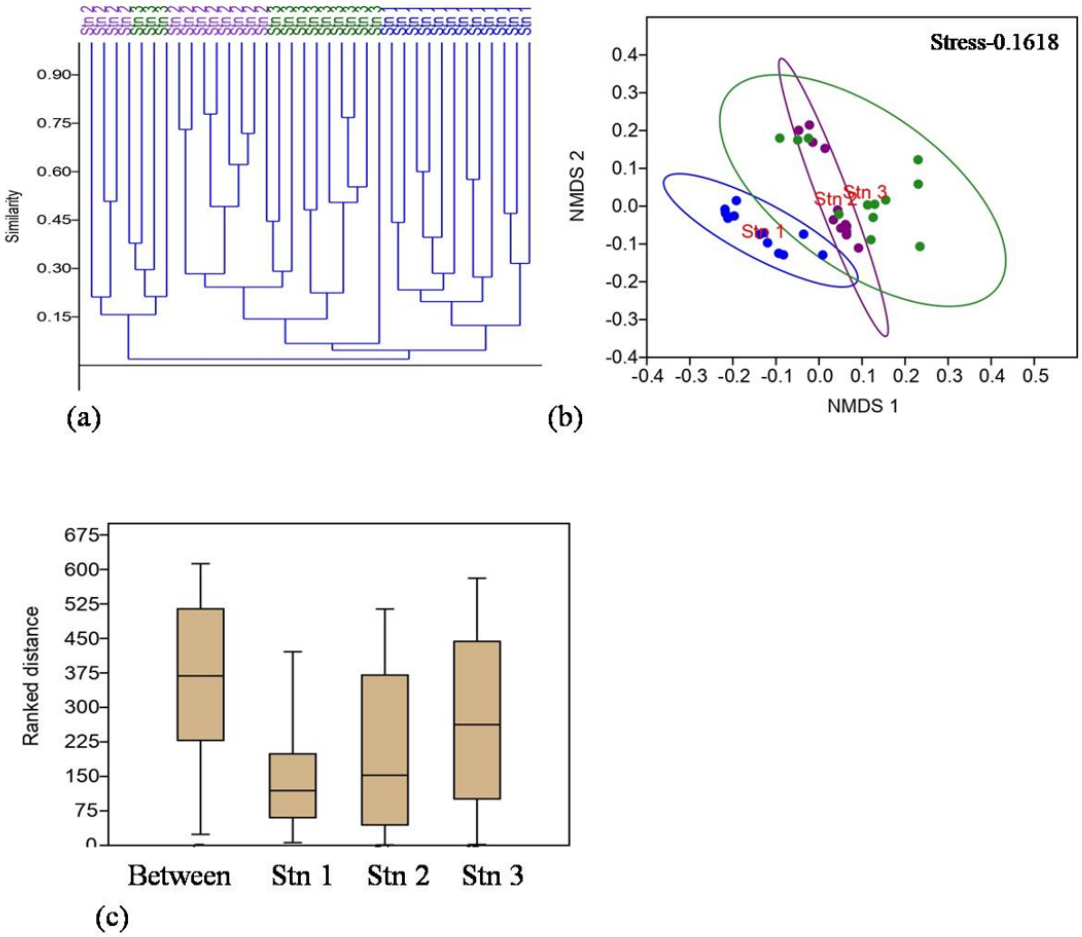

Figure 7

The dendrogram (a) showing cluster based on Bray-Curtis similarity matrix of catch composition, and the ordination in 2D (b) using MDS on the same similarity matrix. ANOSIM (c) is used to statistically test the significant difference between groups

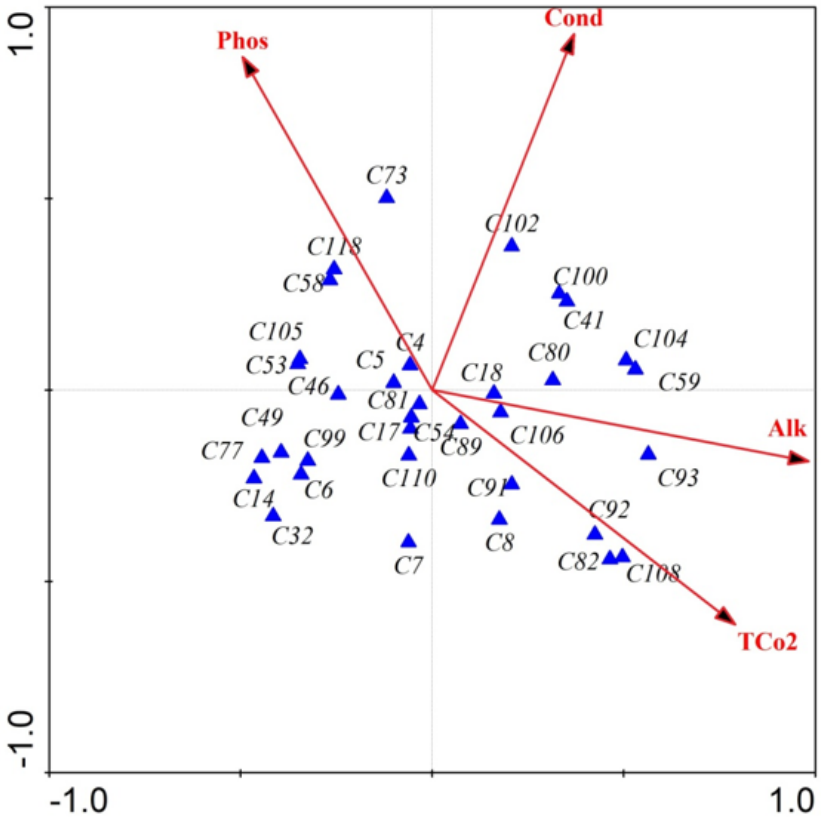

Figure 8

Canonical Correspondence Analysis (CCA) applied to environmental variables and fish species captured in Hooghly estuary. The codes and the corresponding species are included in Table II. Phos-Phosphate, Cond- Conductivity, Alk-Alkalinity, CCo2- Total cabon dioxide