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RESEARCH ARTICLE

Fish assemblage pattern, seasonality and their interaction with environmental variables: insights from canals of Sundarbans, India

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Abstract

In the present study, the fish distribution and assemblage pattern in relation to environmental variables were studied in the canals of Indian Sundarbans. The Permutational analysis of variance (PERMANOVA) depicted the significant variation of water variables between the seasons ($F=10.40$; $p=0.001$), and stations ($F=1.96$; $p=0.011$). A total of 44 species belonging to 39 genera, 30 families and 16 orders were recorded with Cyprinidae (6 species) as the apex contributor. Significant temporal variations of fish Species Richness per sample (*SRp*) ($p\leq 0.05$) were observed between pre-monsoon and monsoon season. By and large, fish assemblages did not portray the significant seasonal variation hinted towards the limited connectivity with tidal water through the sluice gate, thereby minimizing the movement of fish species between the canal and river. The fish assemblages pattern exhibited an overall 30% similarity among all the stations. The calculated value of Margalef richness (d') and Shannon diversity (H') indices (4.42 ± 0.84 and 2.62 ± 0.18 for d' and H', respectively) indicating a moderate fish diversity in the canal system. The water variables such as temperature, dissolved oxygen, pH, salinity, specific conductivity, transparency, depth and water flow play important role in structuring the fish assemblages in the studied canals which were evident from the BIO-ENV module, and the distance-based redundancy analysis (db-RDA). Meagre seasonal variation of fish populations related to variations in species-specific adaptation to the prevalent ecological conditions.

Keywords Canal · Diversity · Environmental variable · Fish assemblages · Sundarbans

Introduction

India is one of the world's biodiversity hotspots, accounting for 11.72 percent of all fish species, and among the Asian countries India contributes the most native fish fauna, with 27.8 percent followed by China, Indonesia and Myanmar (NBFGR 2010). A large diversity of indigenous fish species, an important component of aquatic biodiversity, is found in the water bodies that crisscross the Indian subcontinent. As per NBFGR India, about 2246 fin fish species were recorded in India out of which 765 species have been identified as freshwater fish species. Out of 765 freshwater fish species about 450 fish species have been identified as small indigenous fish species (SIF) (Sarkar 2010). A report of Govt. of India (2020) (https://www.thechanikyaneeti.com/) stated, India harbours 3,137 fin fish belonging to 1022 genera, 247 families and 47 Orders. Based on the habitat category, 1652 fish species reported as marine, 906 as freshwater, 201 as brackish water, 332 as brackish and marine, 96 as fresh and brackish, and 138 fish species have been identified as fresh, brackish and marine forms. Another recent report from ICAR—National Bureau of Fish Genetic Resources (NBFGR), Lucknow stated 3145 native fish species comprising 248 families and 49 orders (Anon 2021). Fish species that grow to a size of 25 cm or 9 inches in the adult stage in their life cycle are known as Small Indigenous Fish Species (SIF) or Small Indigenous Species (SIS) (Felts et al. 1996; Hossain et al. 1999). Although there is a lack of clear definition, in general SIF are considered those which grow up

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to a maximum length of 25–30 cm. Small indigenous fishes are rich in animal protein and essential sources of vitamin A and D as well as micronutrients including calcium, zinc, iron, and fatty acids (Mohanty et al. 2013). About 23% of SIF's had economic value as ornamental fish, which supports livelihood and nutrition, particularly for the people in India's eastern and north-eastern regions (Sarkar 2010; Mandal and Nandi 2015).

India has a diverse range of aquatic resources that comprise an extensive network of 29,000 km rivers; 128,000 km ha man-made canals, 3.15 million ha of reservoirs; 0.3 million ha of estuaries; 2.36 million ha of pond and tanks; 0.19 million ha backwater and lagoons; 0.2 million ha of floodplain wetlands, 0.72 million ha of the upland lake (Ayyapan et al. 2011). Canals are the second most major form of irrigation (26%), with significant potential for fish production (Agricultural Statistics, Govt. of India). In India, Andhra Pradesh, Assam, Bihar, Jammu & Kashmir, Haryana, Punjab, Rajasthan, Karnataka, Tamil Nadu, Uttar Pradesh and West Bengal are the states with the most canal irrigation. Fisheries from canals in India are poorly documented or neglected. Their production is less as they are mostly seasonal in nature and no standard technology is available for canal fishery. Despite having these vast resources in India, it received very little attention which might be a boost in Inland fish production by judicious utilization of these resources. The canal systems in Sundarbans covered an area of about 907.33 ha having vast potential for fisheries development in the region (Mukharjee 2016). Fish enters these canals naturally from their source waters (rivers, estuaries, etc.) and some fish species may establish as natural populations in the canals. Various countries are producing fish from irrigations canals but the fisheries from these canals are poorly documented. It is estimated that almost 16% of the freshwater fishery production comes from the Nile River and its irrigation canals in Egypt while in Sudan, the fish biomass in minor canals of the Geizira irrigation system with an average of 660 kg/ha (Anon 2003). Various studies have shown that channelization or irrigation canals exhibit lower species diversity than nearby static water bodies which is influenced by temperature and low primary producers (Tarplee et al. 1971; Daget 1976). The biotic and abiotic attributes of water and the biological diversity of the ecosystem determine the health of an aquatic ecosystem (Harikrishnan et al. 1999). Any changes in these factors resulted in a shift in the living biota (Ingole et al. 2010; Gogoi et al. 2020). Biotic or abiotic factors play an important role in fish species assemblages, fish diversity and community structure in different aquatic resources (Minns 1989; Villar et al. 2011; Mukerjee et al. 2012). The environmental parameters such as dissolved oxygen, total dissolved solids, pH, transparency, hardness, and alkalinity influenced the fish assemblage pattern in floodplain wetlands (Sarkar et al. 2020). In the coastal environment, the spatio-temporal variation in the fish assemblage is driven mainly by the salinity and the temperature as previously reported by Molina et al. (2020). The migration of fish from the main course of the river into the wetlands via the tributaries, during tidal inundation, and the development of the fish adaptive capacity to stress, are accountable for high fish abundance and their structural distribution in wetlands (Nsor and Obodai 2016).

The fishes form an integral component of the faunal diversity of the Sundarbans. Many species of fish depend on this ecosystem, either throughout their life cycle or during certain stages of their life. The fish fauna of the Hooghly–Matlah estuarine system including the lower zone falling under Sundarbans, has attracted the attention of several scientists since the beginning of the 19th Century (Khan 1994). The first comprehensive work was that of Hamilton–Buchanan who made an extensive study on the fishes of the Ganges. The foundation knowledge laid down by the works of Jayaram (1981), and Talwar and Jhingran (1991) have helped in expanding our knowledge of the fishes of Sundarbans. The influence of freshwater inflow has been demonstrated as a crucial factor in structuring estuarine fish fauna and planktonic communities in several studies (Schlacher and Wooldridge 1996; Strydom et al. 2002; Gogoi et al. 2019). In recent years, research interest is more focused on estuarine fish assemblages in different habitats to establish how the composition of fish fauna and the species richness in the entire estuary changes with the season and with changing environmental conditions. The type and location of the estuary largely influence the major features of fish fauna and population characteristics in typical ways (Potter and Hyndes 1999). Fish diversity studies of estuarine headwaters or upper reaches are scanty, which brings out the importance of focused studies covering the entire length of an estuary (Whitfield and Patterson 2003). Some studies have combined the taxonomic and functional description of estuarine fish assemblages, integrating and identifying the major structuring forces of population dynamics which makes it useful for conservation and management of estuarine resources (Nagelkerken and van der Velde 2004). Many studies have employed species composition, species richness, and abundance to characterize and assess fish community and diversity (Smith 1978; Friedlander and Parrish 1998; Hewitt et al. 2008). In some '*Aila*' affected canals of Sundarbans, ICAR-CIFRI, Barrackpore has worked to restore the Indian Major carps to support the livelihoods of the fishers (Das et al. 2019). Some other studies by ICAR −CIFRI on fish diversity and environmental parameters in Hooghly, Mahanadi, Subarnarekha and Godavari estuaries provide a good deal of useful information related to fisheries in estuarine waters. However, information on fish fauna and their seasonal occurrence in many important rivers, estuaries, and mangrove ecosystems and their relationship with environmental variables is grossly deficient (Ansari et al. 1995). The data on ecology (Kotellat 1984), and the distribution of fish species concerning the environmental and physical variables remain limited (Mukherjee et al. 2013). Most importantly, the information on the trophic status of canal habitat, biotic community structure and hydrological parameters are scarce and very limited. Hence, this study aimed at understanding the fish assemblage structure and their interaction with water variables in the canal systems of Sundarbans, India.

Materials and methods

Study area

The Indian Sundarbans are a globally significant mangrove area with an extremely fragile environment. Two canals namely Bhetkimari (21°36′08.9″ N 88°15′14.8″ E to 21°36′40.1″ N 88°15′22.5″ E) in Madanganj, and Bishalakhi (21°46′47.3″ N; 88°05′30.6″ E) in Sagar Island were selected for this study according to their tidal connectivity from river Hathenia−Dewania and Mooriganga, respectively. Sagar Island is a tide-dominated island in the Indian Sundarbans (Mukharjee 1983). The island has some mangrove patches and is surrounded by two major rivers namely Hooghly and Mooriganga. Human settlements are densely located on both the banks of the canals. The canal provides freshwater supply for agriculture, livestock rearing and household activities including fishing for the locality year-round. Both the canal is about 2.5 km long, and ~ 27.0 m wide having very little natural base flow depending on the riverine tidal influx. In general, the canal remains 2.5−3.5 m deep during peak monsoon, and 1−1.5 m during winter. Salinity has fluctuated in both the canal ranges from 0.2 to 22.7 ppt. The schematic diagram of the study area was prepared by employing QGIS 2.18 (Fig. 1).

Sampling methodology

Three sampling stations were chosen for the collection of samples from each canal, which reasonably represented the determinants of key sites (total = 6 sampling sites, herein referred to S1, S2, S3 in Bhetkimari, and S4, S5, S6 in Bishalakhi) in the canal. From June 2017 to September 2018, seasonal sampling was carried out representing three seasons (constituting 36 samples) viz., pre-monsoon (March−June), monsoon (July−October) and post-monsoon

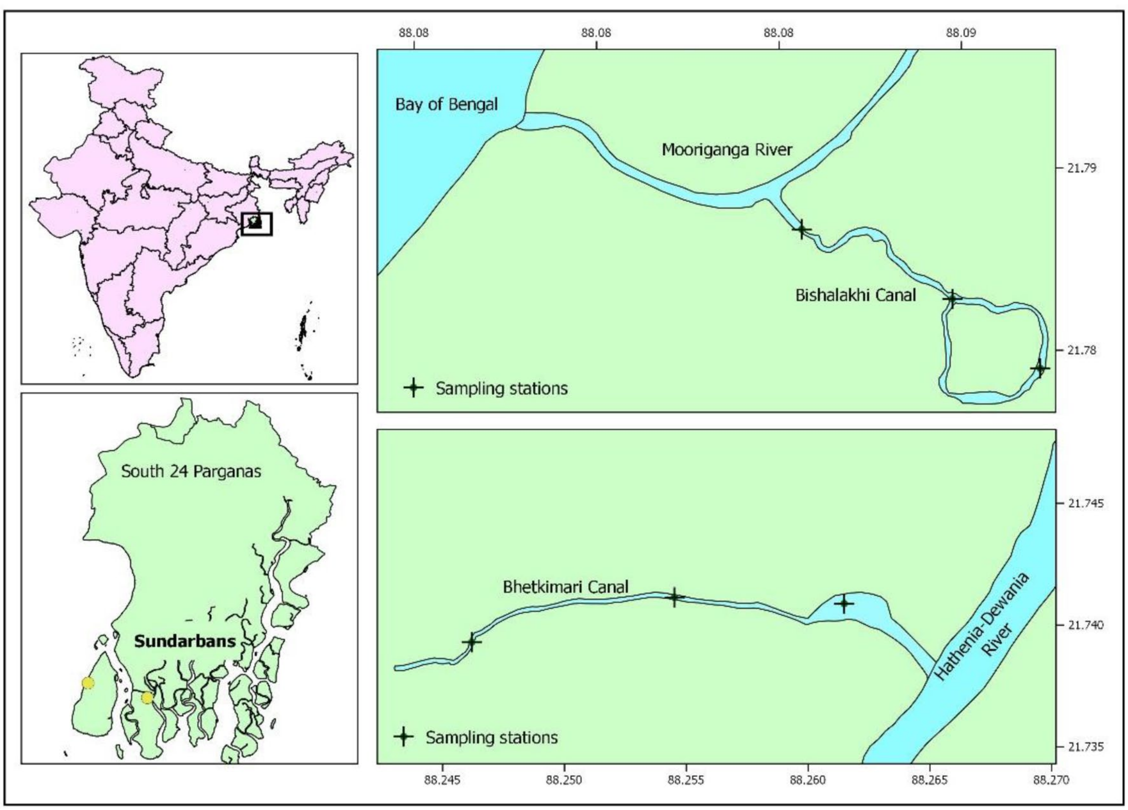

Fig. 1 Map showing the geographic locations and study area of the selected canals in Sundarbans (S1 near the river, followed by S2 and S3 for both the canal)

(November–February) (Chaudhury et al. 2012). Water temperature (Temp.) was measured using a degree centigrade (− 10 to 50 °C) thermometer (P−601466), pH with a digital pH meter (HANNA instruments), and specific conductivity by a digital conductivity meter (Multiline P4−82362). Dissolved oxygen (DO), salinity and total alkalinity (TA) were analyzed in-situ following the titrimetric method (APHA 2012). The standard water sampler based on the design of the 'Ruttner water sampler' was used to gather subsurface water samples (0.5 m depth) at all the specified locations (Das Sarkar et al. 2019), and samples were immediately transferred to pre-rinsed polyethylene bottles (1L). Water samples were then brought to the laboratory in cold conditions and analysed for nutrients such as nitrate ($NO_3{-}N$), total nitrogen (TN), phosphate ($PO_4{-}P$), total phosphorous (TP) and silicate ($SiO_4{-}Si$) following recommendations and methods described in APHA (2012). Transparency (SD) was estimated using Secchi disc (Strickland and Parsons 1972). Flow velocity was measured using a portable digital flow meter (JDC Electronic SA, Switzerland), and depth was measured by a portable depth sounder (Hondex Bx-7, Japan).

Fish samples were collected seasonally from all the sites by employing various mesh size gears. The fishes were mainly harvested by the local fishers through dragnet (1.0 mm), gill nets (10−35 mm), scoop net (1.0 mm), cast net (10−20 mm) and bamboo traps *(Aatol)*. Experimental fishing was conducted both day and night at all the sampling sites through cast nets (10−20 mm), gill nets (10−35 mm) and drag nets (1.0 mm). In addition, local fish market surveys were done as a part of sampling for collecting and verifying the fish samples, which were not recorded during the experimental fishing. Freshly caught fish specimens were preserved in ice first, and then preserved in 5% and 10% buffered formalin for SIF's and large size groups, respectively. The collected fish specimens were identified to species level using standard taxonomic keys of Talwar and Jhingran (1991), Jayaram (1999), Nelson et al. (2016) and Froese and Pauly (2021). The taxonomic names and positions are also evaluated by referring Eschmeyer et al. (2021) and FishBase (Froese and Pauly 2021). Fishes were grouped according to their food and ornamental value, habitat distribution following FishBase (Froese and Pauly 2021).

Data analysis

The variation in water quality parameters during three seasons (pre-monsoon, monsoon and post-monsoon) were subjected to one-way analysis of variance (ANOVA), and Duncan's multiple range tests (Post hoc) using SPSS 16. We performed the Permutational Multivariate Analysis of Variance (PERMANOVA) to test the differences ($p \leq 0.05$) between the water variables in terms of seasons and stations, and also to observe the significant difference between two data sets (canals). Pearson's correlation (2-tailed) between water variables and the total fish abundance was also computed. To explore the overall fish diversity, diversity indices were derived using the standard formulae of Shannon diversity (Shannon-Weiner 1949), Simpson's Index of diversity (Simpson 1949), richness (Margalef 1958) and evenness index (Pielou 1977). All the diversity indices were then subjected to one-way ANOVA, examining seasonal differences in diversity. The graphical representation of *k*-dominance curve was used to understand the dominance pattern across the seasons (Warwick et al. 2008) in both the canal. Hierarchical cluster analysis was carried out for grouping samples, and non-metric multidimensional scaling (NMDS) tool was performed to comprehend the similarity of community structure as well as differential abundance pattern among samples which were then tested using analysis of similarity (ANOSIM) to understand the significant differences between seasons concerning fish species composition. RELATE routine, a mental test was performed to understand the significant difference of fish species compositions between the two canals. Pre-treatment of all the biological data was done by square root transformation to achieve the normality of the fish abundance data. BIO-ENV (Biota and/or Environment matching) module was performed to identify and quantify the environmental variables that potentially influenced the fish abundance. Further distance-based redundancy analysis (db-RDA) was performed to comprehend and visualize the importance of water variables with the square root transformed abundance data/samples. All these analyses were performed by using PRIMER v 6.0 (Clarke and Gorley 2006).

Results

Physicochemical factors

The variation of water variables in different seasons in both the canal are depicted in Table 1. Eight parameters (Temp., depth, flow, Sp. Con. Salinity, SD, $PO_4{-}P$, and $SiO_4{-}Si$) varied significantly ($p \leq 0.05$) among seasons in both the canal (Table 1). The water remained alkaline throughout the study period. pH was observed maximum in the Bhetkimari canal with its maximum during pre-monsoon (8.3 ± 0.1), and exhibited significant variation among seasons. The magnitude of pH in the Bishalakhi canal showed a uniform pattern across seasons, and did not show significant ($p \geq 0.05$) variation. Surface water temperature showed a clear seasonal cycle ($p \leq 0.01$), but displayed slight variation across the stations in both the canals. Specific conductivity and total alkalinity decreased from the pre-monsoon to the post-monsoon. The small fluctuation of DO was observed over space and

Table 1 Variations in water quality parameters of Bhetkimari and Bishalakhi canal, Sundarbans

Variables/Seasons	Bhetkimari canal				Bishalakhi canal			
	PRM	MON	POM	*p* value	PRM	MON	POM	*p* value
Temp. (°C)	31.6 ± 0.2^{a}	30.5 ± 0.4^{b}	27.9 ± 0.1^{c}	0.001	32.3 ± 0.2^{a}	30.4 ± 0.3^{b}	28.0 ± 0.3^{c}	0.001
pH	8.3 ± 0.1^{a}	7.4 ± 0.1^{b}	7.1 ± 0.1^{b}	0.001	7.5 ± 0.1^{a}	7.5 ± 0.1^{a}	7.4 ± 0.1^{a}	0.623
Depth (m)	1.31 ± 0.21^{a}	3.12 ± 0.48^{b}	2.33 ± 0.22^{c}	0.002	1.26 ± 0.26^{a}	2.66 ± 0.22^{b}	1.78 ± 0.16^{c}	0.001
Flow (m sec^{-1})	0.14 ± 0.03^{a}	0.43 ± 0.04^{b}	0.26 ± 0.02^{c}	0.0001	0.16 ± 0.02^{a}	0.36 ± 0.04^{b}	0.23 ± 0.35^{c}	0.001
DO (mg l^{-1})	6.1 ± 0.1^{a}	5.8 ± 0.1^{b}	6.3 ± 0.1^{a}	0.007	6.2 ± 0.1^{a}	6.1 ± 0.1^{a}	6.3 ± 0.1^{a}	0.232
Sp. Con. (mS cm^{-1})	31.0 ± 3.0^{a}	0.8 ± 0.1^{b}	13.9 ± 1.8^{c}	0.001	30.3 ± 1.1^{a}	1.1 ± 0.1^{b}	27.6 ± 0.8^{a}	0.001
TA (mg l^{-1})	125.7 ± 14.7^{a}	114.3 ± 18.9^{a}	110.4 ± 2.3^{a}	0.734	130.0 ± 12.2^{a}	100.0 ± 3.1^{b}	93.7 ± 0.3^{b}	0.026
Salinity (ppt)	20.8 ± 1.9^{a}	0.2 ± 0.03^{b}	2.6 ± 0.7^{b}	0.001	13.2 ± 1.6^{a}	0.3 ± 0.03^{b}	6.2 ± 1.5^{c}	0.001
$NO_3{-}N$ (mg l^{-1})	0.12 ± 0.03^{a}	0.15 ± 0.01^{a}	0.11 ± 0.01^{a}	0.567	0.04 ± 0.0^{a}	0.06 ± 0.0^{a}	0.05 ± 0.0^{a}	0.152
TN (mg l^{-1})	0.4 ± 0.04^{a}	0.4 ± 0.06^{a}	0.6 ± 0.01^{a}	0.123	0.08 ± 0.0^{a}	0.09 ± 0.0^{a}	0.08 ± 0.0^{a}	0.602
$PO_4{-}P$ (mg l^{-1})	0.02 ± 0.0^{c}	0.04 ± 0.0^{b}	0.06 ± 0.0^{a}	0.001	0.06 ± 0.0^{a}	0.02 ± 0.0^{b}	0.07 ± 0.0^{a}	0.001
TP (mg l^{-1})	0.07 ± 0.01^{a}	0.10 ± 0.0^{a}	0.4 ± 0.3^{a}	0.396	0.09 ± 0.0^{a}	0.04 ± 0.0^{b}	0.10 ± 0.0^{a}	0.001
$SiO_4{-}Si$ (mg l^{-1})	1.8 ± 0.5^{b}	2.0 ± 0.4^{b}	$6.8 + 0.7^{a}$	0.001	4.5 ± 0.3^{b}	6.9 ± 0.4^{a}	$4.2 + 0.1^{b}$	0.001
SD Trans. (cm)	42.8 ± 0.4^{a}	26.8 ± 0.2^{c}	40.2 ± 0.6^{b}	0.001	46.5 ± 0.3^{a}	30.1 ± 1.1^{c}	36.9 ± 0.6^{b}	0.001

Values are means ± standard deviation followed by the same letter are not significantly different at 5% probability level; *PRM* Pre-monsoon, *MON* Monsoon, *POM* Post-monsoon

time in both the canal. However, the seasonal differences in DO concentration were found to be significant ($p = 0.007$) in the Bhetkimari canal. The higher magnitude of DO was obtained during the post-monsoon season (> 6.30 mg l^{-1}), and it decreased from pre-monsoon (> 6.0 mg l^{-1}) to monsoon season (> 5.0 mg l^{-1}) in both the canal. Salinity values exhibited significant variation among seasons. Mean salinity was found to be maximum and minimum in Bhetkimari canal during pre-monsoon (20.8 ± 1.9 ppt) and monsoon seasons (0.2 ± 0.03 ppt), respectively.

No specific differences were observed in the concentrations of $NO_3{-}N$ and TN during the study period. $NO_3{-}N$ contents were comparatively higher during monsoon for both the canals. Among the nutrients, $PO_4{-}P$ contents were found to be relatively low. Dissolved $SiO_4{-}Si$ exhibited wide variation across seasons, portrayed significant difference ($p \leq 0.01$) in both the canal. On the whole, PERMANOVA analysis (pooled data set) showed a significant variation of water variables between seasons ($F = 10.40$; $p = 0.001$), and stations ($F = 1.96$; $p = 0.011$). Furthermore, there was a significant difference ($F = 3.06$; $p = 0.013$) of water variables between the two canals. From the correlation matrix, it reflects that pH was significantly correlated with water depth (r = −0.765, $p \leq 0.05$), Sp. Con. (r = 0.852; $p \leq 0.01$), salinity (r = 0.854; $p \leq 0.01$), $PO_4{-}P$ (r = −0.906; $p \leq 0.01$), and $SiO_4{-}Si$ (r = −0.882; $p \leq 0.01$) (Table 2). Flow velocity in turn found to have significant negative correlation with salinity (r = −0.845; $p \leq 0.01$) and transparency (r = −0.845; $p \leq 0.01$) in the Bhetkimari canal. While pH did not portray significant correlation with any of the water variable in the Bishalakhi canal. The water depth exhibited significant positive correlation with flow velocity (r = 0.986; $p \leq 0.01$), and negative correlation with salinity (r = −0.804; $p \leq 0.01$), $PO_4{-}P$ (r = −0.822; $p \leq 0.01$), TP (r = −0.789; $p \leq 0.05$), $SiO_4{-}Si$ (r = −0.889; $p \leq 0.01$) and transparency (r = −0.897; $p \leq 0.01$) in the Bishalakhi canal (Table 3). Dissolved oxygen was seen negatively correlated with water temperature in both the canals.

Fish species composition and distribution

A total of 44 fish species comprised of 39 genera, 30 families and 16 Orders (42 species belonging to 37 genera in the Bhetkimari, and 41 species belonging to 36 genera from the Bishalakhi) were recorded from the studied canals. From these, 40 species were common to both the canal. Two species (*Boleophthamus boddarti* and *Oreochromis mossambicus*) occurred only in Bhetkimari canal; and 2 species (*Megalops cyprinoides* and *Chanos chanos*) only in Bishalakhi canal. Family Cyprinidae showed predominance in terms of species richness (6 species). Family Danionidae was represented by 5 species, and families Ambassidae, Bagridae, Channidae, Oxudercidae and Mugillidae were represented by 2 species for each group. The rest of the 23 families were accounted for one species each to the total fish species diversity. The relative contribution of Danionidae (32.55%), Cyprinidae (28.17%), Anabantidae (3.02%), and Gobiidae (1.92%) were higher in the Bhetkimari canal compared to that of the Bishalakhi canal where it accounted for 20.61%, 10.14%, 2.96% and 1.40%, respectively. However, family Mugilidae (10.54%), Terapontidae (4.83%), Scatophagidae (3.58%), and Polynemidae (2.34%)

Table 2 Correlation matrix of water variables and total fish abundance in Bhetkimari canal

Water var	WT	pH	Depth	Flow velocity	DO	Sp Con	TA	Sal	NO_3-N	TN	PO_4-P	TP	SiO_4-Si	SD	Fish Abun
WT	1														
pH	0.776*	1													
Depth	− 0.262	− 0.765*	1												
Flow	− 0.145	− 0.626	0.964**	1											
DO	− 0.537	− 0.278	− 0.341	− 0.534	1										
Sp Con	0.911**	0.852**	− 0.515	− 0.400	− 0.310	1									
TA	− 0.249	− 0.449	0.271	0.167	0.260	− 0.190	1								
Salinity	0.613	0.834**	− 0.845**	− 0.803**	0.150	0.846**	− 0.190	1							
NO_3–N	0.091	− 0.186	0.386	0.484	− 0.310	0.210	0.147	− 0.050	1						
TN	− 0.628	− 0.614	0.247	0.097	0.520	− 0.540	0.256	− 0.380	0.073	1					
PO_4–P	− 0.943**	− 0.906**	0.507	0.372	0.440	− 0.948**	0.366	− 0.782*	− 0.040	0.713*	1				
TP	− 0.500	− 0.439	0.185	0.054	0.220	− 0.440	0.245	− 0.210	− 0.040	0.100	0.404	1			
SiO_4–Si	− 0.882**	− 0.724*	0.152	− 0.036	0.725*	− 0.727*	0.548	− 0.380	− 0.100	0.723*	0.858**	0.558	1		
SD	0.300	0.610	− 0.845**	− 0.868**	0.440	0.595	− 0.150	0.885**	− 0.100	0.080	− 0.470	− 0.170	− 0.050	1	
Fish Abun	0.903**	0.531	− 0.019	0.007	0.450	0.729*	− 0.190	0.415	0.010	− 0.400	− 0.753*	− 0.360	− 0.727*	0.170	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Table 3 Correlation matrix of water variables and total fish abundance in Bishalakhi canal

Water var	WT	pH	Depth	Flow velocity	DO	Sp Con	TA	Sal	NO_3-N	TN	PO_4-P	TP	SiO_4-Si	SD	Fish Abun
WT	1														
pH	0.515	1													
Depth	− 0.272	− 0.032	1												
Flow	− 0.253	− 0.057	0.986**	1											
DO	− 0.078	− 0.044	− 0.561	− 0.579	1										
Sp Con	0.918**	0.386	0.061	0.088	− 0.310	1									
TA	0.754*	0.449	− 0.478	− 0.530	0.250	0.575	1								
Salinity	0.440	0.092	− 0.804**	− 0.819**	0.370	0.133	0.732*	1							
NO_3–N	− 0.056	0.130	0.443	0.494	− 0.380	0.154	− 0.560	− 0.810**	1						
TN	0.099	0.421	0.264	0.272	− 0.170	0.105	− 0.310	− 0.540	0.738*	1					
PO_4–P	− 0.172	− 0.138	− 0.822**	− 0.833**	0.520	− 0.520	0.137	0.707*	− 0.570	− 0.300	1				
TP	− 0.228	− 0.080	− 0.789*	− 0.819**	0.590	− 0.580	0.193	0.694*	− 0.630	− 0.300	0.976**	1			
SiO_4–Si	0.175	0.239	0.889**	0.893**	− 0.540	0.481	− 0.140	− 0.650	0.454	0.310	− 0.944**	− 0.924**	1		
SD	0.504	0.118	− 0.891**	− 0.875**	0.510	0.180	0.662	0.940**	− 0.630	− 0.400	0.716*	0.672*	− 0.680*	1	
Fish Abun	0.037	0.209	0.755*	0.724*	− 0.180	0.228	0.070	− 0.380	0.052	0.030	− 0.610	− 0.580	0.801**	− 0.400	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed) have accounted comparatively higher percentage in the Bishalakhi canal. Altogether, the compositions of recorded families were represented by Danionidae (29.53%), followed by Cyprinidae (20.15%), Mugilidae (8.54%), Bagridae (6.32%), Adrianichthydae (5.44%), Terapontidae (4.55%) and Ambassidae (2.59%). The other families accounted the least contribution to the total fish assemblage. The percentage contributions of fish families in different seasons for both the canals are shown in Fig. 2.

The occurrence of species richness (*SRp*) varied considerably in seasons. Maximum species richness (28 species) was recorded at station S1 during post-monsoon followed by S2 (27 species), and S4 (24 species) during monsoon. The average species richness was found to be 20 ± 5 across the stations. Overall, the seasonal species richness was maximum during monsoon (22 ± 5 species) followed by post-monsoon (20 ± 4 species), and pre−monsoon (16 ± 3 species) throughout the study period. Significant temporal variations in the species richness were observed between pre-monsoon and monsoon ($F = 3.198$; $p = 0.023$), whereas the variation was not significant between monsoon and post-monsoon. Out of 44 fish species, *Amblypharyngodon mola* accounted maximum (15.18%) followed by *Puntius sophore* (12.27%), *Esomus danricus* (8.80%), *Chelon parsia* (6.83%), *Mystus gulio* (5.0%), *Oryzias dancena* (4.55%), *Terapon jarbua* (3.57%) and *Pisodonophis boro* (3.0%) to the total fish assemblage throughout the study period. However, the seasonal spectrum revealed variation in the species contribution. During monsoon and post−monsoon season, fish species *A. mola* > *P. sophore* > *E. danricus* > *Salmostoma bacaila* > *M. gulio* > *Anabas testudineus* > *Rasbora daniconius* were registered their maximum contribution to the total fish abundance. However, during the pre-monsoon season, species such as *Chelon parsia* (14.82%), *P. sophore* (8.2%), *M. gulio* (7.48%), *T. jarbua* (7.04%), *A. mola* (6.18%), *Puntius terio* (5.61%), *Pethia ticto* (5.0%) and *Glossogobius giuris* (3.88%) had their significant contribution. The occurrence of fish species in seasons (based on their relative abundance) is shown in Table 4.

Our observations revealed that small indigenous fish species were dominated across the stations irrespective of the season. Of the total fish reported, 24 species were categorized as SIF's and 20 species as Non-SIF's. Among SIF's, fish species *A. mola* (6−21%), *P. sophore* (8−17%), *E. danricus* (3−15%), *P. ticto* (1.7−5.6%), *P. terio* (2−5%), *R. daniconius* (2−3.5%), *M. gulio* (3.5−7.5%), *Anabas testudineus* (1.7−3.17%), *Salmostoma bacaila* (1−3%) were contributed significantly in the fish assemblages. Among Non-SIF's fish species viz. *C. parsia, T. jarbua, G. giuris* and *Scatophagus argus* were shared 2−14%, 1−7%, 1−4%, and 1.5−2.5%, respectively in the total abundance. Based on the habitat distribution of the recorded fish species; 22 species were from truly freshwater habitat, 1 species was from marine habitat, 9 species were both fresh and brackish water distributional range, and 12 species formed the ranges from brackish and marine habitat (Table 4). According to the fishery information, 9 species were found to be truly food fishes, 31 species have both food and ornamental value, 4 species have only ornamental value. The exotic fish species *Oreochromis mossambicus* was found only in the Bhetkimari canal during

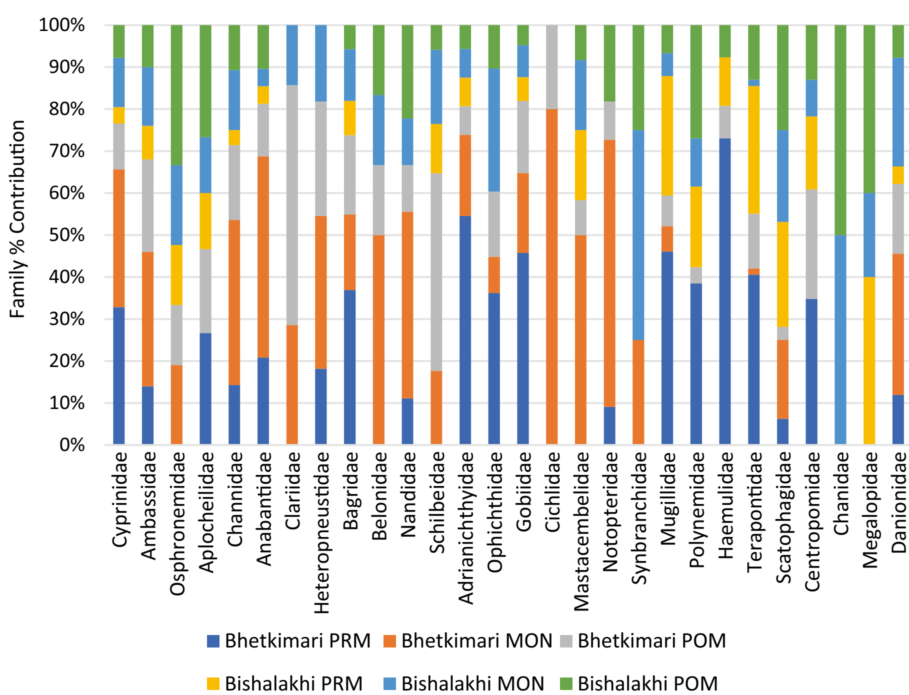

Fig. 2 Family-wise percentage contribution in different seasons

Table 4 Species occurrence in the seasons. Calculated based on relative abundance; − denotes absent; + = present (1−5%); ++ (5−10%), and +++ = (> 10%)

Species	Bhetkimari canal			Bishalakhi canal			IUCN status	Habitat	Uses	SIF/Non-SIF
	PRM	MON	POM	PRM	MON	POM				
Order: Cypriniformes										
Family: Cyprinidae										
Puntius sophore	++	+++	++	++	+++	+++	LC	F	*F/O	SIF
P. terio	++	−	+	−	+	+	LC	F	*F/O	SIF
Puntius chola	−	+	+	+	−	−	LC	F	*F/O	SIF
Pethia ticto	++	+	+	−	+	+	LC	F	*F/O	SIF
Pethia conchonius	−	+	+	−	+	−	LC	F	*F/O	SIF
Oreichthys cosuatis	−	+	+	+	−	+	LC	F	*F/O	SIF
Family: Danionidae										
Laubuka laubuca	−	+	+	+	+	+	LC	F	O	SIF
Salmostoma bacaila	−	+	+	+	+	+	LC	F	*F/O	SIF
Amblypharyngodon mola	+	+++	+++	+	+++	++	LC	F	*F	SIF
Esomus danricus	+	+++	+	+	+++	+++	LC	F	*F/O	SIF
Rasbora daniconius	+	+	+	−	+	+	LC	F	*F/O	SIF
Order: Perciformes										
Family: Ambassidae										
Parambassis ranga	+	+	+	+	+	+	LC	F	*F/O	SIF
Chanda nama	+	+	+	+	+	+	LC	F	*F/O	SIF
Family: Polynemidae										
Eleutheronema tetradactylum	+	−	+	+	+	+	NE	F/B/M	*F/O	Non-SIF
Family: Haemulidae										
Pomadasys argyreus	+	−	+	+	−	+	LC	M	*F	Non-SIF
Family: Latidae										
Lates calcarifer	+	−	+	+	+	+	LC	F/B/M	*F	Non-SIF
Order: Anabantiformes										
Family: Osphronemidae										
Trichogaster fasciata	−	+	+	+	+	+	LC	F/B/M	*F/O	SIF
Family: Channidae										
Channa marulius	+	+	+	−	+	+	LC	F	*F/O	Non-SIF
Channa punctata	+	+	+	+	+	+	LC	F	*F/O	Non-SIF
Family: Anabantidae										
Anabas testudineus	+	+	+	+	+	+	LC	F	*F/O	SIF
Family: Nandidae										
Nandus nandus	+	+	+	−	+	+	LC	F	*F/O	SIF
Order: Cichliformes										
Family: Cichlidae										
Oreochromis mossambicus	−	+	+	−	−	−	LC	F/B	*F/O	Non-SIF
Order: Centrarchiformes										
Family: Terapontidae										
Terapon jarbua	++	+	+	+++	+	++	LC	F/B/M	*F/O	Non-SIF
Order: Acanthuriformes										
Family: Scatophagidae										
Scatophagus argus	+	+	+	+	+	+	LC	F/B/M	*F/O	Non-SIF
Order: Siluriformes										
Family: Clariidae										
Clarias magur	−	+	+	−	+	−	EN	F	*F/O	SIF
Family: Heteropneustidae										
Heteropneustes fossilis	+	+	+	−	+	−	LC	F	*F/O	SIF

Table 4 (continued)

Species	Bhetkimari canal			Bishalakhi canal			IUCN status	Habitat	Uses	SIF/Non-SIF
	PRM	MON	POM	PRM	MON	POM				
Family: Bagridae										
Mystus vittatus	−	+	+	+	+	+	LC	F	*F/O	SIF
Mystus gulio	++	+	+	+	+	+	LC	F/B	*F/O	Non-SIF
Family: Schilbeidae										
Pachypterus atherinoides	−	+	+	+	+	+	LC	F/B	*F/O	Non-SIF
Order: Beloniformes										
Family: Belonidae										
Xenentodon cancila	−	+	+	−	+	+	LC	F/B	*F/O	Non-SIF
Family: Adrianichthyidae										
Oryzias dancena	++	+	+	+	+	+	LC	F/B	O	SIF
Order: Cyprinodontiformes										
Family: Aplocheilidae										
Aplocheilus panchax	+	−	+	+	+	+	LC	F/B	O	SIF
Order: Anguilliformes										
Family: Opichthidae										
Pisodonophis boro	+	+	+	−	++	+	LC	F/B/M	*F	Non-SIF
Order: Gobiiformes										
Family: Oxudercidae										
Boleophthalmus boddarti	+	+	+	−	−	−	LC	F/B/M	*F	SIF
Apocryptes bato	−	+	+	−	+	+	LC	F/B/M	*F/O	Non-SIF
Family: Butidae									*F/O	
Butis butis	+	+	+	+	+	+	LC	F/B/M	*F/O	SIF
Family: Gobiidae										
Glossogobius giuris	+	+	+	+	+	+	LC	F/B	*F/O	Non-SIF
Order: Synbranchiformes										
Family: Mastacembelidae										
Macrognathus pancalus	−	+	+	+	+	+	LC	F	*F/O	SIF
Family: Synbranchidae										
Monopterus cuchia	−	+	−	−	+	+	LC	F/B	*F	Non-SIF
Order: Osteoglossiformes										
Family: Notopteridae										
Notopterus notopterus	+	+	+	−	−	+	LC	F	*F/O	Non-SIF
Order: Mugiliformes										
Family: Mugilidae										
Chelon parsia	+++	+	+	+++	+	+	NE	F/B/M	*F	Non-SIF
Planiliza macrolepis	+	+	+	+	+	+	LC	F/B/M	*F	Non-SIF
Order: Gonorhynchiformes										
Family: Chanidae										
Chanos chanos	−	−	−	−	+	+	LC	F/B/M	*F/O	Non-SIF
Order: Elopiformes										
Family: Megalopidae										
Megalops cyprinoides	−	−	−	+	+	+	DD	F/B/M	*F	Non-SIF

PRM pre-monsoon, *MON* monsoon, *POM* post-monsoon, *LC* least concern, *EN* endangered, *NE* near threatened, *DD* data deficient, *F* Freshwater, *B* Brackish water, *M* Marine, **F* Food value, **F/O* Food/Ornamental value, *O* Ornamental value

monsoon and post-monsoon seasons, where it accounted for less than 0.5%. No other exotics were recorded throughout the study period. According to the International Union for Conservation of Nature and Natural resources (IUCN) Red List Status, out of 44 fish species, 1 species comes under the Endangered (*Clarias magur*), and 2 species under the Near

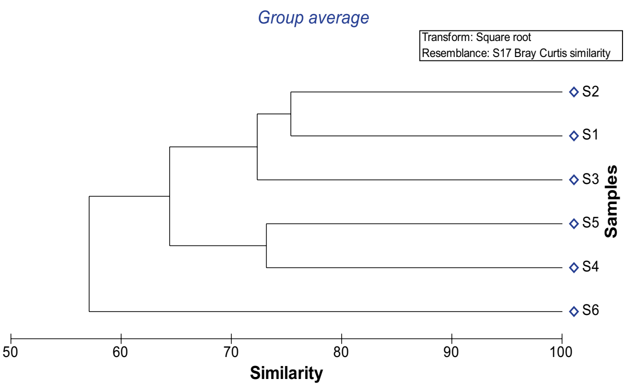

Fig. 3 Dendogram is showing the degree of similarity of fish diversity in different stations

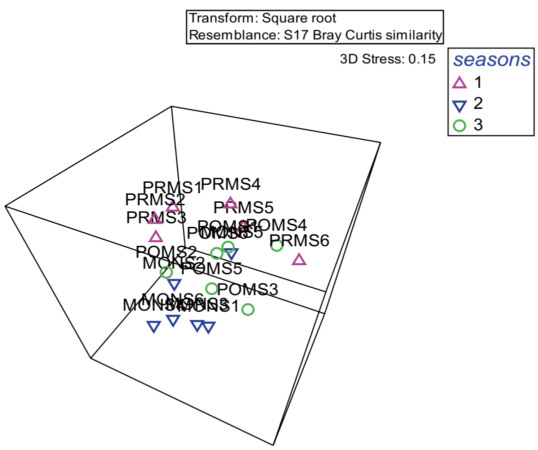

Fig. 4 NMDS ordination diagram (3-D depiction) of sites based on the Bray−Curtis similarity measures (1: Pre-monsoon; 2: Monsoon; 3: Post-monsoon)

Threatened category (*C. parsia* and *Eleutheronema tetradactylum*). The rest of the 40 species were categorized as Least Concern, and 1 as Data Deficient (*Megalops cyprinoides*).

Species similarity

The Cluster analysis on the similarity of fish species abundance in the studied stations is shown in Fig. 2. The group average similarity attained a maximum (75.37%) between stations S1 and S2. A low-level similarity (57%) was observed between S6, and a group of other stations (Fig. 3). The grouping of species composition was further analyzed by the NMDS. The station S4 and S5 during the pre-monsoon season, and S4 and S6 during post−monsoon season together formed a separate group with 40% similarity with regard to the species composition. On the whole, the species composition exhibited 30% similarity throughout the study period (Fig. 4). Further, retreatment of the data by employing ANOSIM revealed that, no significant (Global $R = 0.079$; significance level 19.4%) differences of fish species composition among seasons. However, RELATE routine analysis showed a significant ($\rho = 0.322$; $P = 0.1\%$) difference in the fish community compositions between Bhetkimari and Bishalakhi canals. SIMPER routine based on the seasons revealed that the average similarity was maximum during monsoon season (42.35%) followed by post-monsoon (33.84%) and pre-monsoon (31.03%). During pre-monsoon, *Chelon parsia* contributed maximum (19.88%) followed by *P. sophore* (11.78%), *A. mola* (10.70%), *Terapon jarbua* (9.90%), *M. gulio* (9.06%), *G. giuris* (5.11%) and *P. microlepis* (3.46%). Concurrently, species *A. mola* (28.28%), *P. sophore* (23.65%), *E. danricus* (14.85%), *M. gulio* (4.25%), *S. bacaila* (3.35%), *S. argus* (2.67%) had a major contribution during monsoon. During post-monsoon, the percentage contribution of fish species showed a subtle variation. Species *A. mola* (24.67%) was the chief contributor followed by *P. sophore* (18.44%), *C. parsia* (5.67%), *T. jarbua* (5.60%), *M. gulio* (3.90%), *P. macrolepis* (2.97%), *S. argus* (2.80%) during post-monsoon. Overall, the dissimilarity accounted maximum between pre-monsoon and monsoon with 71.48%, and the species mainly responsible for the dissimilarity were *A. mola* (12.23%), *E. danricus* (10.19%), *P. sophore* (9.82%), *C. parsia* (9.20%), *O. dancena* (4.86%), *T. jarbua* (4.85%), *M. gulio* (4.04%). Table 5 is showing the dissimilarity pattern of fish species between the canals.

Fish diversity and influence of water variables on fish abundance

The *k*-dominance curve plotted for the Bhetkimari canal reflected that the curves overlapped one another, indicating no differences in the species diversity in seasons, illustrating the similar dominance patterns (Fig. 5a). Whereas, in the Bishalakhi canal the species abundance and diversity were noticeably higher during the post-monsoon as compared to the other seasons (Fig. 5b). The Shannon-Wiener diversity *(H′)*, Margalef's species richness (*d′*), and Pielou's evenness index (*J′*) in the studied stations for both the canal are shown in Fig. 6. The Margalef species richness (*d′*) was highest at S1 during post-monsoon (5.88), and lowest at S4 during pre-monsoon (3.16). The Shannon Weiner (*H′*) values also showed a similar trend with the maximum during monsoon and post-monsoon at S5 (2.87) and S1, respectively. The lowest *H′* value was observed at S4 during pre-monsoon (2.0). The values of evenness (*J′*) were found to be ranged from 0.684 to 0.903 with the maximum at S6 during post-monsoon, and lowest at S1 during monsoon season. ANOVA post hoc test showed no significant variations ($p > 0.05$) of diversity indices (J', H' and $1-D$) across seasons except d'.

The correlation matrix revealed that total fish abundance was positively correlated with the Temp. ($r = -0.903$;

Table 5 SIMPER analysis depicting the dissimilarity of fish species between the studied canals

Species	Bhetkimari (S1, S2, S3)	Bishalak hi (S4, S5, S6)	Average dissimilarity = 67.64%		
	Av. Abun	Av. Abun	Av. Diss	Contrib. %	Cum. %
Amblypharyngodon mola	21.67	10.89	7.7	11.38	11.38
Puntius sophore	18.67	7.67	6.13	9.06	20.45
Esomus danricus	8.33	10.56	5.65	8.35	28.8
Chelon parsia	8.33	6.33	4.4	6.5	35.3
Oryzias dancena	7.89	1.89	3.32	4.91	40.21
Mystus gulio	7.78	2.89	3.1	4.59	44.8
Terapon jarbua	4.22	3.44	2.63	3.89	48.68
Puntius terio	5.67	0.78	2.48	3.67	52.35
Rasbora daniconius	5.67	0.89	2.34	3.47	55.82
Pethia ticto	5.33	0.44	2.21	3.27	59.08
Pisodonophis boro	3.89	2.56	1.99	2.94	62.02
Anabus testudineus	4.33	1	1.82	2.69	64.71
Salmostoma bacaila	2.44	1.78	1.5	2.22	66.93
Glossogobius giuris	3.56	1.44	1.42	2.1	69.03
Butis butis	3.22	0.44	1.35	1.99	71.02
Mystus vittatus	2.22	0.67	1.29	1.9	72.92
Chanda nama	2.22	1	1.12	1.66	74.58
Planiliza macrolepis	2.56	1.11	1.1	1.62	76.2
Pethia conchonius	1.89	0.22	1.08	1.59	77.8
Pomadasys argyreus	2.33	0.56	1.06	1.56	79.36
Eleutheronema tetradactylum	1.22	1.67	1.05	1.56	80.92
Scatophagus argus	1	2.56	1	1.47	82.39
Parambassis ranga	1.56	0.78	0.88	1.3	83.69
Trichogaster fasciata	0.78	1.56	0.86	1.27	84.96
Lates calcarifer	1.56	1	0.83	1.22	86.18
Channa marulius	1.44	0.22	0.77	1.14	87.32
Pachypterus atherinoides	1.22	0.67	0.74	1.09	88.4
Boleopthalmus boddarti	1.33	0	0.73	1.08	89.48
Oreichthys cosuatis	1.33	0.22	0.68	1.01	90.49

Av average, *Abun.* Abundance, *Diss.* Dissimilarity, *Contrib.* contribution, *Cum.* Cumulative

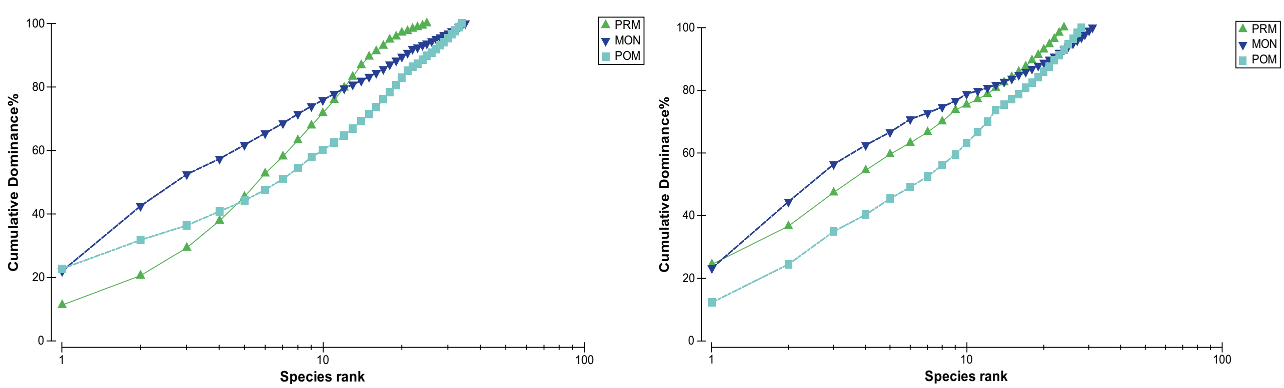

Fig. 5 Cumulative dominance curve plotted for **a** Bhetkimari (left panel) and **b** Bishalakhi canal (right panel) representing three seasons

$p \leq 0.01$), pH (r = 0.531), DO (r = 0.450) and Sp. Con. (r = 0.729; $p \leq 0.05$) in Bhetkimari canal. In Bishalakhi, fish abundance had significant positive correlation with depth (r = 0.755; $p \leq 0.01$) and flow velocity (r = 0.724;

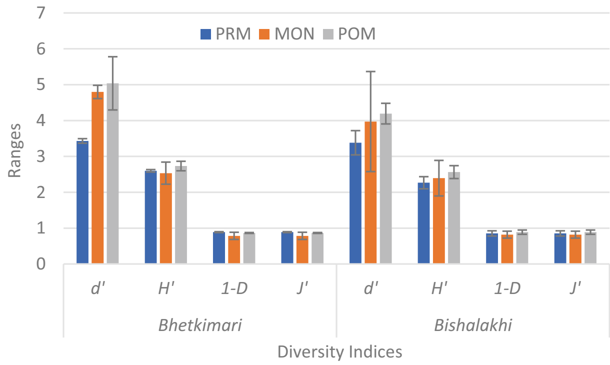

Fig. 6 Seasonal diversity indices of fishes in the selected canals (PRM: Pre-monsoon, MON: Monson, POM: Post-monsoon)

$p \leq 0.05$). Further, the BIO-ENV module reflected that water variables such as water depth, DO, salinity, SD and flow velocity were correlated with the fish abundance and composition. The highest correlation value $\rho = 0.316$ was observed in a combination of variables viz., water depth, salinity, DO, PO_4–P and SD. Whereas, the lowest correlation value ($\rho = 0.296$) has been calculated between the combinations of flow velocity, salinity, NO_3–N, PO_4–P and SD (Table 6). In addition, the multivariate plot of db-RDA analysis separated the samples among seasons, and it showed 34.6% total variation (i.e., db-RDA1 20.1% of the total variation, and db-RDA2 14.5% of total variation). Water variables such as pH, salinity, Sp. Con., DO, depth, water flow and PO_4-P were the important influencing variables for the distribution of species in the canal which was evident from db-RDA (Fig. 7).

Table 6 BIO-ENV analysis observed in the fish assemblage compared with water variables (pooled data)

No. of variables	Corr. selection	Spearman correlation
5	Depth, Salinity, DO, PO_4–P, SD	0.316
4	Salinity, DO, PO_4–P, SD	0.313
5	pH, Depth, DO, PO_4–P, SD	0.309
3	Salinity, NO_3–N, SD	0.306
4	Depth, Salinity, NO_3–N, SD	0.306
4	pH, Depth, NO_3–N, SD	0.304
5	Salinity, PO_4–P, SD	0.302
4	Depth, DO, PO_4–P, SD	0.301
5	pH, DO, Salinity, NO_3–N, SD	0.298
5	Flow, Salinity, NO_3–N, PO_4–P, SD	0.296

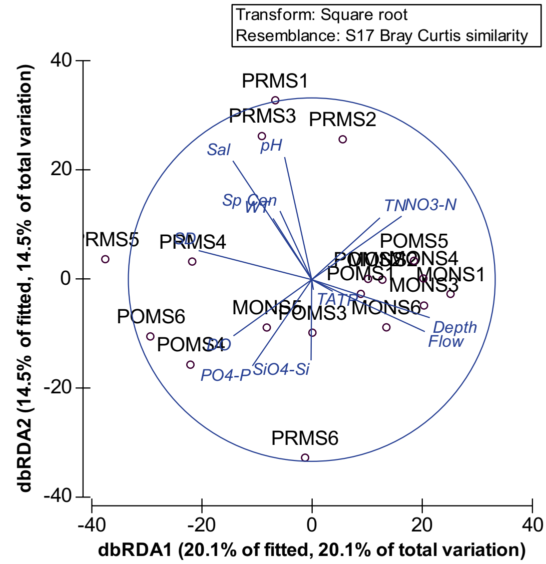

Fig. 7 Distance−based Redundancy analysis (db−RDA) ordination based on the environmental variables and samples data (PRM: Pre-monsoon; MON: Monsoon; POM: Post−monsoon). The length and direction of environmental vectors indicate the strength and direction of the relationship with the samples, respectively

Discussion

Species composition and diversity

Several studies mentioned the diverse opinions regarding the number of fish species that inhabit the Sundarbans estuarine system. Decade-old studies such as Pillay (1967) recorded over 120 fish species from the estuarine area of the Indian Sundarbans. Bose et al. (1999) had conducted a survey on the different zones of Sundarbans and recorded 74 fish species belonging to 40 families. A comprehensive work available regarding the fish fauna of Indian Sundarbans is that of Mandal et al. (2013) in which the author reported 267 fish species belonging to 81 families and 17 Orders. Some of the fragmented studies by Nandi et al. (1993), Bose et al. (1999), Basu et al. (2012) which have documented 76 species, 74 species and 52 indigenous (freshwater) fish species, respectively from the Sundarbans region. A recent study by Bhattacharya et al. (2018) reported 312 marine and brackish water fish species under 71 Families and 18 Orders from the Indian Sundarbans. The author accounted for the dominance of the Order Perciformes (164 species) followed by Clupeiformes (36 species) and Siluriformes (24 species). Although, extensive literature exists in Sundarbans, most of them are focused on estuarine core and region-specific for Hooghly-Matla estuarine system. However, the studies on the evaluation of fish resource assessment in canals in Sundarbans are lacking. In the present study a total of 44 species were recorded from the studied canals where Cyprinidae constituted a major percentage (in nos. of species). Dubey et al. (2015) reported 62 fish species distributed into 45 genera, 28 families and 9 orders in Sundarbans (Basanti and Sagar Island) with Cyprinidae as the dominant family. Previous studies have found that large seasonal changes in the structure of estuarine fish communities are related to salinity, which is regulated by seasonal rainfall and freshwater intake (James et al. 2007; Becketr and Laurensen 2008; Mukharjee et al. 2013). The species richness was maximum during monsoon which was due to the dominance of freshwater fish species, and thus during monsoon and post-monsoon season the occurrence of freshwater resident species (*A. mola, P. sophore, E. danricus, S. bacaila, A. testudineus, Rasbora daniconius*) was high as compared to brackish water resident species (*C. parsia, T. jarbua, S. argus, M. gulio*) (Fig. 4b). Significant temporal variation of fish species richness in the present study is in agreement with the former studies. The mangrove estuarine ecosystem supports the rich availability of all essential nutrients in the entire trophic levels that allows gathering fish fauna (Mandal et al. 2013). In such a highly heterogeneous environment, the species evenness is more important than the species richness to comprehend the overall diversity as compared to the stable systems (Mukharjee et al. 2013). The strong positive correlation between the Shannon diversity (H') and species evenness (J') ($r = 0.719$; $p \leq 0.01$) in the present study indicates a healthy fish composition in terms of fish diversity as well as their distribution pattern in the canals. This finding is in agreement with the Nair et al. (1989) ($r = 0.84$) and Chowdhury et al. (2011) ($r = 0.86$) in their study from River Neeyar, Western Ghat and river Naaf, Bangladesh, respectively. Mukharjee et al. (2013) have shown a significant positive correlation between diversity and evenness ($r = 0.811$, $p \leq 0.01$), and the probability of interspecific encounter ($r = 0.923$, $p \leq 0.01$) from the Matla River System, Sundarbans, which also supported the present findings. The significant correlation between H' and SRp in the present study contrasted with the observation made by the former, but consistent with special reference to post−monsoon maxima of H'. Albeit the number of species occurred maximum during monsoon but, it was marked by low evenness as compared to the other seasons; that it supports to the high diversity index (H') during the post−monsoon season. The Pielou's evenness index was ranged from 0.71 and 0.90, implying a consistent distribution of fish species across the sampling sites. The calculated value of d' and H' found to be > 2.62, indicating a moderate fish diversity in the canal system. Although, the overall fish assemblages did not show the significant temporal variation in the canal systems, but some of the fish species showed their significant temporal variations. And, the species were *P. sophore, P. ticto, P. terio, A. mola, E. danricus, N. notopterus, C. magur, C. parsia, M. gulio, A. bato, C. chanos, M. cyprinoides, T. jarbua* and *S. argus,* where they clearly characterized their assemblage according to the wet and dry seasons, freshwater inflow and most importantly the influence of salinity fluctuations in the canal system, which is consistent with the several studies from the tropical and sub-tropical system (Flores-Verdugo et al. 1990; Fraser 1997; Mukherjee et al. 2012). The only exotic species *O. mossambicus* was recorded during monsoon and post-monsoon season in the studied canal may be due to the accidentally escaping from the nearby aquaculture ponds. The polyculture of indigenous major/minor carps (*Labeo rohita, Cirrhinus mrigala, Catla catla* and minor carps such as *L. bata, L. calbasu*), and the exotics fish species (*Cyprinus carpio, Ctenopharyngodon idella*, *Hypophthalmichtys molitrix*) are accepted by the locality as profitable venture in the Sundarban eco-region. The other exotics such as *H. nobilis, Oreochromis mossambicus, O. niloticus* are also culturing as candidate species in pond aquaculture in the Sundarbans (Dubey et al. 2016). Dubey et al. (2015) reported the introduction of alien species *Pygocentrus natererri, Clarias gariepinnus* in the Sundarbans, and cultured in aquaculture ponds mixed with other freshwater species. The invasion of such highly carnivory as well as predatory alien fish species in the natural ecosystem of Sundarbans has been emerged as a growing threat to the indigenous fish species, and its diversity. These exotic species are hardy, and the ability to adapt a wide range of environmental perturbation and can compete with the native fish species for food and space (Kumar et al. 2016, 2020). The invasion of alien fish species is now a growing concern in the Sundarbans natural ecosystem which has been reported by many previous studies (Singh and Lakra 2011; Dubey et al. 2014, 2015; Gupta et al. 2016). Kumar et al. (2016) also reported the presence of exotics viz., *O. mossambicus,* and *O. niloticus* in the creeks of South Andaman Islands, and speculated the many endemic species are threatened due to habitat loss, and the introduction of non-native fish species in the Andaman Islands. About thirty-one fish species are found to have both food and ornamental value in the present investigations from the canal environment. Gupta et al. (2016) recorded 84 indigenous ornamental fish species belonging to 11 orders, 28 families, and 59 genera from different habitat types of Sundarban Biosphere Reserve. It is noteworthy that the majority of the indigenous fish species from Sundarbans have high ornamental value as well as food value (Basu et al. 2012; Gupta and Banerjee 2013; Dubey 2015). Sarkar and Lakra (2010) reviewed a total of 450 small indigenous freshwater fish species in India with 104 SIFs (23%) that have both food value and ornamental value. According to Blaber (2008), the abundance and diversity of brackish water fish resources in mangrove areas are largely determined by factors such as food availability, water flow, sound-free breeding grounds, temperature and the environment free from anthropogenic pressure by various social activities. The low diversity of fish species in the canal ecosystem could be related to the limited connectivitywith the tidal water through the sluice gate thereby minimizing the movement of brackish water fish species between canal and river. Thus, it also supports our results (ANOSIM) of insignificant temporal variation of overall fish species composition in the canals. In addition, high fishing pressure from the local populace leads to recruitment overfishing and growth overfishing of resident fish species. The use of small mesh size net, denuding of mangrove patches and gradually increasing anthropogenic stress also influenced the assemblage structure and well distribution of piscine resources in the canal systems of Sundarbans (Mandal et al. 2013). The significant variation of species composition between the two canals could be related to the variation of environmental and biotic variables coupled with varying degree of fishing pressures in both the canals. The occurrence of more brackish water resident fish species in Bishalakhi canal might be due to prolonged favourable salinity, and tidal connectivity with Mooriganga River. Peres-Neto (2004) suggested that the fish species occurrence is driven more by the relationship with abiotic factors and the habitat types than the species interaction.

Influence of physicochemical traits on fish community assemblage

Overall fish abundance in the Bhetkimari canal was positively correlated with temp., pH, DO and Sp. Con. and negatively correlated with $PO_4{-}P$ and $SiO_4{-}Si$; the correlation between these variables were found significant ($p \leq 0.01$ and $p \leq 0.05$, respectively). Growth and physiological functions in fish are regulated by physicochemical traits (Haldna et al. 2008), and thus, the temperature had a substantial impact on overall fish abundance in the current investigation. In the estuarine fish assemblage, temperature has been one of the influential environmental variables (Blaber et al. 2000; Harrison and Whitfield 2006). The temperature was also found to be the most important abiotic factor impacting the abundance distribution of fish assemblage in a coastal lagoon, Ria De Aveiro (Portugal), which was proving to be the best predictor of total abundance (Pombo et al. 2005). However, Mukherjee et al. (2012), on the other hand, found no significant role of temperature in structuring fish assemblages in the Matla River, Indian Sundarbans. The authors speculated the minor importance of water temperature for fish community structure related to the lagoon's warm environment, and its inherent tropical ichthyofauna. Lakra et al. (2010) mentioned that the habitat attributes viz., water depth, pH and DO were the key habitat features, and happened to be the most important parameter in shaping fish distributions, which is in consistent with the present findings. The significant positive correlation between fish abundance and the variables such as pH, DO, Sp. Con. in the present study agreed with the findings of De Silva et al. (2007); Lakra et al. (2010) and Shahnawaz et al. (2010).

Salinity shifts are the major determinant in the distribution of both marine and estuarine species, as well as a limiting factor for freshwater species, making salinity a crucial component in the formation and modification of aquatic ecosystem assemblage structure and functioning (Smyth and Elliot 2016). The complete absence of the freshwater fish species or low salinity tolerant species like *Monopterus cuchia* in both the canals; and *Oreichthys cosuatis, Trichogaster fasciata, Clarias magur, Mystus vittatus, Macrognathus pancalus* in the Bhetkimari canal during pre-monsoon season when salinity was more than 13.0 ppt were the indication of how changing salinity or increasing salinity influence the abundance and composition of fish species in these canals. According to Gelwick et al. (2001), salinity can work synergistically or antagonistically with various environmental stressors to freshwater species. While the euryhaline or brackish water resident species, *Chelon parsia, Planiliza macrolepis, Lates calcarifer, Terapon jarbua,* were observed highly abundant during higher saline pre-monsoon season because of the limited connectivity with tidal water through the sluice gate during this period thereby minimizing the movement of brackish water fish species between canal and river. Moreover, these species showed high tolerance to large fluctuations in salinity; therefore, they are abundant in both pre-monsoon and post-monsoon seasons. Species diversity and assemblage structure in Matagorda Bay, Gulf of Mexico were strongly affected by the connectivity between freshwater wetland and brackish zones (Gelwick et al. 2001), which is in conformity with the present study. During monsoon season, species abundance/richness at low salinity or freshwater zone canals was enhanced by the presence of freshwater species, as well as species that tolerate low salinity, and euryhaline marine species with broad salinity tolerance. It was observed a distinct separation of fish species depicting their inclination to the particular season. A similar study conducted in Buenaventura Bay estuary, Colombia by Molina et al. (2020) observed salinity and temperature as the most influential environmental variables. In the present study, there was a weak association between the ranks ($\rho = 0.316$) for the best set of environmental variables (BIO-ENV), which indicates there are other factors or variables that could influence the total fish abundance in these canals. From this study, it is eminent that fish utilize canal areas with diverse environmental conditions year-round, identifying general dynamics for each functional group and specific for each species. This suggest that species belonging to the same functional group may react to environmental changes in various ways.

Conclusion

The present study revealed a total of 44 fish species belonging to 16 orders, 30 families and 39 genera with Cyprinidae (6 species) being the apex contributor in the canal system. The species richness was maximum during the monsoon season; however, the Shannon diversity (H') and evenness (J') were calculated maximum during the post-monsoon season indicating uniform distribution of fish species during this season. The insignificant changes of fish community assemblage between seasons hinted towards the limited connectivity with the tidal water through the sluice gate thereby minimizing the movement of fish species between the canal and river. Thus, the erection of the sluice gate at the mouth of the canals could also be one of the reasons for low fish diversity in the canals. The water variables (temp., DO, pH, salinity, Sp. Conductivity, SD transparency) play a role in structuring the fish assemblage in the studied canals. The variable PO_4-P that are correlated to the fish assemblages implied their indirect effect on fish distribution. In addition, there are other biotic factors that could also influence the total fish abundance in these canals as evident from BIO-ENV analysis. The present investigation benchmarks the fish abundances, seasonality pattern, community indices, and relationship with physicochemical factors in the canal system, which will be helpful to understand further interactions of fish species in the tide-fed ecotone. The present study advocates the need for conservation and sustainable management of indigenous fish species through plausible guidelines to restore habitat or mitigate the loss of fish diversity in the canal systems.

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Declarations

Conflict of interest The authors declare they have no conflict of interest.

Ethical Statement The authors declare that they have strictly followed all the rules and principles of ethical and professional conduct while completing the research work.

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