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Seasonal changes in fish assemblages and trophic guilds in selected interconnected rivers in eastern India

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ABSTRACT

The study aimed to assess seasonal changes in species diversity and trophic guilds in selected connected rivers in eastern sub-Himalayan India. The environmental influence was reflected in seasonal differences in the fish assemblages over five main climatic seasons. Diversity estimators indicated that species richness and evenness were greater in the monsoon and autumn as was overall species diversity. Dominance-diversity measures also showed greater richness and evenness of fish species during monsoon and autumn, and overall diversity was reduced concomitantly with increase in species dominance in the later months. From the Canonical Correspondence Analysis (CCA), it could be concluded that dissolved O_2, CO_2, temperature and nutrients were the most significant determinants of species assemblages in these tropical rivers. Fish samples were categorised into seven trophic guilds. The fish community was dominated by planktivores during monsoon and plankti-detrivores in other seasons. Assessments of the conservation status of the available fish species indicated that most species encountered during the monsoon and autumn were threatened. Since these rivers provide important refuge for a number of species due to their shallowness, varied trophic niches and suitability as a reproductive site, this study suggests a community level conservation approach considering the seasonal impacts to integrate with the population specific conservation programmes.

Keywords: Continuum, Habitat degradation, Ichthyofauna, Physico-chemical parameters, Trophic guild

Introduction

Fish communities in rivers are composed of both migrant and resident species depending upon shifts in environmental properties (Merringer *et al*., 1976). In a river continuum, integrity of the ecosystem is highly dependent on the available components. One conspicuous result of these shifting environmental properties is the accumulation of the fish species in only a selected stretch of the entire river (Aarts and Nienhuis, 2003; Lasne *et al*., 2007; Louca *et al*., 2009). These communities show a dynamic structure that reflects characteristics and alternations of the vital biotic processes (Perrson, 1997; Jackson *et al*., 2001). Therefore, the structure of the fish communities in a river in its natural state can be an important reference for the assessment and restoration of the ecological integrity of the same river in a disturbed state (Lenders *et al*., 1998; Schmutz *et al*., 2000). One way of understanding riverine habitats and processes is by distinguishing functional groups or guilds: groups of species that exploit a resource in a similar fashion (*e.g.,* food), and that can substitute one another's functional roles in an ecosystem.

Ecological integrity of the rivers implies an adaptive assemblage of fish fauna that has a definite species composition, species richness and equitability and is organised in functional groups. These functional groups can then be compared between the natural and modified riverine habitat in the region. An understanding of the aquatic system and its biodiversity will assist in making decisions to minimise adverse impacts of anthropologic activities and frame policies that lead to sustainable water use practices. As emphasised, for management and conservation of the natural resources, ecological inventory of the biodiversity pattern is crucial. In India, few studies have been done on the riverine fish assemblage structure in relation to microhabitat variables (Arunachalam, 2000; Weigel *et al*., 2006) and patterns of species distribution along habitats and environmental parameters (Shaji and Easa, 1995, 1998; Bhat, 2003). The present study aims to characterise ichthyofaunal diversity in a specific stretch of three rivers connecting two large river systems and to construct and compare the feeding guild of fishes seasonally.

Materials and methods

Study site

Mahananda, Tangon and Punarbhaba are the three important rivers of lower stretches of Terai (sub-Himalayan region) (Fig. 1). The Mahananda originates in the Himalayas, flows through India, enters Bangladesh and returns back to India. After flowing through Malda District in West Bengal (India), it joins the Ganges. Tangon and Punarbhaba originate independently in the Thakurgaon District in Bangladesh and enter India through South Dinajpur and meets Mahananda. Depths of these rivers vary from a maximum 3.0 - 3.6 m during the monsoon, to a minimum 0.6 - 0.9 m during summer. These stretches have a silty-clayey substratum, and the banks are flanked by graminoid and scrub vegetation along with matrix of agricultural fields. These sites were selected for study because the connection between the rivers provides a corridor for fishes over a large area.

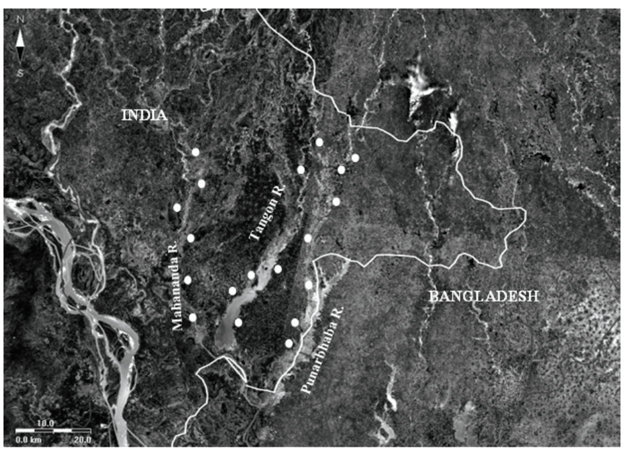

Fig. 1. Location of Mahananda, Tangon and Punarbhaba Rivers and the sampling sites, marked with white dots.

Sampling

Sampling was conducted at 15 sites along the stretches of the Mahananda, Tangon and Punarbhaba rivers (Fig. 1) during September 2005 to August 2011. The annual cycle is divided into five seasons *viz.*, monsoon (June-August), autumn (September-November), winter (December-January), spring (February-March) and summer (April-May). Eighteen nettings were undertaken on 15 selected sites in each month during all the five respective seasons, using a gillnet of 20 m length with 3 cm spacing between adjacent knots for sample collection. The nets were placed for 12 h from evening (18.00 hrs) to the next day early morning (06.00 hrs) in order to ensure maximum fish catch per unit effort. The specimens were retrieved from the net, identified and species abundance recorded to investigate species assemblages. Sampling data from the three rivers were pooled together as the rivers are interconnected in the same geographical location having similar physico-chemical attributes. After preserving individuals representing each fish species in 5% formalin, the live fishes were released. Fish specimens were identified morphologically to the lowest taxonomic level following Shaw and Shebbeare (1937), Day (1958) and Talwar and Jhingran (1991).

Certain physico-chemical parameters, *viz.*, dissolved oxygen (DO), carbon-di-oxide (CO_2), pH, salinity (Sal), alkalinity (Alk), total hardness (TH) and calcium hardness (Ca H), magnesium hardness (Mg H), nitrate-nitrogen (NO_2-N), nitrite-nitrogen (NO_3-N) and phosphate ($P0_4$) were also assessed following APHA (2005) during sampling. In order to explain the abundance of species with environmental variables, CCA (a direct gradient analysis) with biplot type of scaling on inter species distance and down weighting of rare species was performed. Square root-transformation was done for species abundance data. Both test of significance of first canonical axis and all canonical axes were made under Monte Carlo test with 499 permutations under reduced model (Jongman *et al*., 1995; Ter Braak and Smilauer, 2002). Relationships of species abundance with environmental variables are presented in ordination diagrams (biplot) for first two axes using CANOCO 4.5 software package.

Trophic guild analysis

Gut contents were collected from six adult individuals of each species from each netting session and preserved in 4% formaldehyde solution for analysis using the methods of Amudsen *et al*. (1996) and Jobling *et al*. (2001). Based on the major (>80%) food types (zooplankton, phytoplankton, small aquatic plants, molluscs, crustaceans, aquatic insects, small fishes and detritus), the feeding guild classification was made following Van den Brink *et al*. (1996).

Diversity analysis

Alpha diversity was assessed from assemblage attributes such as Shannon-Wiener index (Shannon and Wiener, 1949), species evenness or equitability (Pielou, 1969), dominance index (Berger and Parker, 1970), species richness (Margalef, 1957). A comparison of species richness across seasons was estimated following Kruscal Wallis ANOVA (using single netting effort as replicate) according to Zar (1999). To overcome sampling errors, non-parametric methods were also used to assess species richness. Rarefaction (Hurlbert, 1971) is given by the calculation of *E(S)* for a sequence of *n*. The computation was performed using EstimateS software. The expected and observed frequencies of correctly classified rarefaction results were compared by chi-square analysis.

For characterisation of the biodiversity at the level of species diversity, rank abundance curves were also constructed (King, 1964). The Jaccard similarity index takes into account the presence or absence of a species and compare species similarities (Magurran, 1991). The Morisita-Horn index $(C_{M\text{-}N} = 2\sum (a_{ni} . b_{ni}) / da+db)\ aN.bN;$ $(da = \sum\ (a_{ni}^{2} / aN^{2}$ and $db = \sum b_{ni}^{2}/bN^{2}$; where, aN = total number of individuals at season A, bN = total number of individuals at season B, a_{ni} = number of individuals of species i at season A, b_{ni} = number of individuals of species i at season B) (Wolda, 1981) is also used to compare similarity.

Threat status

The threat status of the fish species were obtained from the national red list of India (BCPP-CAMP, 1998) that was compiled using the IUCN Red List Categories and Criteria Version. Species were categorised as: data deficient (DD); lower risk-least concern (LR-LC), lower risk-near threatened (LR-NT), vulnerable (V), endangered (E), and critically endangered (CR).

Results

A total of 50 species distributed amongst 7 orders and 21 families were recorded in this study (Table 1). A comparison of species richness across seasons indicated seasonal variation with species richness being greatest during the monsoon and autumn, but then declining during winter, spring and summer (df=4, p<0.05).

The CCA analysis (based on species abundance) indicated that abiotic variables explained significantly about 96.6% of fish assemblage in different seasons throughout successive years. Although several axes were determined within the analysis, only axes 1 and 2 were plotted as they accounted for 80.7% of the variability explained by 4 axes. Fig. 2 indicate relative environmental preference of the fish species. Considering their vector length, dissolved O_2 (r = -0.89), dissolved CO_2 (r = 0.89), alkalinity (r = -0.87) (best correlated with axis 1), temperature (r = 0.84) and nitrate-N (r = 0.81) (best correlated with axis 2) were the most important environmental variables influencing the fish assemblages.

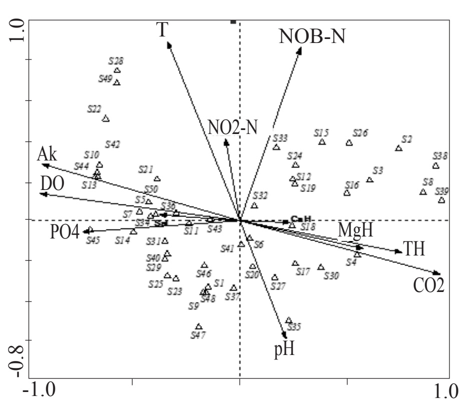

Fig. 2. Biplot showing the species-environment association by first two canonical axes during different seasons in interconnected drivers of Mahananda, Tangon and Punarbhaba.

Axis 1 separated the species (*Aspidoparia morar*, *Sinilabeo dero*, *Tetraodon cutcutia*, *Badis badis*, *Pangasius pangasius*, *Gudusia chapra* and *Clupisoma garua*) with more affinity towards dissolved O_2 and alkaline condition from those (*Ompok pabda*, *Labeo calbasu*, *Anabas testudineus*, *Puntius chola*, *Mystus vittatus*, *Sperata aor* and *Lepidocephalichthys guntea*) tolerant towards hypoxic and higher dissolved CO_2. Temperature and nutrients were other important determinants for species like *Neotropius atherinoides*, *Esomus danricus*, *Chanda nama*, *Sinilabeo dero* and *Tetraodon cutcutia.*

This pattern of species richness was confirmed by the species accumulation curves which suggested that summer had the lowest diversity, with an asymptote in the region of 15 species, whilst the asymptotes during all other seasons were in the region 46, 47, 46, 48, species. The rarefaction curves further confirmed the poor species accumulation during summer even after repeated sampling (Fig. 3). It was also indicated that during autumn and spring, species accumulation was high even within a few samples and did not vary with sample size. Species evenness, however, was higher during monsoon, autumn and spring than in winter and summer. The fish diversity was further analysed from diversity indices (Table 2). The Shannon-Wiener index was found to be higher in autumn (3.61) and the least in summer (2.45). These indices indicated that during autumn and monsoon, the species are not only diverse but also quite evenly distributed. This is evident from species richness index, which was also greater in monsoon (5.81) and autumn (4.9). Species evenness index further corroborate this finding showing high values in monsoon (0.92), autumn (0.92) and spring (0.95). Consequently, winter (0.22) and summer (0.2) showed higher dominance index.

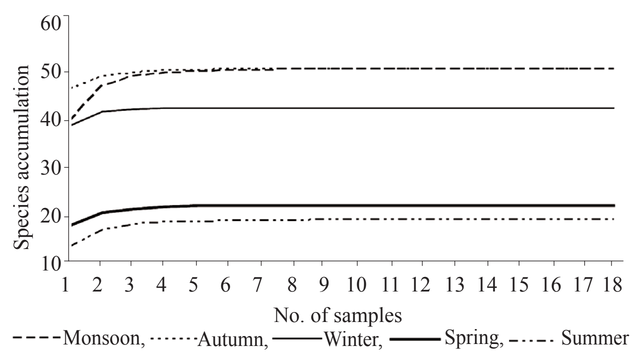

Fig. 3. Pattern difference in rarefaction curves during various seasons.

The rank abundance curves (Fig. 4) of all seasons confirmed that higher species dominance during winter,

Table 1. Seasonal variation in fish assemblage in interconnected rivers of Mahananda, Tangon and Punarbhaba along with trophic guild and respective IUCN status.

Species	Family	Spring	Summer	Monsoon	Autumn	Winter	Trophic guild	IUCN status
Arius gagora Hamilton-Buchanan, 1822 † (S1)	Ariidae			*	*	*	Detritivory	DD
Mystus cavasius Hamilton-Buchanan, 1822 (S2)	Bagridae	*	*	*	*	*	Detritivory + Planktivory	LR-NT
Mystu stengara Hamilton-Buchanan, 1822 (S3)	Bagridae	*	*	*	*	*	Detritivory + Planktivory	DD
Mystus vittatus Bloch, 1797 (S4)	Bagridae	*	*	*	*	*	Detritivory + Planktivory	V
Rita rita Hamilton-Buchanan, 1822 (S5)	Bagridae			*	*	*	Detritivory	LR-NT
Sperata aor Hamilton-Buchanan, 1822 (S6)	Bagridae	*	*	*	*	*	Piscivory	DD
Chaca chaca Hamilton-Buchanan, 1822 † (S7)	Chacidae	*		*	*	*	Detritivory	DD
Clarias batrachus Linnaeus, 1758 (S8)	Clariidae	*	*	*	*	*	Detritivory	V
Heteropneustes fossilis Bloch, 1794 (S9)	Heteropneustidae			*	*	*	Detritivory	V
Pangasius pangasius Hamilton-Buchanan, 1822 (S10)	Pangasiidae			*	*		Malacovory	CR
Ailia coila Hamilton-Buchanan, 1822 (S11)	Schilbeidae			*	*	*	Planktivory	V
Ailiichthys punctata Day, 1871 (S12)	Schilbeidae	*	*	*	*	*	Planktivory	V
Clupisoma garua Hamilton-Buchanan, 1822 (S13)	Schilbeidae			*	*		Piscivory	V
Eutropiichthys vacha Hamilton-Buchanan, 1822 (S14)	Schilbeidae			*	*	*	Piscivory	EN
Neotropius atherinoides Bloch, 1794 † (S15)	Schilbeidae	*	*	*	*	*	Planktivory	EN
Silonia silondia Hamilton-Buchanan, 1822 (S16)	Schilbeidae			*	*	*	Detritivory + Planktivory	LR-NT
Ompok pabda Hamilton-Buchanan, 1822 (S17)	Siluridae	*	*	*	*	*	Piscivory	EN
Ompok pabo Hamilton-Buchanan, 1822 (S18)	Siluridae	*	*	*	*	*	Piscivory	EN
Wallago attu Schneider, 1801 (S19)	Siluridae	*	*	*	*	*	Piscivory	LR-NT
Lepidocephalichthys guntea Hamilton-Buchanan, 1822 (S20)	Cobitidae	*	*	*	*	*	Planktivory	DD
Amblypharyngodon mola Hamilton-Buchanan, 1822 (S21)	Cyprinidae			*	*	*	Planktivory	LR-LC
Aspidoparia morar Hamilton-Buchanan, 1822 (S22)	Cyprinidae			*	*		Planktivory	LR-NT
Cirrhina cirrhosa Hamilton-Buchanan, 1822 (S23)	Cyprinidae			*	*	*	Detritivory + Planktivory	LR-NT
*Bangana ariza*Hamilton-Buchanan, 1822 (S24)	Cyprinidae	*	*	*	*	*	Planktivory	V
Cyprinus carpio carpio Linnaeus, 1758 (S25)	Cyprinidae			*	*	*	Phytivory	DD
Esomus danricus Hamilton-Buchanan, 1822 (S26)	Cyprinidae	*	*	*	*	*	Planktivory	LR-LC
Labeo calbasu Hamilton-Buchanan, 1822 (S27)	Cyprinidae	*		*	*	*	Detritivory + Planktivory	LR-NT
Sinilabeo dero Hamilton-Buchanan, 1822 (S28)	Cyprinidae			*	*		Detritivory + Planktivory	V
Labeo rohita Hamilton-Buchanan, 1822 (S29)	Cyprinidae			*	*	*	Planktivory	LR-NT
Puntius chola Hamilton-Buchanan, 1822 (S30)	Cyprinidae	*	*	*	*	*	Detritivory + Planktivory	V
Puntius sarana Hamilton-Buchanan, 1822 (S31)	Cyprinidae			*	*	*	Detritivory + Planktivory	V
Salmophasia bacaila Hamilton-Buchanan, 1822 (S32)	Cyprinidae	*	*	*	*	*	Detritivory	LR-LC
Chanda nama Hamilton-Buchanan, 1822 (S33)	Ambassidae	*	*	*	*	*	Planktivory	DD
Parambassis ranga Hamilton-Buchanan, 1822 (S34)	Ambassidae			*	*	*	Planktivory	DD
Anabas testudineus Bloch, 1795 (S35)	Anabantidae			*	*	*	Piscivory	V
Polyacanthus fasciatus Schneider, 1801 (S36)	Belontiidae			*	*	*	Planktivory	DD
Channa orientalis Bloch and Schneider, 1793 (S37)	Channidae			*	*	*	Detritivory + Planktivory	V
Channa punctatus Bloch, 1793 (S38)	Channidae	*	*	*	*	*	Detritivory + Planktivory	LR-NT
*Channa striatus*Bloch, 1793 (S39)	Channidae	*	*	*	*	*	Detritivory + Planktivory	LR-NT
Glossogobius giuris Hamilton-Buchanan, 1822 † (S40)	Gobiidae			*	*	*	Detritivory	LR-NT
Mastacembelus armatus Lacepede, 1800 (S41)	Mastacembelidae	*		*	*	*	Detritivory	DD
Badisbadis Hamilton-Buchanan, 1822 (S42)	Nandidae			*	*		Detritivory	DD
Nandus nandus Hamilton-Buchanan, 1822 (S43)	Nandidae	*	*	*	*	*	Detritivory	LR-NT
Gudusiachapra Hamilton-Buchanan, 1822 † (S44)	Clupeidae			*	*		Detritivory	LR-LC
Tenualosa ilisha Hamilton-Buchanan, 1822 † (S45)	Clupeidae			*	*		Detritivory + Planktivory	V
Setipinna phasa Hamilton-Buchanan, 1822 † (S46)	Engraulididae			*	*	*	Detritivory	DD
Chitala chitala Hamilton-Buchanan, 1822 (S47)	Notopteridae			*	*	*	Piscivory	EN
Notopterus notopterus Pallas, 1769 (S48)	Notopteridae			*	*	*	Piscivory	LR-NT
Tetraodon cutcutia Hamilton-Buchanan, 1822 (S49)	Tetraodontidae			*	*		Planktivory	LR-NT
Xenentodon cancila Hamilton-Buchanan, 1822 (S50)	Belonidae			*	*	*	Insectivory	LR-NT

† represents the endemic ichthyofaunal species found in Mahananda, Tangon and Punarbhaba rivers of North Bengal and adjacent areas

Table 2. Seasonal variation in diversity estimators from fish assemblage.

Index	Seasons						
	Monsoon	Autumn	Winter	Spring	Summer	F value	p
Dominance index	0.117[b]	0.046[c]	0.221[a]	0.135[b]	0.199[a]	33.02	0.00
Shannon-Weaver index	3.597[a]	3.608[a]	3.005[b]	2.942[b]	2.453[c]	40.17	0.00
Species evenness index	0.92	0.922	0.804	0.952	0.833	2.29	0.13
Species richness index	5.813[a]	4.903[b]	4.501[c]	2.935[d]	2.72[d]	151.99	0.00

summer and spring with steeper curves signifying overall lowering of diversity. Greater species evenness and less dominance with higher and flatter curves during monsoon and autumn were significant observations. Species similarity between different seasons was also analysed by Jaccard similarity index and Morisita-Horn similarity index (Table 3). The value demonstrated a close resemblance of species composition between monsoon and autumn, but dissimilarity between monsoon-summer and winter-summer.

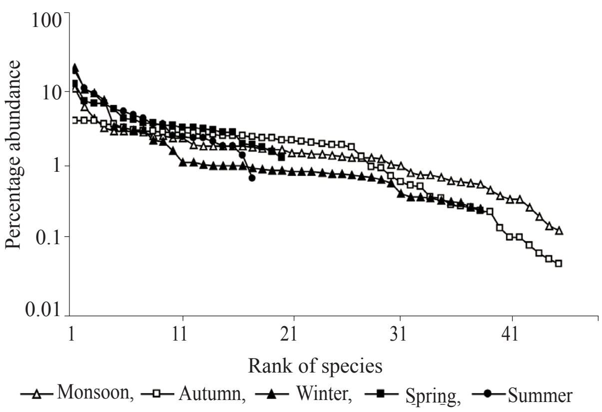

Fig. 4. Rank abundance curves and their underlying distribution of species in abundance classes in different seasons.

Table 3. Similarity of fish assemblage in different seasons

		Morisita-Horn similarity index				
	Seasons	Monsoon	Autumn	Winter	Spring	Summer
Jaccard similarity Index	Monsoon		0.864	0.325	0.399	0.298
	Autumn	1		0.552	0.567	0.381
	Winter	0.84	0.84		0.524	0.452
	Spring	0.44	0.44	0.524		0.8
	Summer	0.38	0.38	0.452	0.864	

Trophic guilds

The feeding niche of each fish species was differentiated on the basis of the percentage occurrence of the ingested food material as revealed by analysis of the preserved gut contents (Fig. 5). This analysis indicated that the following trophic guilds were represented: detritivores, planktivores, a mixed detritivore and planktivore guild (≈50% each), piscivores, malacovores, phytivores and insectivores. The proportion of species in different guilds varied seasonally, and the diversity of guilds represented in the samples were greatest in monsoon, autumn and winter (6-7 guilds). In contrast, only 4 guilds were encountered during the spring and summer months. Planktivores dominated the monsoon months (35.61%) with the planktivorous *Amblypharyngodon mola* being most common. During other seasons, majority of the species were classified as using the mixed strategy of detritivory and planktivory with the plankti-detritivorous *Mystus vittatus* being the species most commonly encountered. During winter, over 70% of species were classified as mixed detrivore-planktivores. Specialist guilds such as malacovores, phytivores and insectivores were only observed during the monsoon, autumn and winter seasons and each accounted for less than 5% of the observations.

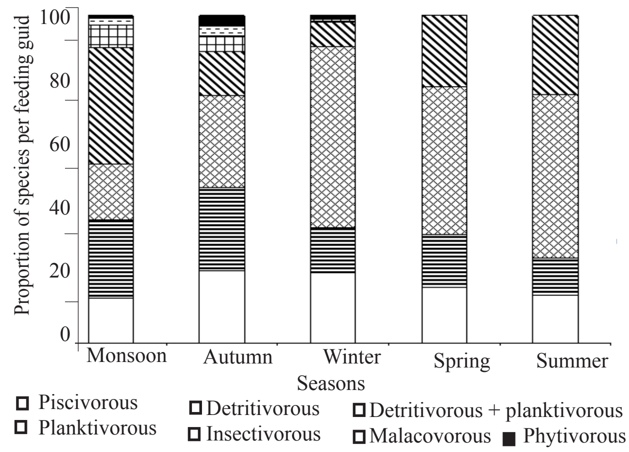

Fig. 5. Composition of feeding guilds of ichthyofauna in various seasons.

Discussion

The fish fauna of the world are changing rapidly as the result of human-caused extinctions and invasions (Bruton, 1995). Freshwater environments are particularly sensitive because of both high level of endemism and the massive global demand of water and water services. About 20% of freshwater species (globally) are already extinct or in serious decline (Moyle and Leidy, 1992). Many small rivers providing refuge for many fish populations are also undergoing major habitat alterations caused by construction of dams, uncontrolled use of pesticides and fertilisers, deforestation, siltation and introduction of genetically inbreeding fish population from adjacent aquaculture practices and other basins. As habitat or environmental degradation leads to loss of species diversity it can be concluded that an endangered species is often part of an endangered ecosystem (Moyle and Moyle, 1995). In India, quantitative descriptions of fish assemblages and environmental conditions are very limited despite the enormous diversity (930 species) of freshwater fishes (Jayaram, 1999). Out of the total indigenous fish fauna, only 327 species have been evaluated and categorised for their threatened status and many remain as data deficient (BCPP-CAMP, 1998). In addition, fishes have considerable value for monitoring of aquatic system given their sensitivity to change (Angermeier and Winston, 1998; Penczak *et al*., 2009).

Mahananda, Tangon and Punarbhaba, are small rivers connecting two large rivers belonging to two adjacent countries, and are known to harbour many species of fish with high levels of endemicity. Flanked by crop fields and numerous wetlands, the river banks are well vegetated which helps retain precipitation in the drainage basin for longer time so as to enhance the nutrient quality of the rivers as observed earlier (Shaji and Easa, 1995, 1998; Arunachalam, 2000; Bhat, 2003; Kar *et al*., 2006; Shahnawaz *et al*., 2010) elsewhere in India. Very few studies were made in the rivers of sub-Himalayan Indo-Gangetic plains of Bengal, which revealed huge freshwater fish faunal diversity in the shallow rain fed rivers (Menon, 1974, 1999; Chakraborty and Bhattacharjee, 2008).

The relationship between species distribution and environmental variables (Table 4) allows identification of the ecological processes that regulate different populations and communities. Apart from the influence of environmental factors, many species change their habitats according to their ontogeny and seasonal rhythms. Therefore, the relationship between different species and their environment or habitat becomes spatially and seasonally dynamic (Tejerina-Garro *et al*., 1998; Feyrer and Healey, 2003; de Mérona *et al*., 2005; Korai *et al*., 2008; Sarkar *et al*., 2010). CCA ordination diagram based on species abundances with environmental factors represented by vectors demonstrated dominance by a few species, a pattern generally observed in freshwater riverine environments (Petry *et al*., 2003; Sutin *et al*., 2007; Gutiérrez-Estrada *et al*., 2008).

As in many other freshwater streams, temperature, dissolved oxygen and nutrients were found to be the most important environmental variables influencing species richness, abundance and fish assemblage in the present study (Schiemer and Zalewski, 1991; Henderson and Crampton, 1997). In the present study, higher values of dissolved oxygen were recorded during the months of monsoon (6.617 mg l^{-1}) and post-monsoon (5.808 mg l^{-1}). Higher dissolved oxygen and alkalinity of water were correlated with the abundance of many fish species such as *Aspidoparia morar, Sinilabeo dero, Tetraodon cutcutia, Badis badis, Pangasius. pangasius, Gudusia chapra* and *Clupisoma garua*.

Temperature has been a key factor to influence physiological, biochemical and life-history processes of fish (Beitinger and Fitzpatrick, 1979; Reash and Pigg, 1990) and therefore determine structure of fish assemblages (Thiel *et al*., 1995; Pegg and Taylor, 2007). Maximum summer temperature of water (28.16 ± 0.19 ºC) and minimum water depth (3.0-3.6 m) is unfavourable for most of the fishes except few silurids like *Mystus vittatus* and *Wallago attu*. while others are susceptible to changes in water temperature. Thus the present study also indicates temperature dependent assemblage of different species in different seasons.

Nutrients in freshwater vary seasonally as well as due to allochthonous runoff, chemical effluents and fertilisers from watersheds (Galacatos *et al*., 2004). During the present study, the nutrients (nitrate-N, nitrite-N and phosphate) were found to be high during post-monsoon seasons (autumn and winter) and low during summer. The

Table 4. Seasonal variation in physico-chemical parameters in different seasons (Mean ± SD)

Seasons	Monsoon	Autumn	Spring	Winter	Summer
Dissolved O_2 (mg l^{-1})	6.617 ± 0.041	6.417 ± 0.051	5.2 ± 0.099	5.267 ± 0.073	3.589 ± 0.043
Combined CO_2 (mg l^{-1})	0.049 ± 0.003	0.023 ± 0.002	0.914 ± 0.078	1.03 ± 0.003	1.052 ± 0.003
pH	7.522 ± 0.039	7.583 ± 0.048	8.022 ± 0.036	8.067 ± 0.027	6.856 ± 0.074
Alkalinity (mg l^{-1})	23.444 ± 0.132	23.539 ± 0.115	15.861 ± 0.669	14.9 ± 0.054	15.056 ± 0.095
Salinity (ppt)	1.844 ± 0.028	1.889 ± 0.031	1.772 ± 0.038	1.922 ± 0.093	1.994 ± 0.1
Total hardness (mg l^{-1})	4.139 ± 0.047	4.306 ± 0.042	4.633 ± 0.039	4.672 ± 0.039	5.128 ± 0.092
Ca^{+2} hardness (mg l^{-1})	0.633 ± 0.031	0.65 ± 0.036	0.7 ± 0.046	0.767 ± 0.04	0.733 ± 0.021
Mg^{+2} hardness (mg l^{-1})	3.506 ± 0.047	3.656 ± 0.07	3.933 ± 0.058	3.906 ± 0.055	4.394 ± 0.103
Temperature (°C)	26.939 ± 0.096	24.883 ± 0.324	19.111 ± 0.185	24.289 ± 0.285	28.156 ± 0.188
Nitrite-nitrogen (NO_2-N) (mg l^{-1})	0.163 ± 0.009	0.038 ± 0.005	0.02 ± 0.001	0.207 ± 0.004	0.16 ± 0.009
Nitrite-nitrogen (NO_3-N) (mg l^{-1})	0.023 ± 0.001	0.025 ± 0.001	0.014 ± 0.002	0.039 ± 0.002	0.019 ± 0.001
Phosphate (PO_4) (mg l^{-1})	0.407 ± 0.03	1.175 ± 0.058	0.181 ± 0.032	0.092 ± 0.018	0.124 ± 0.011

highest nitrate-N content was recorded during autumn (0.94 $\mu M\ l^{-1}$) and winter (0.72 $\mu M\ l^{-1}$). Abundance of some species *viz*., *Neotropius atherinoides, Esomus danricus, Chanda nama, S. dero* and *T. cutcutia* was found to be correlated with high nitrate-N. Other environmental factors (pH, salinity, hardness, nitrite-N and phosphate) are minor determinants of fish assemblage in freshwater systems.

Considerable similarity between monsoon and autumn was observed while estimating species similarity by Jaccard and Morisita-Horn similarity index in different seasons, due to similarity in habitat quality, environmental conditions and species composition. Rarefaction curves compared between different seasons confirmed poor species accumulation during summer even after repeated sampling. On the contrary, during autumn and spring, species composition and accumulation were both high even within a few samples and did not vary with sample size. During monsoon and winter, species accumulation was less in initial samples but the diversity increased concomitantly with increase in sample size. Evenness in species distribution was higher during monsoon, autumn and spring.

The rank abundance curves explicitly revealed that the curves were flatter and higher in monsoon and autumn when environment was suitable for harbouring faunal diversity. Greater species diversity, richness and evenness during these periods can be related to diversification of trophic functions with increased resource availability. This observation is in line with the earlier evidence that fish distribution is determined by feeding habit and habitat variables including nutrients (Ferreira *et al*., 2001).

During monsoon and autumn, as many as seven feeding guilds were found with planktivory being predominant during monsoon as planktonic abundance increases following nutrient availability (de Mérona and Rankin-de-Mérona, 2004). But, trophic specialists like strictly detritivorous, piscivorous, planktivorous, malacovorous, phytivorous and insectivorous fishes were also found in good proportion. De Mérona *et al*. (2005) also described an increase in relative abundance of detritivorous species and consequent parallel decrease of fish species during pre-monsoon in case of shallow rivers, which corroborates with the prevailing results.

The degree of food partitioning is dependent on habitat segregation among most of the species (Esteves and Lobo̊n-Cerviá, 2001; Lasne *et al*., 2009; Rito-Santo *et al*., 2009). In the present work, seasonal variations in guild structure were apparent suggesting that there is fluctuation in food supply. While assessing the species dominance in a gradient approach, two distinct peaks were found. The peak of *Amblypharyngodon mola* (planktivorous) was found during monsoon and another peak of *Mystus vittatus* (planktivorous-detritivorous) during autumn and rest of the seasons. The low abundance of most of the fishes, high number of endemic species and the strong dependence of the species on a few types of resources suggest that these systems may be sensitive to anthropogenic impacts. Feyrer *et al*. (2003) suggested that altered food web dynamics caused by any stress might change the fish diets and contribute to decline in fish diversity. Taxonomic and ecological characterisations of community composition are complementary and are useful in conservation context (Angermeier and Winston, 1998; King *et al*., 2009). In a river continuum, the guild structure is more stable than its species composition because the species within a guild can replace other's functional role, following slight fluctuations in environmental conditions. Hence, analysing feeding guild is more important than studying species diversity (Muñoz and Ojeda, 1997; Petry *et al*., 2003).

This study demonstrates that the stretches of Mahananda, Tangon and Punarbhaba rivers seems to be preferred habitats for feeding and reproduction of a large number of fishes due to stratifications imparted by submerged and riparian vegetation. Therefore, such diversity including many threatened species is a result of habitat structure *viz*., shallowness of the river, varied feeding niches and reproductive sites. Systematic conservation of community types could be more advantageous than the usual conservation programmes which only focus on populations of imperilled species. Most effective conservation of fishes will require recognition of the value of both species and assemblages, even at taxonomic diversity levels throughout different seasons of the year, emphasising protection of key landscape and habitat processes involved.

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