



***Research Paper***

**TAXONOMIC AND FUNCTIONAL DIVERSITY OF FISH ASSEMBLAGE IN  
THREE INTERCONNECTED TROPICAL RIVERS IN INDIA IN  
ACCORDANCE WITH LIMITING SIMILARITY HYPOTHESIS**

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**Abstract**

Freshwater fishes are declining rapidly due to their high sensitivity to the quantitative and qualitative alteration of aquatic habitats and India is no exception. The small rivers of this country provide refuge to innumerable fish species with hardly any documentation. This study was directed to assess fish biodiversity with reference to species diversity, phylogenetic diversity and functional diversity of the fish assemblage in three interconnected shallow rivers in the northern part of West Bengal. Sampling was conducted in between September 2007 to August 2011 and diversity estimators depict higher species richness and evenness and less dominance during monsoon and autumn with progressive declining trend through winter, spring and summer. The taxonomic and functional diversity also depicted similar trend in relation with total fish catch. However, the average taxonomic distinctness, phylogenetic diversity and functional diversity estimator indicate the inherent taxonomic diversity and functional complementarity of the fish assemblage throughout the year irrespective of total fish catch. This fact signifies the importance of these three interconnected rivers as a precious habitat for indigenous fish species ensuring effective niche segregation and coexistence in a stable way for the resident fish fauna. In order to ensure, long term sustainability of fish stock in this habitat efforts need to be given to minimize disruption of ecosystems to protect the precious habitat.

Key words: fish biodiversity, taxonomic diversity, functional diversity, limiting similarity, Aquatic Ecological System.

**INTRODUCTION**

Freshwater fish are one of the most threatened taxonomic groups (Darwall and Vie, 2005) because of their high sensitivity to the quantitative and qualitative alteration of aquatic habitats (Laffaille *et al.*, 2005; Kang *et al.*, 2009; Sarkar *et al.*, 2008). Maintenance of Hydrological connectivity is essential for the viability and recruitment of native biota (Bunn and Arthington, 2002) and any alteration may lead to local extinction. Longitudinal and lateral connectivity between river channels and floodplains leads to characteristic high biodiversity

pattern (Ward and Stanford, 1995) whereas river regulation leads to reduced native species abundance and recruitment (Cadwallder and Lawrence, 1990).

The term “biodiversity” should never be equated with species diversity, but can be considered as ‘the sum of the taxonomic or numerical diversity, and the ecological, genetical, historical and phylogenetic diversity’ (Van der Spoel, 1994). The phylogenetic structure of the assemblage, the functional role of the organism play significant role in shaping biodiversity of a particular habitat. However, all these different elements are impossible to encapsulate objectively in the same units to provide a single ‘biodiversity’ index. Hence, in this study, data was collected on species richness, phylogenetic and functional diversity of the fish assemblage of three interconnected rivers, namely Mahananda – Tangon – Punarbhaba, in West Bengal, India. The importance of this site lies with the connectance between the rivers providing a corridor for migration of fishes over a large area. Side by side, these small rivers provide refuge to large number of indigenous fish population (Kundu et al., 2014) and are also undergoing major habitat alterations due to anthropogenic stresses. Before this rich species diversity of the region is lost forever, the documentation of the extant fish biodiversity is crucial.

## MATERIAL AND METHODS

### Study site

The fishes were collected from the Mahananda – Tangon – Punarbhaba river system (MTPRS) in Malda district of West Bengal, India near Indo-Bangladesh border. The Mahananda originates in the Himalayas, flows through India and parts of Bangladesh and drains into the Ganges after flowing through and Malda district in West Bengal (India). The Tangon and Punarbhaba originate separately in the Thakurgaon district in Bangladesh and enter India through South Dinajpur and ultimately drain into the Mahananda. The importance of this site lies with the connectance between the rivers and provides a corridor for fishes over a large area. The depth of river varies from a maximum 4-4.5 meter during the monsoon, to a minimum of less than 1 meter during summer with a silty-clayey substratum. The basin consists of recent alluvium soil type flanked by arable land, especially graminoid and scrub vegetation, with sporadic rural settlements. Throughout the catchment, the stream waters are heavily used for cultivation of crops. (Fig. 1)

### Sampling

Sampling was conducted at 20 sites along different sites of the MTPRS (24° 57' N, 88° 20' E) on the Indian side in Malda district of West Bengal with the help of local fisher folk in between September 2007 to August 2013. The annual cycle is divided into five seasons as follows: monsoon (June-August), autumn (September-November), winter (December-January), spring (February-March) and summer (April-May). Experimental nettings were undertaken the 5 respective seasons using a gill net of 20 m length with 3 cm spacing between adjacent knots for sample collection. Each site was sampled for at least 10 times to minimize sampling error. The nets were placed alongside the Indian bank of the rivers for 12 h from evening (6 pm) to early morning (6 am) in order to ensure maximum fish catch per unit effort. The specimens were retrieved from the net, identified morphologically to the lowest taxonomic level following Shaw and Shebbeare, 1937; Day, 1958 and Talwar and Jhingran, 1991 and then released in wild after preserving representative specimens in 4% formaldehyde. All species names adhere to Fishbase (Froese and Pauly, 2015). The fish abundance pattern did not vary significantly among the various sites, so instead of comparing fish diversity and hydrological parameters among the study sites, we pooled the data to minimize sampling errors for seasonal comparison.

### Species diversity, abundance and distribution

In order to assess ichthyofaunal diversity in the MTPRS in association with year wise seasonal variation some of the following diversity indices were used. These were: Shannon-Weaver index (H') (Shannon and Weaver, 1949), Species evenness or equitability (J) (Pielou, 1969), Dominance index (D) (Berger and Parker, 1970), Species richness (Margalef, 1958), Fish Species Richness (Lakra et al., 2010). To normalize variation, the number of species, number of fish and

species diversity were  $\log_{10}(x+1)$  transformed (Underwood, 1997) prior to analysis whenever required. One way analysis of variance (ANOVA) and Duncan's Post Hoc tests were employed to check for differences in the abundance of species between all pairs of seasons. The seasonal variation in fish assemblage structure was graphically represented by the application of cluster analysis based on Bray-Curtis similarity index and non metric Multi dimensional scaling (MDS). In order to overcome sampling errors, non-parametric methods like Chao 1, Chao 2, Jackknife, Bootstrap estimators and Rarefaction curve were used to ascertain actual species richness. All the computation was performed using EstimateS (version 8) and SPSS (Statistical Package for Social Sciences, Version 13.0; Norušis 2000) and PRIMER 5 software. IUCN and NBFGR (Lakra *et al.*, 2010; Viswanath *et al.*, 2010) proposed threat criteria of species was considered.

### Assessment of Taxonomic diversity of the fish assemblage

In order to assess phylogenetic structure of the assemblage as a measure of biodiversity, five indices were employed, viz. Phylogenetic diversity (Faith, 1992), average phylogenetic diversity (AvPD), Taxonomic distinctness ( $\Delta$ ) (Warwick and Clarke, 1995) Average taxonomic distinctness ( $\Delta+$ ), Variation in taxonomic distinctness (VarTD,  $\Delta+$ ) (Clarke and Warwick, 2001).

### Calculation of Functional Diversity of the fish assemblage

Representative specimens ( $n = 10$ ) of all fish species were fixed in 4% formaldehyde and transferred to the laboratory for further morphometric analysis taking care of following parameters as depicted by Mouillot *et al.*, 2007 for calculation of functional diversity following Mason *et al.*, 2003. The parameters were biomass, ratio of standard length to body depth, caudal fin aspect ratio, eye diameter and the mean value of each trait were taken for each species. We considered that intraspecific differences are much lower than interspecific differences for functional traits (Dumay *et al.*, 2004).

## RESULTS

A total of 52 species distributed amongst 7 orders, 23 families, 45 genera and 52 species (Table 1) were obtained from MTPRS in this study. Cyprinidae (22.05%) was the most abundant fish family followed by Bagridae (12.31%) and Schilbeidae (11.28%) respectively (Figure 2). A comparison of species richness across seasons indicated seasonal variation with species richness being greatest during the monsoon and autumn showing a declining trend through winter, spring and summer ( $P < 0.05$ ,  $df=4$ ) following Kruskal Wallis ANOVA according to Zar (1999). Out of 52 fish species found in the river, Siluriform catfishes *M. cavasius*, *M. tengara*, *M. vittatus*, *C. batrachus*, *O. pabo*, *O. pabda*, *W. attu*; members of order Cypriniformes like *C. reba*, *E. danricus*, *P. chola*, *S. bacaila* and Perciformes like *C. nama*, *C. fasciatus*, *C. punctatus*, *C. striatus*, *N. nandus* were found throughout the year (Table 1). Out of these 16 species 5 belonged to vulnerable, 2 belonged to endangered category (Table 1) as per NBFGR report (Lakra *et al.*, 2010) and Goswami *et al.*, 2012 signifying it as a preferred home for threatened fishes also.

The fish diversity was also analyzed from diversity estimators. The Shannon-Weaver index, species richness and evenness (Table 3) was found to be higher in monsoon (3.7, 66, 0.94 respectively) and the least in summer (2.42, 18, 0.84 respectively) signifying existence of more diverse fish assemblage in monsoon. Consequently, autumn (0.046) and monsoon (0.117) showed least value of dominance index signifying higher evenness in fish assemblage structure. Shannon-Weaver diversity index showed positive correlation ( $r = 0.97$ ) with the Evenness, Fish species richness (FSR) ( $r = 0.99$ ) and Species richness ( $r = 0.69$ ) index (Table 4). However, the Dominance index was found to be negatively correlated ( $r = -0.55$ ,  $-0.52$ ) with Shannon-Weaver diversity index and FSR (Table 4). This pattern of species richness was confirmed by the rarefaction curves, which suggest that summer had the lowest diversity, with an asymptote in the region of 7 species, whilst the asymptotes during monsoon, autumn, winter and spring were in the region 52, 50, 38, 21 species respectively. Similar trends were shown by Jackknife1, 2 and Chao 1 estimators, sample based rarefaction curve, bootstrap values, MM runs, ACE and ICE mean values when plotted in a curve (Figure 3). The Bray Curtis (Figure 4) similarity index and

MDS plot (Figure 5) demonstrated a close resemblance of species composition between monsoon and autumn, but dissimilarity between monsoon-summer and winter-summer.

Estimation of taxonomic diversity of a fish assemblage also depicted similar trend. The phylogenetic diversity (PD) and total taxonomic distinctness of the fish assemblage was found to be at higher side in monsoon (3150 and 4753.9) and autumn (3100 and 4648) with progressive declining trend in winter (2650 and 3990.7) and spring (2000 and 2880.6) and lowest value in summer (1050 and 1570.6) (Fig. 6). On the other hand, average PD and average taxonomic distinctness (AvTD) was found to be fairly constant with highest value in winter (62.5 and 91.42) and lowest value in summer (58.33 and 87.25). The variation in taxonomic distinctness (VarTD), ( $\Delta$ ) was found to be highest in summer (425.8) with least number of species and lowest in monsoon (259.6) with highest species richness. The AvTD and VarTD value for all the seasons (except summer) were found to lie well within the 95% probability funnel with 1000 simulations with summer lying just beneath the funnel (Figure 7). Thin line denotes the theoretical mean for such random selections. Mean  $FD_{var}$  (Figure 8) were calculated for the selected characters and found to be relatively high in all the five seasons with highest value in Monsoon (0.846) and least in Summer (0.826).

## DISCUSSION

The MTPRS is an aggregation of small river systems ultimately draining to the Ganges providing corridor for migration of fishes over large area. 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 present study reported capture of 52 fish species in the river distributed amongst 7 orders, 23 families, 45 genera (Table 1). This data was comparable with distribution pattern of different finfishes in river of various climatological regions as depicted in Table 2. This comparison established MTPRS as a precious habitat for fish species conservation. Cyprinidae (22.05%) was the most abundant fish family and similar results were noted in other river systems in Southeast Asia (Bhat, 2003).

Several statistical estimators have been used for calculating and extrapolating species richness taking into account the possible proportion of rare species and make conservative estimates of the true species richness of an area (Colwell and Coddington, 1994). The fish diversity estimators across seasons indicated higher diversity and lower dominance of fish fauna during the monsoon and autumn with progressive declining trend through winter, spring and summer respectively. This observation was also confirmed by the rarefaction curves, which suggest that summer had the lowest diversity, with an asymptote in the region of 7 species, whilst the asymptotes during monsoon, autumn, winter and spring were in the region 52, 50, 38, 21 species respectively (Figure 3). More diversity and evenness in the fish assemblage elaborated less dominance of resident fish species and vice versa. Nair *et al.* (1989) and Chowdhury *et al.* (2010) have shown similar results in their study. The higher diversity in monsoon was due to increased niche availability supported by huge nutrient flux from allochthonous sources along with surface run-off. 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). This was followed by autumn as the post-monsoonal elevated nutrient pool supported survival of a diversified fish assemblage. However, the constantly declining diversity pattern over winter, spring and summer could be attributed to overfishing and progressive depletion in nutrient pool as well as water availability. The shallowness of the riverine banks also provides suitable sites for fish breeding during monsoon. (Kundu *et al.*, 2014). The Bray Curtis (Figure 4) similarity index and MDS plot (Figure 5) demonstrated a close resemblance of species composition between monsoon and autumn due to similarity in habitat quality, environmental conditions and species composition, but dissimilarity between monsoon-summer and winter-summer.



However, it should be noted that richness is not the only measurable component of community level biodiversity. The phylogenetic structure of the assemblage is also clearly important, and an assemblage comprising a group of closely related species must be regarded as less 'biodiverse' than an assemblage of the same number of more distantly related species. The importance of measuring taxonomic diversity of the assemblage gained impetus in last decade for setting conservation priorities (Vane-Wright *et al.*, 1991; Williams *et al.*, 1991) and environmental monitoring (Warwick and Clarke, 1995; Clarke and Warwick, 1998; 1999). Taxonomic distinctness ( $\Delta^+$ ) was used to summarize the pattern of relatedness in the sample. The fish assemblage under study, elaborate highest taxonomic distinctness and phylogenetic diversity in monsoon and autumn with progressive declining trend through winter, spring and summer (Figure 6) in relation with total fish catch. However, the mean statistic, average phylogenetic diversity (AvPD) and average taxonomic distinctness (AvTD) value was found to be fairly constant for most of the seasons signifying inherent taxonomic diversity in the fish assemblage throughout the year despite fluctuation in species richness value. The variation in taxonomic distinctness (VarTD,  $\Delta^+$ ) can be defined as the variance in the pairwise path lengths and reflects the unevenness of the taxonomic tree. VarTD showed highest value in summer with progressive declining trend through spring, winter, autumn and least in monsoon. This trend found support in Clarke and Warwick (2001) with negative correlation coefficient between taxonomic distinctness and variance close to 1. This indicated greater variance in taxonomic composition of the fish assemblage with summer containing representation of eight families and eighteen species. On the other hand, monsoon showed less variance with representation of 23 families and 52 species. Increased variability might also be a symbol of stress as found in marine system by Clarke and Warwick (2001). The term "stress" in this study might be on account of overfishing and progressive depletion in nutrient pool as well as least water availability in summer. The null hypothesis that the taxonomic distinctness of the fish assemblage is not significantly different from the global list was tested by repeated subsampling (1000 simulations) of species list of appropriate size. In this study, 95% confidence funnel (Figure 7) was constructed across the full range of species found throughout the year. Similarly, VarTD ( $\Delta^+$ ) values for all seasons with 1000 simulations fall within the funnel with summer falling above the upper limit of funnel, indicating higher than expected variation in taxonomic composition.

The phenomenon of increased phylogenetic diversity with increasing environmental stability could be substantiated over an evolutionary and ecological time scale from the study of marine realm vis-à-vis terrestrial biota (Briggs, 1994). In the marine realm there are 34 phyla. Although these vary in their total numbers of species, none of them is overwhelmingly predominant. However, the terrestrial biota, which has been subjected to a much higher degree of environmental variability in comparison with sea over the last 450 million years, comprises only 15 phyla, with more than 90% of the species belonging to the phylum Arthropoda (Briggs, 1994). The study testified the aforementioned hypothesis in having increased taxonomic distinctness in monsoon and autumn with lowest value in summer signifying more stability in the riverine system in monsoon and autumn. A stable system could accommodate higher fish diversity, i.e. higher taxonomic richness ensuring higher taxonomic distinctness and less variance as found in the case of monsoon and autumn. On the other hand, water level drops down in summer with minimum influx of nutrient leading to lowering of fish diversity in the river. This results in further loss of nutrients in species poor season (Thorp *et al.*, 1994). Thus, taxonomic distinctness of the fish assemblage is lowered with corresponding increment in VarTD. The self-conservative nature of the lotic system is well established.

The fundamental idea behind the study of biodiversity patterns is the presumed connection between the shape of species assemblages and the functional ways in which they are organized, as competitors or members of a web of interactions and to how species are facing similar environmental constraints. Taxonomic and ecological characterisations of community composition are complementary and are useful in conservation context (Angermeier and Winston, 1998; King *et al.*, 2009). Functional diversity is certainly a key for understanding ecosystem processes. According to the limiting similarity hypothesis (MacArthur and Levins,

1967), species were always in competition and the magnitude of competition would be higher between those, who are more similar to each other, i.e. functionally redundant. Hence, species eventually co-existing in a stable way would be those that are dissimilar to each other and therefore allowed niche segregation minimizing competition. The results of this study suggested high functional diversity for the fish assemblage with highest value in Monsoon (0.846) and least in Summer (0.826) signifying preponderance of limiting similarity hypothesis and high functional complementarity of the resident fish fauna and indicative of ecosystem processes in the river network.

## CONCLUSION

At the end of this length discussion on different facets of biodiversity, the stretches of Mahananda, Tangon and Punarbhaba rivers seems to be preferred habitats for feeding and reproduction of a large number of indigenous fishes some of which belong to the threatened categories amongst the Indian fishes. This could be attributed to the fact that i) an aggregation of small river systems ultimately draining to the Ganges providing corridor for migration of fishes over large area, ii) shallowness of the rivers providing good spawning site, iii) input of allochthonous nutrients along with surface run off, iv) stratifications imparted by submerged and riparian vegetation. In order to ensure, long term sustainability of fish stock in this habitat efforts need to be given either to ensure minimum biological and economical over-fishing as well as minimize disruption of ecosystems to protect the precious habitat. Hence, this study identify MTPRS as an Aquatic Ecological System (AES) having i) stream networks less than 1000 Km<sup>2</sup>, ii) identical hydrologic, nutrient and temperature regime should be treated as an actual conservation target according to Nature Conservancy Classification (Higgins *et al.*, 2005). The conserved fish stock in rivers could also serve as 'banks' of organisms for the replenishment of unprotected or degraded areas (Nevill and Philips, 2001) with the aim to i) provide refuge, ii) allow population to increase for further introduction to newer habitats as a part of rehabilitation programme. This type of investigation at local community level indicated patterns of diversity which would help conservation biologists to develop management strategies for effective long-term conservation of biological diversity (Magurran, 2004).

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**Table 1: Seasonal occurrence of fish fauna in the Mahanada – Tangon - Punarbhaba river along with their Family name, Economic use and threat status as per NBFGR report, 2010.**

Sl No.	Species	Family	Economic use	Mons oon	Autu mn	Winte r	Sprin g	Sum mer	Threat Status
1	<i>Arius gagora</i> Hamilton-Buchanan, 1822	Ariidae	Fisheries: commercial	*	*	*	*	a	NT
2	<i>Mystus cavasius</i> Hamilton-Buchanan, 1822	Bagridae	Fisheries: commercial	*	*	*	*	*	VU
3	<i>Mystus tengara</i> Hamilton-Buchanan, 1822	Bagridae	Fisheries: commercial	*	*	*	*	*	LC
4	<i>Mystus vittatus</i> Bloch, 1797	Bagridae	Fisheries, aquarium: commercial	*	*	*	*	*	LC
5	<i>Rita rita</i> Hamilton-Buchanan, 1822	Bagridae	Fisheries: commercial	*	*	*	*	a	VU
6	<i>Sperata aor</i> Hamilton-Buchanan, 1822	Bagridae	Fisheries: commercial; gamefish	*	*	*	a	*	VU
7	<i>Chaca chaca</i> Hamilton-Buchanan, 1822	Chacidae	Aquarium: commercial	*	*	*	*	a	EN
8	<i>Clarias batrachus</i> Linnaeus, 1758	Clariidae	Fisheries, aquaculture, aquarium: commercial	*	*	*	*	*	LC
9	<i>Heteropneustes fossilis</i> Bloch, 1794	Heteropneusti dae	Fisheries, aquaculture, aquarium: commercial	*	*	*	a	a	VU
10	<i>Pangasius pangasius</i> Hamilton-Buchanan, 1822	Pangasiidae	Fisheries, aquaculture: commercial; gamefish	*	*	a	a	a	VU
11	<i>Ailia coila</i> Hamilton-Buchanan, 1822	Schilbeidae	Fisheries: commercial	*	*	*	*	a	VU
12	<i>Ailiichthys punctata</i> Day, 1871	Schilbeidae	Fisheries: commercial	*	*	*	*	a	VU
13	<i>Clupisoma garua</i> Hamilton-Buchanan, 1822	Schilbeidae	Fisheries: commercial; gamefish	*	*	a	a	a	VU
14	<i>Eutropiichthys vacha</i> Hamilton-Buchanan, 1822	Schilbeidae	Fisheries: commercial; gamefish	*	*	*	*	a	VU
15	<i>Neotropius atherinoides</i> Bloch, 1794	Schilbeidae	Fisheries: minor commercial; aquarium: potential	*	*	*	*	a	LC
16	<i>Silonia silondia</i> Hamilton-Buchanan, 1822	Schilbeidae	Fisheries: commercial; gamefish	*	*	*	*	a	VU
17	<i>Ompok pabda</i> Hamilton-Buchanan, 1822	Siluridae	Fisheries: commercial	*	*	*	*	*	VU
18	<i>Ompok pabo</i> Hamilton-Buchanan, 1822	Siluridae	Fisheries: commercial	*	*	*	*	*	EN
19	<i>Ompok bimaculatus</i> Bloch, 1794	Siluridae	Fisheries, aquaculture, aquarium: commercial	*	*	*	*	a	EN
20	<i>Wallago attu</i> Schneider, 1801	Siluridae	Fisheries: commercial; gamefish	*	*	*	*	*	VU
21	<i>Lepidocephalichthys guntea</i> Hamilton-Buchanan, 1822	Cobitidae	Aquarium: commercial	*	*	*	*	a	VU
22	<i>Botia dario</i> Hamilton-Buchanan, 1822	Cobitidae	Aquarium: commercial	*	*	*	*	a	VU
23	<i>Amblypharyngodon mola</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries: commercial	*	*	*	a	a	LC
24	<i>Cabdio morar</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries: commercial	*	*	a	a	a	LC
25	<i>Cirrhinus cirrhosus</i> Bloch, 1795	Cyprinidae	Fisheries: commercial	*	*	*	a	a	VU
26	<i>Cirrhinus reba</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries: commercial	*	*	*	*	*	VU
27	<i>Cyprinus carpio carpio</i> Linnaeus, 1758	Cyprinidae	Fisheries, aquaculture, aquarium: commercial; gamefish	*	*	*	a	a	NE
28	<i>Esomus danricus</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries: minor commercial; aquarium: commercial	*	*	*	*	*	VU
29	<i>Labeo calbasu</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries: commercial; aquaculture: commercial	*	*	*	*	a	LC

30	<i>Bangana dero</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries: commercial; bait: usually	*	*	a	a	a	VU
31	<i>Labeo rohita</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries, aquaculture: commercial; gamefish	*	*	*	a	a	LC
32	<i>Puntius chola</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries, aquarium: commercial	*	*	*	*	*	VU
33	<i>Systemus sarana</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries, aquarium: commercial; gamefish	*	*	*	a	a	VU
34	<i>Salmophasia bacaila</i> Hamilton-Buchanan, 1822	Cyprinidae	Fisheries: commercial	*	*	*	*	*	DD
35	<i>Chanda nama</i> Hamilton-Buchanan, 1822	Ambassidae	Fisheries: minor commercial; aquarium: public aquariums	*	*	*	*	*	LC
36	<i>Parambassis ranga</i> Hamilton-Buchanan, 1822	Ambassidae	Fisheries: subsistence fisheries; aquarium: commercial	*	*	*	a	a	LC
37	<i>Anabas testudineus</i> Bloch, 1795	Anabantidae	Fisheries, aquaculture, aquarium: commercial	*	*	*	a	a	VU
38	<i>Trichogaster fasciata</i> Bloch and Schneider, 1801	Osphronemidae	Fisheries: commercial	*	*	*	*	*	NK
39	<i>Channa orientalis</i> Bloch and Schneider, 1793	Channidae	Fisheries, aquarium: commercial	*	*	*	a	a	NK
40	<i>Channa punctatus</i> Bloch, 1793	Channidae	Fisheries, aquaculture, aquarium: commercial;	*	*	*	*	*	NK
41	<i>Channa striatus</i> Bloch, 1793	Channidae	Fisheries, aquaculture, aquarium: commercial	*	*	*	*	*	NK
42	<i>Glossogobius giuris</i> Hamilton-Buchanan, 1822	Gobiidae	Fisheries, aquaculture, aquarium: commercial	*	*	*	a	a	NT
43	<i>Mastacembelus armatus</i> Lacepede, 1800	Mastacembelidae	Fisheries, aquarium: commercial	*	*	*	*	a	VU
44	<i>Badis badis</i> Hamilton-Buchanan, 1822	Badidae	Fisheries: of no interest; aquarium: commercial	*	*	a	a	a	NK
45	<i>Nandus nandus</i> Hamilton-Buchanan, 1822	Nandidae	Fisheries, aquarium: commercial	*	*	*	*	*	NK
46	<i>Gudusia chapra</i> Hamilton-Buchanan, 1822	Clupeidae	Fisheries: subsistence fisheries	*	*	a	*	a	VU
47	<i>Tenuulosa ilisha</i> Hamilton-Buchanan, 1822	Clupeidae	Fisheries: highly commercial; aquaculture: experimental	*	a	a	a	a	VU
48	<i>Setipinna phasa</i> Hamilton-Buchanan, 1822	Engraulidae	Fisheries: commercial	*	*	*	a	a	LC
49	<i>Chitala chitala</i> Hamilton-Buchanan, 1822	Notopteridae	Fisheries, aquaculture: commercial; gamefish	*	*	*	*	a	EN
50	<i>Notopterus notopterus</i> Pallas, 1769	Notopteridae	Fisheries, aquaculture: commercial; gamefish	*	*	*	*	a	EN
51	<i>Tetraodon cutcutia</i> Hamilton-Buchanan, 1822	Tetraodontidae	Fisheries: minor commercial;	*	*	a	a	a	NK
52	<i>Xenentodon cancila</i> Hamilton-Buchanan, 1822	Belonidae	Fisheries: minor commercial; aquarium: potential	*	*	*	a	a	VU

\* = present, a= absent, EN= Endangered, VU= Vulnerable, NT= Near threatened, DD= data deficient, LC= Least Concerned, NK = Not known

**Table 2: Comparison with distribution pattern of finfishes in aquatic bodies of different climatological region with present study.**

Location	Number of finfishes	References
Punarbhaba River, West Bengal, India	52	Present study
Naaf River Estuary, Bangladesh	98	Chowdhry et al. 2010
Bhadra River, Western Ghats, India	56	Shahnawaz et al. 2010
Bhadra Reservoir, Karnataka, India	33	Thirumala et al. 2011
Copper Creek, Australia	14	Arthington et al. 2005
Itaipu reservoir, Brazil	85	Oliveira et al. 2004
Sharavati River, Western Ghats, India	51	Bhat 2003
Aghanashini River, Western Ghats, India	52	Bhat 2003
Bedti River, Western Ghats, India	63	Bhat 2003
Kali River, Western Ghats, India	53	Bhat 2003
Rivers of North Karnataka	20	Arunachalam et al. 1997
Neyyer River, India	33	Nair et al. 1989

**Table 3: Seasonal variation in diversity estimators calculated from fish abundance data.**

Diversity Estimators	Monsoon	Autumn	Seasons Winter	Spring	Summer
Dominance index	0.117	0.046	0.221	0.135	0.199
Shannon-Weaver index	3.7	3.63	3.44	2.99	2.43
Pielous Evenness index	0.94	0.92	0.91	0.86	0.84
Species richness index	28.23	66	32.01	18.69	13.08
Fish Species Richness	52	51	44	32	18

**Table 4: Correlation coefficient between diversity indices with respect to fish abundance in the Punarbhaba river.**

	Shanon-Weaver index	Evenness index	Dominance index	Species richness
Fish species richness	0.99*	0.97*	-0.55*	0.72*
Shanon-Weaver index		0.97*	-0.52**	0.69*
Evenness index			-0.44***	0.63**
Dominance index				-0.72*

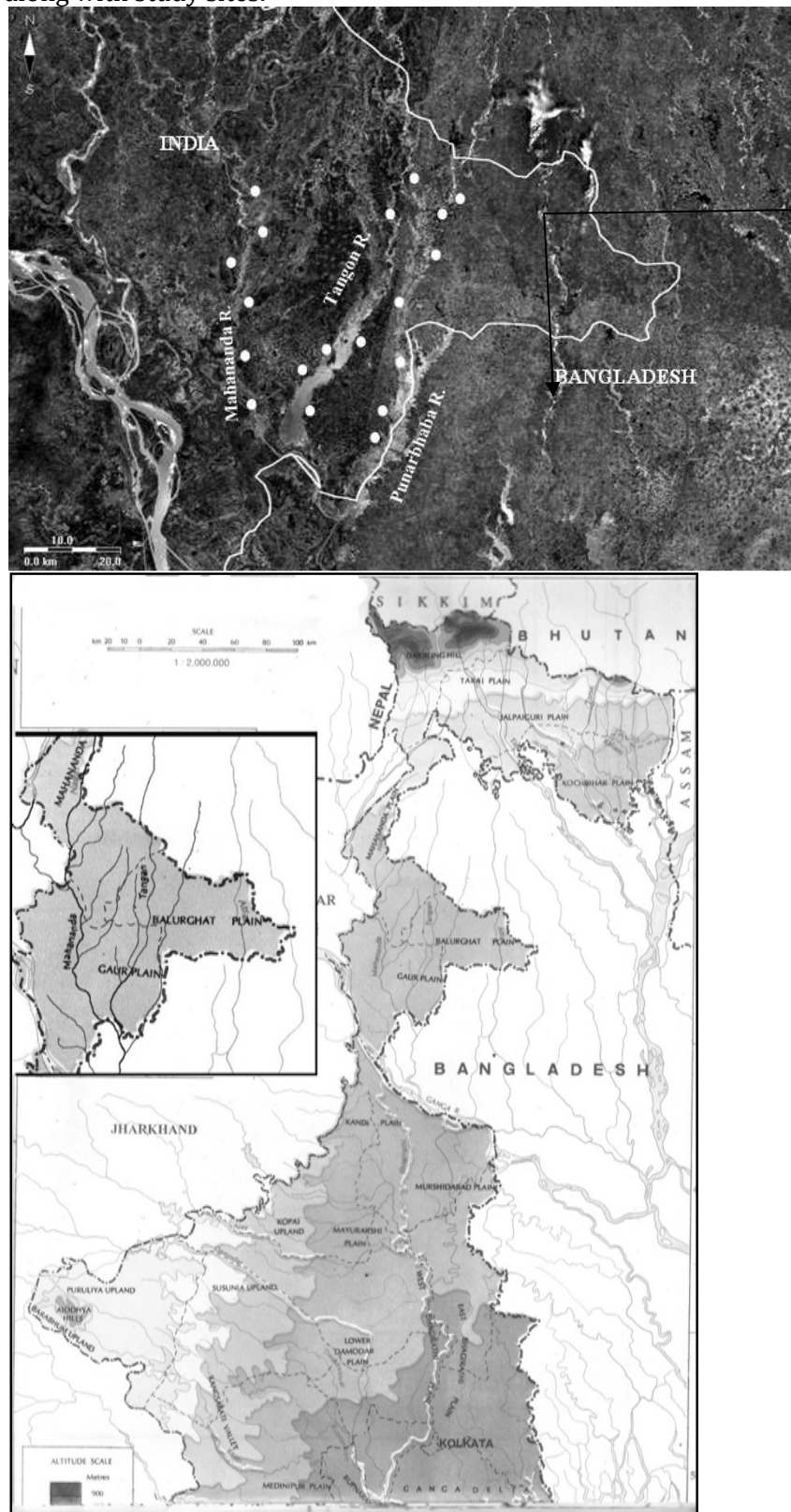
\* Correlation is significant at the 0.05 level (2 tailed).

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

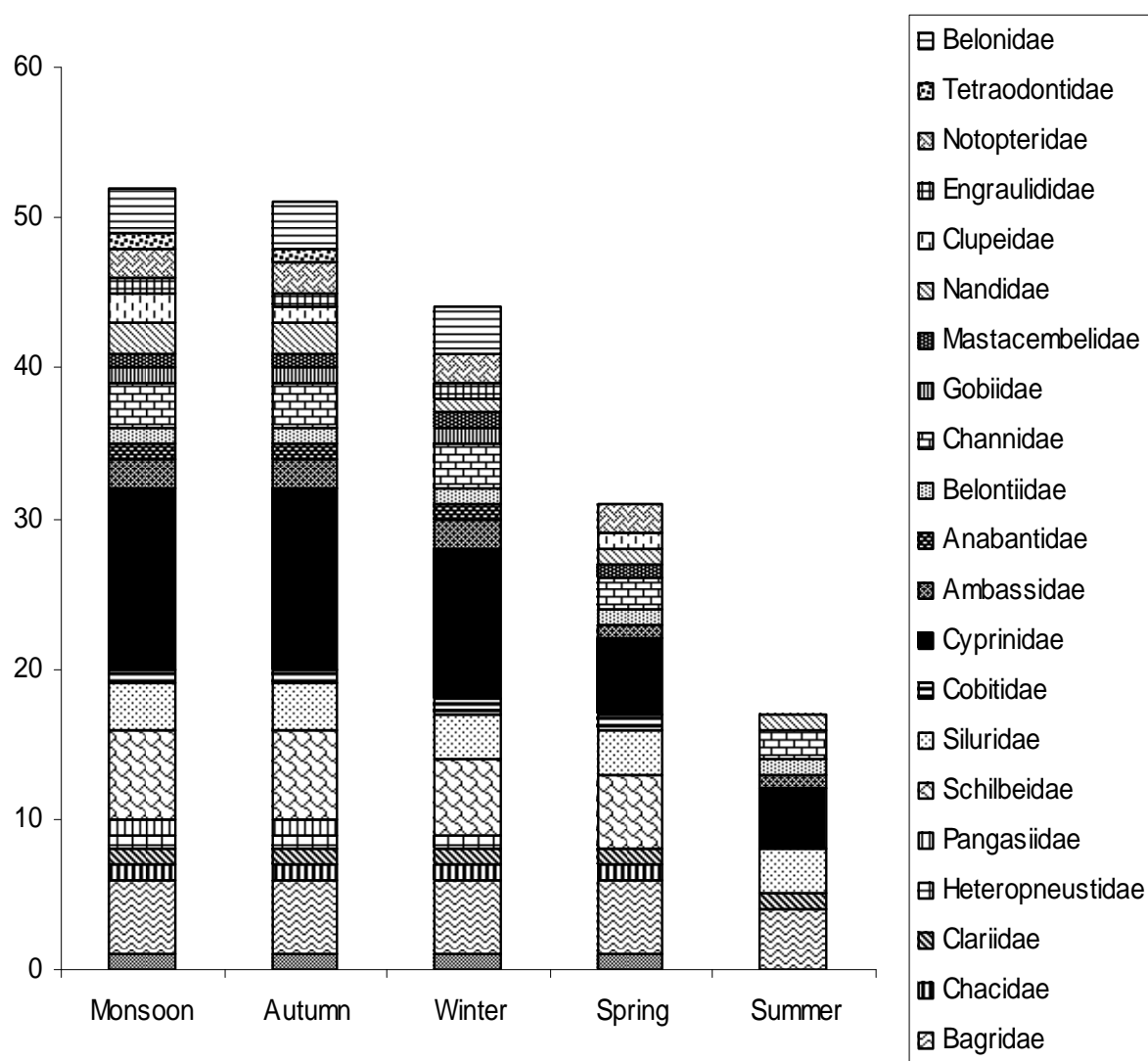
\*\*\* Not significant



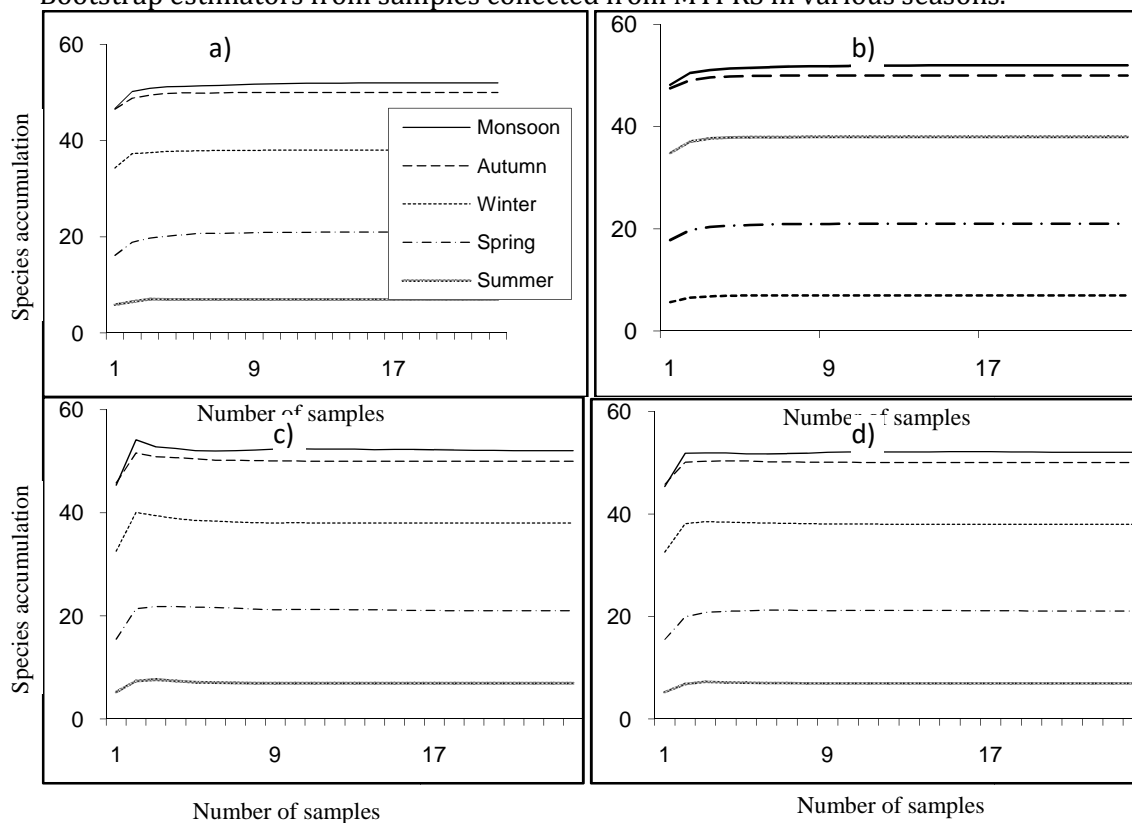
**Figure 1:** Map showing location of Mahananda-Tangon-Punarbhaba river system (MTPRS) along with study sites.



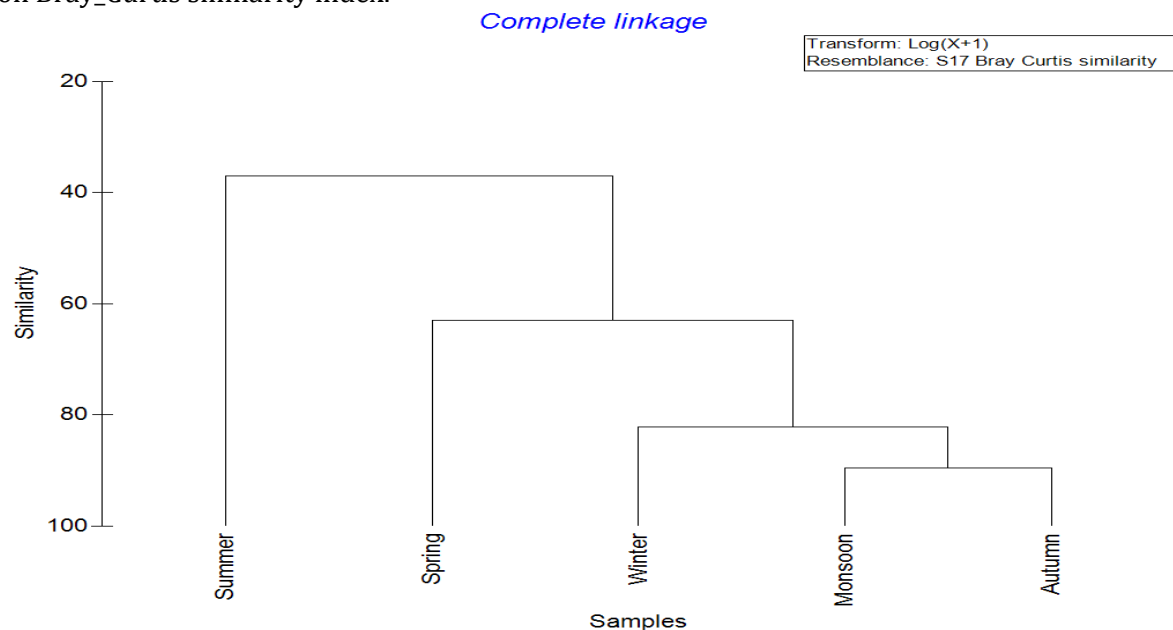
**Figure 2:** Abundance of existing fish family in different seasonal regime in MTPRS.



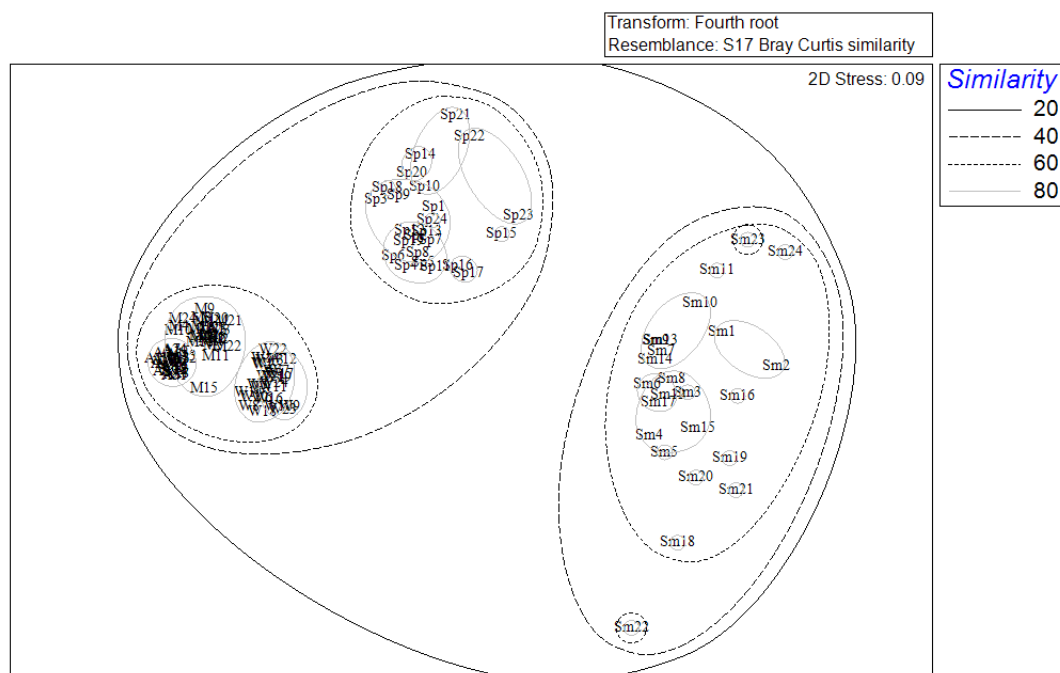
**Figure 3:** Pattern difference in a) Chao 1, b) Individual based rarefaction curve, c) Jackknife, d) Bootstrap estimators from samples collected from MTPRS in various seasons.



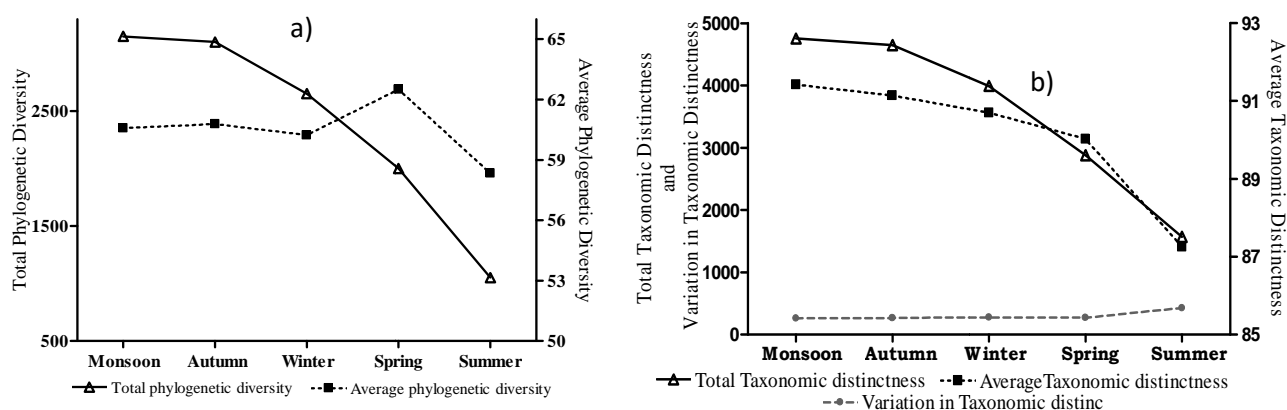
**Figure 4:** Dendrogram showing resemblance between seasonal fish assemblage structure based on Bray\_Curtis similarity index.



**Figure 5:** Non-metric multidimensional scaling (nMDS) of samples collected at different seasons based on abundance of fishes using Bray–Curtis similarity at 20,40, 60 and 80 % of similarity. M1-M24= monsoon, A1-A24= Autumn, W1-W24=Winter, Sp1-Sp24= Spring, Sm1-Sm24= Summer samples.



**Figure 6:** Seasonal variation on a) Phylogenetic diversity and b) Taxonomic distinctness of the fish assemblage in the MTPRS.





**Figure 7:** Funnel plot showing (a) Average Taxonomic Distinctness ( $\Delta^+$ ) and (b) Variation in Taxonomic distinctness of the fish assemblage in the MTPRS. Thin line in middle indicate mean of 1000 simulations confirming theoretical unbiasedness. Continuous line indicates 95% probability limits for each.

