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Response of fish communities to abiotic factors in Western Ramganga, Kumaun Lesser Himalaya, India

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Abiotic factors in the riverine ecosystem are important in structuring fish communities along the longitudinal gradients. Quantitative data on species abundance were collected during October 2015–September 2016 in the mountain stretch of the River Western Ramganga from Kumaun Lesser Himalayas, India. Multivariate analyses were done to study the relationship between fish assemblages and abiotic parameters. Cluster analysis and non-metric multidimensional scaling indicated two distinct groups in the upstream and downstream zones. The composition of fish assemblages in different zones was found to be strongly associated with habitat characteristics. Canonical correspondence analysis revealed species abundance association with temperature, conductivity, stream width and altitude. Further analysis showed conductivity–altitude combination as the primary factor determining the longitudinal distribution of species composition in the studied stretch of this river. The present study aids in understanding the factors that determine the spatial segregation of species for the restoration, conservation and management of aquatic resources.

Keywords: Abiotic factors, assemblage structure, fish communities, multivariate analysis, riverine ecosystem.

THE riverine or lotic ecosystem consists of rich and varied biota, including diverse fish species adapted to the different environmental factors operating in the habitat[1]. The fish community structure varies along the upstream–downstream gradient of river ecosystems on a spatial and temporal scale as a result of differences in habitat structure and resource availability[1,2]. Moreover, changes in different biotic (e.g. competition, predation) and abiotic factors such as channel morphology, stream order, water quality, stream flow regimes and temperature operating at local and regional scale also influence the species richness and diversity within a river basin[1–5]. Fish communities in a riverine system are also sensitive to changes in multiple environmental factors. Accordingly, they have widely been employed for studying the ecological integrity and well-being of biological communities in the freshwater ecosystem[6–8]. Apart from natural regulation of species distribution, human alterations to stream

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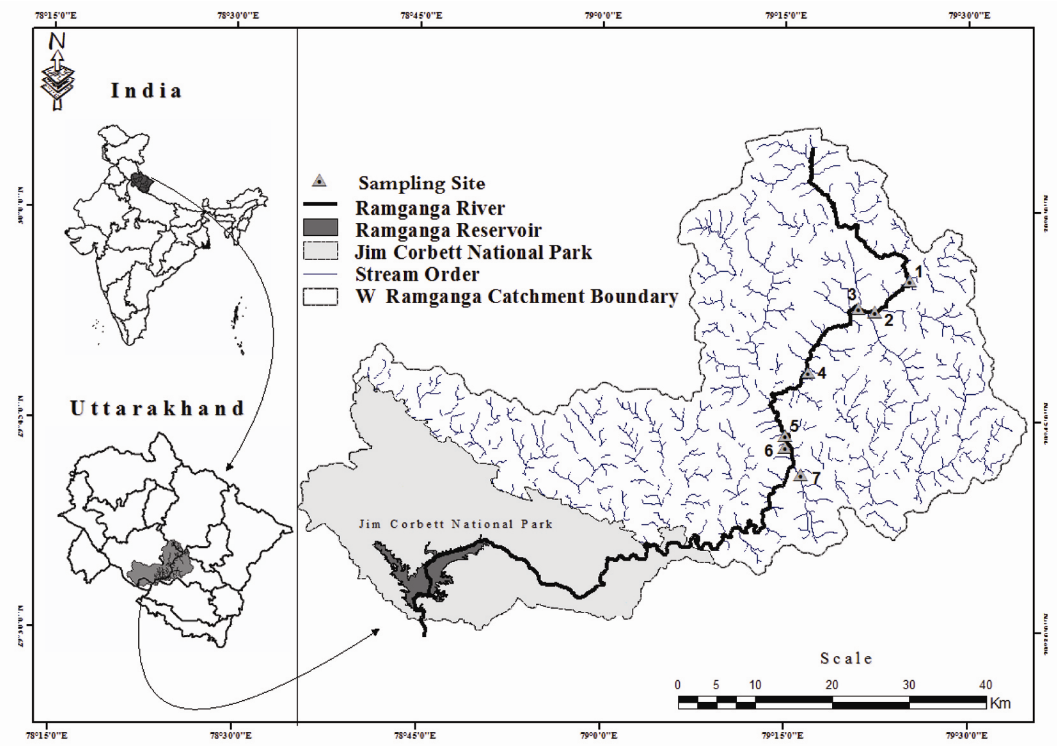

Figure 1. Location of sampling sites at River Western Ramganga, Uttarakhand, India.

ecosystems also result in changes to community structure[9]. Therefore, understanding and quantifying the factors affecting the pattern of fish assemblage is crucial because it provides critical information for the restoration, remediation and rehabilitation of freshwater ecosystem[10].

Kumaun Himalaya is the source of many perennial rivers and seasonal streams which drain into the River Ganga[11]. Rivers in this region have diverse fish fauna; the mountain sections of the rivers support a rich diversity of valuable cold-water fishes which are endemic to the region and also provide subsistence fisheries to people inhabiting in area[12]. The Western Ramganga is one of the principal rivers from Kumaun Lesser Himalaya and also a major tributary of the Ganga. Due to intense human intervention, both the riverine ecosystem and natural fish populations of several Indian rivers, including hill streams have become endangered[13,14]. The major threat to the cold-water fisheries of the region is from rapid environmental degradation, loss of habitat due to river impoundment, overexploitation and use of destructive fishing methods creating enormous pressure on resources in general and fish stocks in particular[15].

The relationship between environmental variability and regional patterns of riverine fish assembly has been studied worldwide[4,7–9,16]. In India, studies have been undertaken to highlight the relationship between environmental variables and complexity of fish assemblage structure in the rivers of the Central and Northern Highlands from the Western Ghats region[5,17,18]. The rivers in the Kuamun Himalayan region though important from the fisheries viewpoint, have not been studied for habitat assessment and relationship of species with environmental variables. Therefore, in this study we examined the pattern of species assemblage in the mountain section of the Western Ramganga. The objective of the study was to document the response of fish assemblage structure to abiotic factors along longitudinal stream gradients. The study would be useful in understanding the ecological status of the river as well as monitoring and conservation of the species. It also provides tools for the assessment of ecological integrity of rivers based on fish assemblage for developing management strategies.

The quantitative data on fish species were collected from seven locations of varying elevations (altitude 755–1026 m amsl) in the mountain stretch of the River Western Ramganga, Kuamun region (lat. 28°44′ and 30°49′N; long. 78°45′ and 81°05′E), Uttarakhand, India (Figure 1). The length of the sampled mainstream is around 80 km and no dams or weirs prevent fish migration in the mainstream. The sampling sites have been categorized as upstream (sites: WR 1–3) and downstream zones (sites: WR 4–7) based on altitudinal variation. Sampling was conducted over a 150 m stream reach along a transect line fixed at each site. Fishes were sampled for a period of one year (October 2015–September 2016) covering all seasons (pre-monsoon, monsoon and post-monsoon) from each location during day hours (10 : 00–16 : 00 h) using

Table 1. Summary of study site characteristics

Site code	Sampling site	GPS coordinates	Altitude (m)	Stream order	Width* (m)	Depth* (m)	Current* (m/s)	Temperature (°C)	Conductivity (µmho/cm)
WR 1	Kheeda	79 51 11.7°E and 29 55 05.1°N	1026	3	20.61 ± 0.58	1.66 ± 0.24	0.61 ± 0.04	18.29 ± 0.99	228 ± 5.21
WR 2	Amshyari	79 22 22.5°E and 29 52 52.3°N	945	4	22.16 ± 0.84	1.77 ± 0.12	0.60 ± 0.03	18.18 ± 1.02	230 ± 3.97
WR 3	Chaukhutia	79 21 03.3°E and 29 53 08.1°N	935	5	25.82 ± 0.52	1.78 ± 0.22	0.65 ± 0.05	18.71 ± 0.92	223 ± 5.06
WR 4	Masi	79 16 56.3°E and 29 48 35.4°N	815	5	23.66 ± 0.53	2.11 ± 0.23	0.52 ± 0.06	18.55 ± 0.49	172 ± 4.65
WR 5	Simtoli	79 15 04.1°E and 29 44 04.3°N	806	5	22.88 ± 0.58	1.90 ± 0.12	0.54 ± 0.07	19.66 ± 0.71	171 ± 4.06
WR 6	Barkhinda	79 15 38.0°E and 29 43 10.0°N	780	5	21.50 ± 0.34	2.17 ± 0.26	0.48 ± 0.07	19.44 ± 0.67	169 ± 5.35
WR 7	Bhikiyasen	79 16 22.6°E and 29 41 11.7°N	755	4	25.32 ± 0.25	2.06 ± 0.23	0.51 ± 0.03	20.16 ± 1.12	177 ± 5.38

*Values are shown as mean ± SE, $n = 5$.

Table 2. Species presence/absence at different sampling locations. Threat status of fishes in the Western Ramganga is also shown

Family/species	Sampling site							Relative abundance of species (%)	Relative abundance of families (%)	Threat status[38]
	WR1	WR2	WR3	WR4	WR5	WR6	WR7			
Cyprinidae										
Barilius bendelisis	+	+	+	+	+	+	+	12.56	86.71	Lower risk, near threatened
Barilius barna	–	+	+	–	–	–	–	0.89		Lower risk, near threatened
Barilius vagra	–	+	+	+	–	+	+	1.77		Vulnerable
Barilius shacra	–	–	–	+	+	–	–	1.18		Vulnerable
Crossocheilus latius latius	+	+	+	+	+	–	–	5.47		Data deficient
Chagunius chagunio	–	–	–	+	+	+	+	3.84		Not assessed
Garra gotyla gotyla	+	+	+	+	+	+	+	11.37		Vulnerable
Garra lamta	+	+	+	–	–	–	–	0.74		Not assessed
Labeo dero	–	–	+	+	+	+	+	6.35		Vulnerable
Labeo dyocheilus	–	–	+	+	+	+	+	4.58		Not assessed
Nezitor chelynoides	–	+	+	–	–	–	–	1.92		Not assessed
Raiamas bola	–	–	–	+	–	+	+	3.25		Lower risk, near threatened
Schizothorax richardsonii	+	+	+	+	+	–	–	18.46		Vulnerable
Schizothorax plagiostomus	+	+	+	–	+	+	–	7.09		Not assessed
Tor putitora	+	+	+	+	+	+	+	7.24		Endangered
Cobitidae										
Botia lohachata	–	+	–	–	–	–	–	0.44	2.36	Endangered
Lepidocephalus guntea	–	–	+	+	–	+	–	1.92		Not assessed
Nemacheilidae										
Nemacheilus rupicola	+	+	+	–	–	–	–	0.59	2.51	Not assessed
Nemacheilus montanus	+	+	–	–	–	–	–	0.44		Endangered
Nemacheilus denisoni	–	+	+	–	–	–	–	0.30		Not assessed
Nemacheilus botia	–	–	+	–	–	–	–	1.18		Lower risk, near threatened
Sisoridae										
Glyptothorax pectinopterus	–	–	+	+	+	+	+	2.66	5.91	Lower risk, near threatened
Glyptothorax telchitta	–	+	–	+	–	–	–	0.74		Lower risk, near threatened
Glyptothorax conirostris	–	–	+	–	+	–	+	0.89		Not assessed
Pseudecheneis sulcatus	–	–	–	+	+	+	–	1.62		Vulnerable
Belonidae										
Xenentodon cancila	–	–	–	+	+	+	+	1.48	1.42	Lower risk, near threatened
Mastacembelidae										
Mastacembelus armatus	–	–	–	–	+	+	–	1.03	1.09	Not assessed

cast net (mesh size: 0.37–0.50 in), gill net (1.0–2.0 in) and dragnet (0.78–1.57 in). The total number of individuals belonging to each species was identified and counted at each sampling site. However, representative specimens (preserved in 10% formaldehyde solution) were brought to the laboratory for further confirmation to the lowest possible taxonomic level based on the available keys[19,20]. The fishes, including vulnerable and endangered species caught were immediately released back after identification and counting. At each sampling site, a set of the following abiotic parameters was recorded: altitude, stream order, stream width (m), water depth (m), current velocity (m/s), water temperature (°C) and conductivity (μmho/cm) (Table 1).

The change in species diversity along the gradient was studied using Shannon–Weiner index (H'). Fish assemblage structure was evaluated using multivariate analyses, i.e. cluster analysis and non-metric multidimensional scaling (nMDS). Bray–Curtis similarity index was calculated based on quantitative data on species abundance[21]. The data were $\log(1 + x)$ transformed for down-weighting the highly abundant species and correct the missing values[22]. Hierarchical agglomerative clustering was done, and the resulting dendrogram depicted the similarity of fish assemblage structure between the sampling sites. Further, to understand the similarity of habitats based on abiotic factors, Euclidean distance was calculated using the log-transformed data on abiotic parameters and the dendrogram was constructed. Two nMDS ordinations plots were also built to ordinate sites on the similarity of the fish assemblages and abiotic parameters based on the Bray–Curtis similarity and Euclidean distance respectively. Canonical correspondence analysis (CCA) was performed to determine the association of species composition to stream environmental gradients. It formed a linear combination of environmental variables that maximally separate the niches of the species[23]. We included only cyprinid species in CCA, being the predominant group in the assemblage. The ordination diagram in the form of triplot represented species, sites and abiotic factors by points with respect to the supplied explanatory variables, represented by a line. The lines indicated the maximum variation in the value of the corresponding variable. Multivariate community structure and a combination of abiotic factors were also examined using the BIO-ENV routine[24] of BEST program available in PRIMER-v_6 (ref. 25). It calculates the rank correlation between a similarity matrix derived from biotic data and matrices derived from various subsets of environmental variables. Based on this, it defines suites of variables most closely correlated with the observed biotic structure. The parameters were log-transformed to reduce skewness in the data prior to the analyses. Data analysis was done using PRIMER-v_6 (ref. 25) and PAST *v*-3.15 (ref. 26).

During the study, a total of 568 individuals of 27 species belonging to 16 genera and 6 families were recorded. Overall, cyprinids were the most dominant members of the assemblage that comprised 86.71% of the total recorded species (Table 2). Among the species, *Schizothorax richardsonii*, *Barilius bendelisis*, *Garra gotyla* and *Tor putitora* were numerically dominant at all but the upstream sites and accounted for 18.46%, 12.56%, 11.37% and 7.24% respectively, of all fish captured. The dominance of the cyprinids in the assemblage structure may be attributed to their high adaptive ability to occupy all possible habitats in this river and also to their capability of tolerating a wide range of environmental conditions[7,27]. Earlier studies have also indicated the dominance of cyprinids in this river[28]. A gradual increase in species diversity was observed towards the downstream zone with decreasing elevation (Figure 2). Typically, native fishes in rivers exhibit longitudinal zonation in distribution and abundance from upstream to downstream due to higher habitat diversity. A number of studies showing significant association between species abundance and longitudinal gradient have pointed out that streams support higher species diversity towards decreasing elevation due to change in geomorphology, availability of more resources and living space[2,8,16]. Furthermore, moderating environmental conditions towards lower elevation also influences fish communities[29].

Cluster analysis of species abundance and abiotic factors revealed that sites in the upstream (WR 1–3) and downstream (WR 4–7) zones formed two distinct groups, thus indicating different species assemblage patterns and habitat composition in different zones (Figure 3 *a* and *b*). A two-dimensional nMDS ordination (stress = 0.01) arranged sites by longitudinal gradient based on fish species composition and abiotic factors, and delineated the upstream and downstream sites into two distinct groups

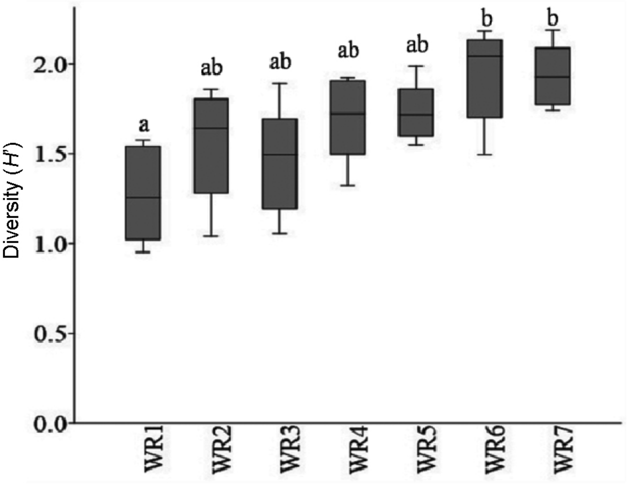

Figure 2. Box plots of Shannon–Weiner diversity (H') of fish communities at different sampling sites. Boxes, central bars and solid lines represent the interquartile range, median and data range respectively. One-way ANOVA: $F_{1,33} = 18.03$; $P = 0.001$. Different superscripts (a, b) differ significantly ($P < 0.05$).

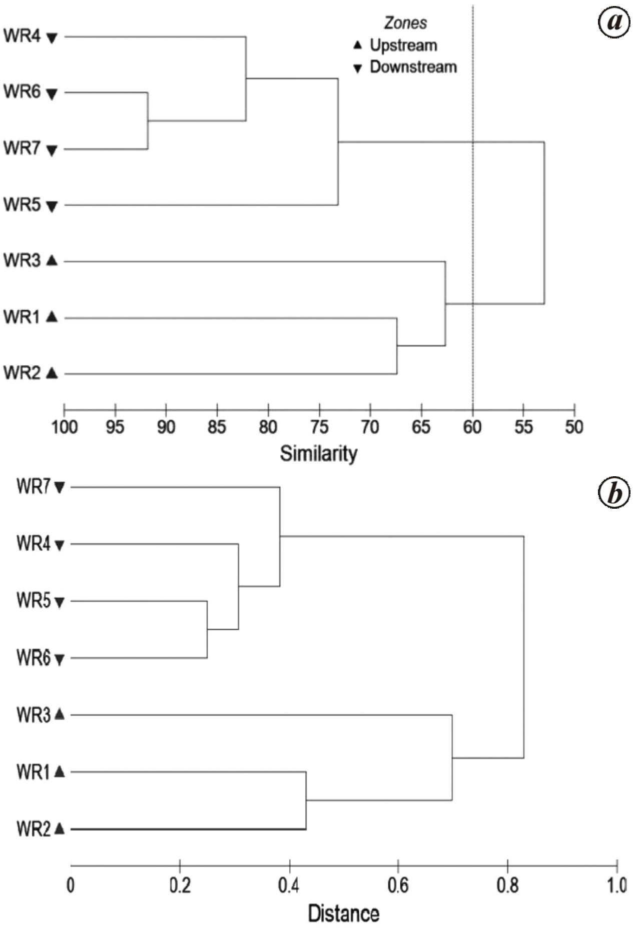

Figure 3. Dendrogram for hierarchical clustering (using group average linking) for sampling sites in upstream and downstream zones based on (***a***) Bray–Curtis similarity matrix derived from $\log(1 + x)$ transformed species abundance at different sites and (***b***) Euclidean distance derived from the log-transformed abiotic parameters.

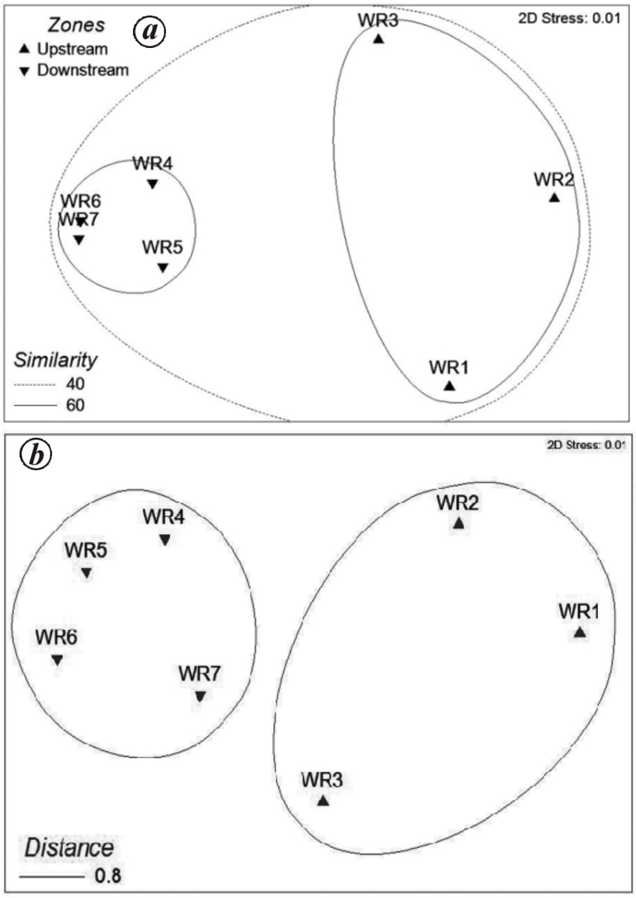

Figure 4. Non-metric multidimensional scaling ordination for sampling sites in the upstream and downstream zones based on (***a***) log(1 + x) transformed species abundance and Bray–Curtis similarities and (***b***) log-transformed abiotic parameters and Euclidean distance. NMDS plots are represented without axis scaling.

(Figure 4 *a* and *b*). In the present study, composition of fish assemblages in different zones was found to be associated with abiotic factors on a spatial scale. Longitudinal variation in species assemblages in a riverine system depends on abiotic and biotic factors, in which regional species pool responds similarly to environmental factors. Different studies describing species co-occurrence across stream gradient revealed that abiotic factors and recolonization dynamics play a more important role in structuring fish assemblage pattern than biotic interaction[30–32]. These abiotic or environmental constraints largely determine the local species composition on a spatial scale. Further, it was also found that different hydrobiological variables limit species distribution, leading to different assemblages according to habitat characteristics[30]. Moreover, individual physical parameters correlated with the distribution of individual species or composition of local assemblages also influence the community structure[33].

CCA depicted the relationship between 15 of the most abundant cyprinid fish species, sites and abiotic factors in ordination space (Figure 5). The eigenvalues of axes 1 and 2 were 0.25 and 0.08 which explained 60.1% and 19.9% variation by abiotic factor respectively. The scatter plot shows that conductivity and altitude are the two most important variables for the first axis, although current velocity and stream width also influence species distribution. Stream order, temperature and depth are significant variables for the second axis. The sites in the upstream (WR 1–3) are related to altitude, higher conductivity and current velocity, whereas downstream zone (WR 4–7) is associated with stream order, temperature and greater depth. Species which are abundant in the upstream sites (*S. richardsonii*, *G. lamta*, *C. latius latius*, *B. barna* and *Nezitor chelynoides*) have higher scores on axis 1, while species common to the downstream sites (*L. dero*, *L. dyocheilus*, *C. chagunio* and *R. bola*) have higher scores on axis 2. Widely distributed species occupying both upstream and downstream regions are clustered at the centre (*G. gotyla*, *T. putitora* and *B. bendelisis*). It was found that all abiotic factors measured influenced the species distribution, but four environmental variables, viz. temperature, conductivity, stream order and altitude significantly affected the distribution of the cyprinid fish species. Similar observations have also been reported from rivers in Central India[5,17,18,27]. Thus species in the downstream sites are mostly found associated with depth parameter and higher stream order, and those in the upstream sites are influenced by conductivity (Figure 5). Stream order is an indicator of morphometric characteristics of a stream such as depth, width and discharge[3]. It has been suggested that fish assemblages change gradually with stream order. Increasing diversity with increasing stream order has been documented in previous studies and it may be related to higher habitat heterogeneity and productivity with decreasing gradient[3,34,35].

The BIO-ENV analysis showed the highest Spearman correlation value for conductivity and altitude. The next best combinations were of four environmental variables, viz. temperature, conductivity, stream order and altitude (Table 3). These results suggest conductivity–altitude combination as the primary factor determining the longitudinal distribution of species composition in this river. Different factors such as climatic, biological and geographical attributes have been suggested as the cause of variation in species richness along the elevational gradients[8,36]. Spatial difference in physical and chemical variables also affects the distribution of species in a stream[37]. However, in the present study, species composition and their relationship to abiotic factors were detected on a smaller scale. Therefore, a stronger correlation with conductivity and altitude might be due to the small number of sample sites, which probably simplified the longitudinal gradient and increased the apparent difference in species composition.

Nevertheless, the present study shows that abiotic factors play a significant role in the organization of species assemblage at different zones in this river and thus

Table 3. Summary of results from BIO-ENV analysis. The subset of environmental variables showing the highest overall correlation with species abundance matrices (highest correlations indicated in bold)

Number of variables	Best variable combination	Correlation (p_s)
2	Conductivity, altitude	**0.804**
3	Conductivity, stream order, altitude	0.784
	Temperature, conductivity, altitude	0.779
	Conductivity, depth, altitude	0.768
	Temperature, conductivity, stream order	0.753
4	Temperature, conductivity, stream order, altitude	**0.794**
	Temperature, conductivity, depth, altitude	0.769
5	Temperature, conductivity, depth, stream order, altitude	0.756
Global test	Sample statistic (Rho) ρ: 0.883 Significance level of sample statistic: 0.005 Number of permutations: 999 (random sample)	

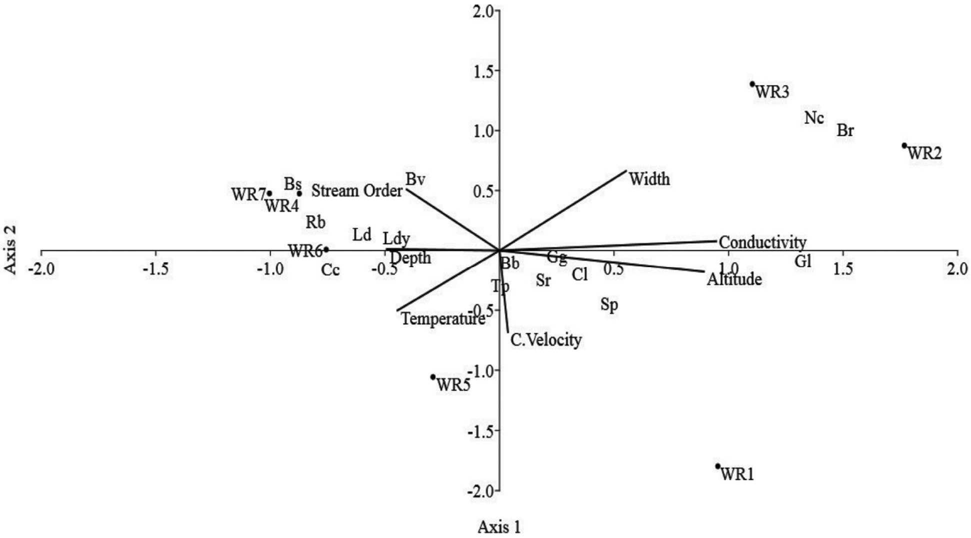

Figure 5. Canonical correspondence analysis triplot depicting the relationship between all cyprinid species, study sites and environmental factors. Bb, *Barilius bendelisis*; Br, *Barilius barna*; Bv, *Barilius vagra*; Bs, *Barilius shacra*; Cl, *Crossocheilus latius latius*; Cc, *Chagunius chagunio*; Gg, *Garra gotyla gotyla*; Gl, *Garra lamta*; Ld, *Labeo dero*; Ldy, *Labeo dyocheilus*; Nc, *Nezitor chelynoides*; Rb, *Raiamas bola*; Sr, *Schizothorax richardsonii*; Sp, *Schizothorax plagiostomus*; Tp, *Tor putitora*.

are likely to be affected by any alteration in the habitat characteristics, such as river mining or pollution. The clear separation of zones indicates that different biological traits (such as body size, feeding, migration behaviour) of the species might be responding to environmental gradients in the river, which necessitates further studies to establish the fact. The abundance of Golden Mahseer (*Tor putitora*), an endangered species[38] and favourite sports fish, as well as the presence of other vulnerable species at certain locations in this river, need conservation through regulation and awareness programmes. An understanding of the factors determining the spatial segregation of species is important for the restoration and management of aquatic resources. The present study is a step in understanding the ecological status of the western Ramganga river.

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