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Fish diversity, habitat ecology and their conservation and management issues of a tropical River in Ganga basin, India

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Abstract In the present communication habitat ecology, species diversity; distribution and different indices of fish biodiversity management were studied in a Central India river (River Betwa, a tributary of River Ganga basin approved under India's first river linking plan). Correlation between fish species richness with the hydrological attributes showed good relationship and water depth, dissolved oxygen and pH were found the most important variables in shaping fish assemblage. Altogether, sixty-three fish species belonging to 20 families and 45 genera were collected from five sampling stations spread along the upstream, mid stream and lower streams. Cyprinids were the most dominated group represented by 26 species belonging to 15 genera, followed by Bagridae (6 species from 3 genera), and Schilbeidae (4 species from 4 genera). The distribution of fish showed interesting pattern and about 10% species were common to all the sites showing long migration range. Shannon-Weiner diversity index showed considerable variation and ranged from 1.89 to 3.51. Out of 63 species status of 10 species were not known due to data deficit, 29 categorized as lower risk, 14 as vulnerable, 8 as endangered, while the remaining two species were introduced. Our study shows that the River supports considerable diversity of the fishes and is important for conservation and about 34% fish fauna is threatened being either vulnerable or endangered. We assessed that the river supports considerable percentage of food fish (89.47), ornamental fish (49.12%) and sport fish (5.26%). Among the eight major types of fish habitats identified along the entire stretch of river, open river, shallow water and deep pools were habitats contributing maximum diversity. Fish species richness (FSR) were significantly different ($P < 0.05$) in all the habitats except channel confluence and scour pool. Trophic niche model may be useful for assessing altered as well as less altered fish habitat of the tropical rivers. Since this river will be interlinked in near future, this study would be useful for conservation planning and management and also for future assessment after interlinking. Issues related to various threats to aquatic environment and conservation management strategies have been discussed.

Keywords River Betwa · Habitat ecology · Distribution · Fish diversity · Trophic niche · Conservation

1 Introduction

Over the last century, riverine ecosystems have suffered from intense human intervention resulting in habitat loss and degradation and as a consequence, many fish species have become highly endangered, particular in rivers where heavy demand is placed on freshwaters. The main causes are habitat destruction and defragmentation (Cuizhang and others 2003), water abstraction, industries and private use (Szollosi-Nagy 2004; Ricciardi and Rasmussen 1999; Gibbs 2000; Dawson and others 2003) exotic species introduction (Copp and others 2005), pollution (Lima-Junior et al. 2006) and global climate change impacts (Leveque et al. 2005; Mas-Marti et al. 2010). Freshwater fish are one of the most

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threatened taxonomic groups (Darwall and Vie 2005) because of their high sensitivity to the quantitative and qualitative alteration of aquatic habits (Laffaille et al. 2005; Kang et al. 2009; Sarkar et al. 2008). As a consequence, they are often used as bioindicator for the assessment of water quality, river network connectivity or flow regime (Chovance et al. 2003). Today the fish diversity and associated habitats management is a great challenge (Dudgeon et al. 2006). Conservation measures to mitigate the impact of the pressures have largely been slow and inadequate and as a result many of the species are declining rapidly.

In India the tributaries of river Ganga basin though supports rich biodiversity and offers livelihood and nutritional security has been less studied from conservation point of view. Studies in some cases have been limited to scattered works on commercial fisheries based on catch data of some major groups and even these have been largely restricted to some of the major River systems (Mishra and Moza 1997; Payne et al. 2004).

In India out of 30 river interlinks have been identified and among these River Betwa has been approved as the country's first River to be interlink with River Ken (NWDA 2004). River Betwa is one of the perennial tributaries of River Yamuna (tributary of river Ganga) and support livelihood and nutritional security. The fish fauna of the River Betwa is highly threatened due to presence of dams and water diversions resulting fragmentation of habitat. The proposed interlinking also involves building another dam and diverting the water to Betwa through a link canal. The review of literature shows that except for a single account of fish taxonomy (Adholia 1977), flow pattern and water use balance (Pandey et al. 2008; Chaube 1988), no information is available on the pattern of fish species diversity, abundance, distribution, and fish habitat aspects at different spatial scales. Detailed studies required for conservation and management of the large Indian rivers are very less except few (Payne and others 2004; Sarkar et al. 2008, 2010). The aim of this study was to assess the present status of fish community structure, abundance, diversity, distribution, richness, trophic ecology of the fishes, threats and to recommend conservation management measures in view of river interlinking plan.

1.1 Study area

The Betwa sub-basin of Yamuna (Fig. 1) falls in the Bundelkhand region in central India between latitudes 77° 15′ and 79°45′ N and longitudes 23° 5′ and 25° 55′ E. It originates in the Raisen district in Madhya Pradesh at an elevation of 475 m above mean sea level and joins River Yamuna near Hamirpur in Uttar Pradesh, traveling a total distance of about 590 km. Annual discharge rate of River Betwa is 10,000 million cum, Kaliasod, Bina, Bahaora, Guhari, and Dhasan Rivers are the major tributaries of this river, draining the total area of about 43,319 km^2. The river is regulated by 3 large dams (Rajghat, Matatila, Paricha) and 2 small dam/weirs in the middle and upper stretch of the river. The basin is saucer-shaped with sandstone hills around its periphery. The topography and elevation (ranging from 700 to 300 m above mean sea level) cause variation in land use, from flat open wheat and gram growing areas to steep forest-covered hills. The average annual rainfall varies from 700 to 1,200 mm with an average annual rainfall of 1,138 mm, the average annual evaporation losses are of the order of 1,830 mm, and the average annual runoff is about 13,430 million m^3, out of which nearly 80% occurs in monsoon.

2 Materials and methods

The present study encompassed 590 km of the Betwa River covering entire stretch from upstream to downstream. Five study sites were selected along the entire stretch of River Betwa has shown in Table 1. Sites were chosen on the basis of accessibility and similarity in physical habitat. The study was carried out during January 2008 to January 2010.These study sites were Bhojpur (Site-B1), Ganjbasoda (Site-B2), Rajghat (Site-B3), Paricha (Site-B4) and Hamirpur (Site-B5). All study sites (approximately 110 km) consists of five sub sites of about 20 km. Among these study station two are located in the upstream (Site-B1 and Site-B2), two in the middle stream (Site-B3 and Site-B4) and one in the lower stream (Site-B5). The locations of sampling sites were documented by using global positioning system.

For physical and chemical parameters analysis random samples of water were collected from subsites of all stub sites in morning of the first week of every month during January 2008 to December 2008. Water depth (cm), water temperature (°C), turbidity (NTU), water flow (cm s^{-1}), conductivity (μ mhos cm^{-1}), total dissolve solid (ppm), pH and substrate type were recorded. Water temperature and conductivity were measured by Cyber Scan water proof PC 300 multiparameter. Water velocity was measured by flow meter (JDC electronics SA; Switzerland). The dominated substrate materials for each sampling site was determined by inspection and striking the River bottom with a bamboo pole. The dominated substrate was expressed in with a numeric code: 0 for silt and clay, 1 for sand, 2 for gravel, 3 for pebble and 4 for cobble (Bain and Stevenson 1999; Sarkar and Bain 2007). The habitat categorization method was followed as per Bain and Stevenson (1999) with little modifications.

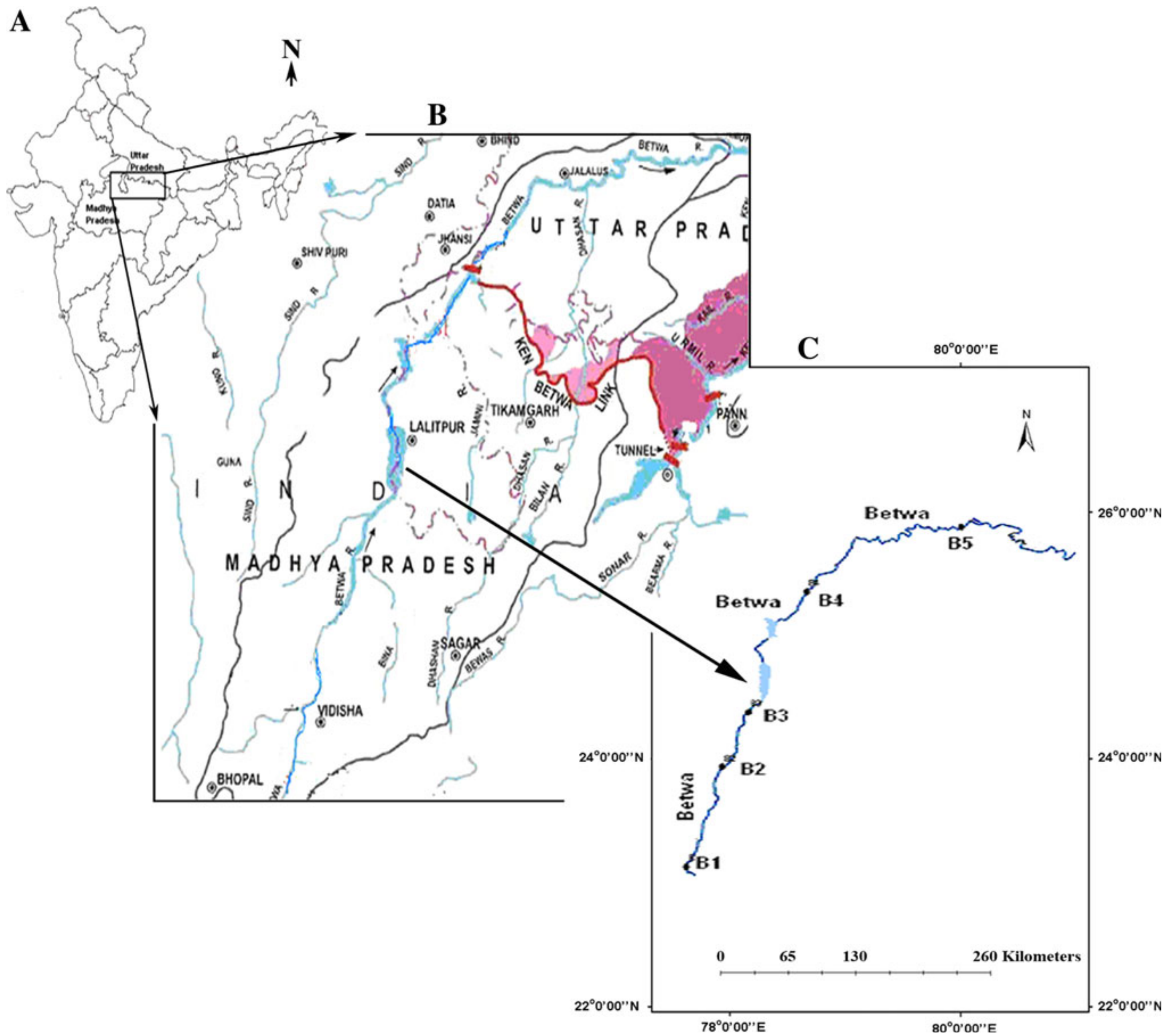

Fig. 1 River Betwa Location and Geographical distribution *a* India's state Map highlighting the Uttar Pradesh and Madhya Pradesh where the River Betwa present. *b* Map of Uttar Pradesh and Madhya Pradesh regions showing River Betwa stretch. *c* Highlighting the geographical distribution of River Betwa and showing sampling sites B1–B5 (Betwa River is proposed to be interlinked with Ken River at B4 site)

Experimental fishing was carried out both by members of the project team as well as by using the expertise of local fisher folk. Daytime (08:00–17:30) and night (19:30–05:00) sampling were carried out at all the five sites on a monthly basis during the study period. Different types of gear including cast nets (9′, 1″; 9′, 1/2″), gill nets (75 × 1.3 m, 2″; 50 × 1 m, 3″; 30 × 1 m, 2.5″), drag nets (all with varying mesh sizes) and other local contrivances were used for collecting the fishes allowing us to sample a range of fish sizes and minimize the bias due to specific gears. Each gear was used at least ten times in all the sites/sub sites during all the four sampling periods (daytime, night) bringing the total effort to 20 per day. For the sake of the present study, fish species richness (FSR) is defined as the number of fish species encountered at least five times in each sampling site.

We classified riverine microhabitat types (Armantrout 1999; Arunachalam 1999; Johal et al. 2002; Manojkumar and Kurup 2002) to determine its relation with FSR. We sampled three sub sites, each of 10–50 m area (considered as replicates) within each available microhabitat at the five study sites and mean values calculated to express the results. Changes in size, form, presence or absence of specific microhabitats at each study site proved a sampling challenge and the area of actual sampling in each microhabitat was restricted to 10 m (minimum) and 50 m (maximum) as the case maybe.

Table 1 Details of the sampling sites of river Betwa along with physical attributes and land use patterns

Sampling sites	Altitude (ft)	Stream segment	Position	Fishing methods	Land use patterns	Habitat type
B1 (Bhojpur)	1,430	Upstream head water	N 18°00.000′ E 77°34.626′	Legal, illegal	Small dams, water lifting pumps, new road construction activities, industrial discharge, temples, rural, small dams/weirs, industries, lifting of boulders, agriculture	SW, ShW, CC, SP
B2 (Ganjbasoda)	1,314	Upstream	N 23°53.063′ E 77°55.133″	Legal	Semi urban area, irrigation dam/weir, barriers, domestic pollution, temple, cremation, cultivation of crops.	OR, SW, ShW, DP, SP,
B3 (Rajghat)	1,162	Midstream	N 23°45.388′ E 78°14.929′	Legal, illegal	Semi urban area, dams with large reservoir, construction activities	OR, SW, DP, SP
B4 (Orcha)	659	Midstream near proposed interlinking site	N 25°20.690′ E 78°38.557′	Illegal	Semi urban, power plant, dams, temple and industrial pollution	FW, R, SHW, SP
B5 (Hamirpur)	260	Downstream confluence point	N 25°86.971′ E 080°80.959′	Illegal, legal	Semi urban, sand mining, discharge of sewage, agriculture	CC, SW, SP

OP open river, *SW* slow water, *DP* deep pool, *SP* scour pool, *CC* channel confluence, *ShW* shallow water, *R* riffle, *FW* fast water

Representative specimens ($n = 10$) of all fish species were fixed in 10% formaldehyde and transferred to the laboratory and stored in glass bottles. We also visited fish markets and landing centers associated with the river system to monitor and look for the presence of any species which were not available during our experimental fishing. They were subsequently identified by following standard literature (Jayaram 1981, 1999; Talwar and Jhingran 1991). All species names adhere to Fishbase (Froese and Pauly 2010) even though primary literature(s) from where they were taken have used outdated or invalid scientific names. Data regarding threats faced by the fish fauna were obtained from both primary (direct observations and interactions with local stakeholders and fishermen) and secondary (journal articles, reports, books, and internet search tools).

The relative abundance (percentage of catch) of fish across different sites was worked out. RA of individual species was calculated by the following formula.

$$\text{Number of samples of particular species} \times 100/\text{Total number of samples}$$

The fish diversity indices were calculated as per standard method (Shannon and Wiener 1963).

$$H = \sum_{i=1}^{n} \left(\frac{n_i}{N} \log 2 \left(\frac{n_i}{N} \right) \right)$$

where H = Shannon–Wiener index of diversity; n_i = total numbers of individuals of species, N = total number of individual of all species.

Similarity of the species in all sampling station was calculated using Jacquard's index:

$$S_j = j/(x + y - j)$$

where S_j is the similarity between any two zones X and Y, j the number of species common to both the zones X and Y, x the total number of species in zone X and y total number of species in zone Y. The similarity in species composition across River has shown as a dendogram in Fig. 4, obtain from the JI coefficients of similarity using the average linkage method. Similarity (Colwell 1996) within the sites was generated by using the EstimatesS (version 8) software. Other analyses were carried out using the Statistica package (Statsoft Inc 1999). The catch per unit effort (CPUE) of the gill net was calculated for each sampling sites following Biswas (1993). Species in a fish community was classified into trophic groups based on feeding habits (Karr et al. 1986; OPEA 1987). By analyzing the gut content we distinguished four types of trophic level, namely planktivores (PL), herbivores (HE), omnivore (OM), and carnivore (CA). The threat status of the fish species mentioned in our results was adapted from Lakra and Sarkar (2007).

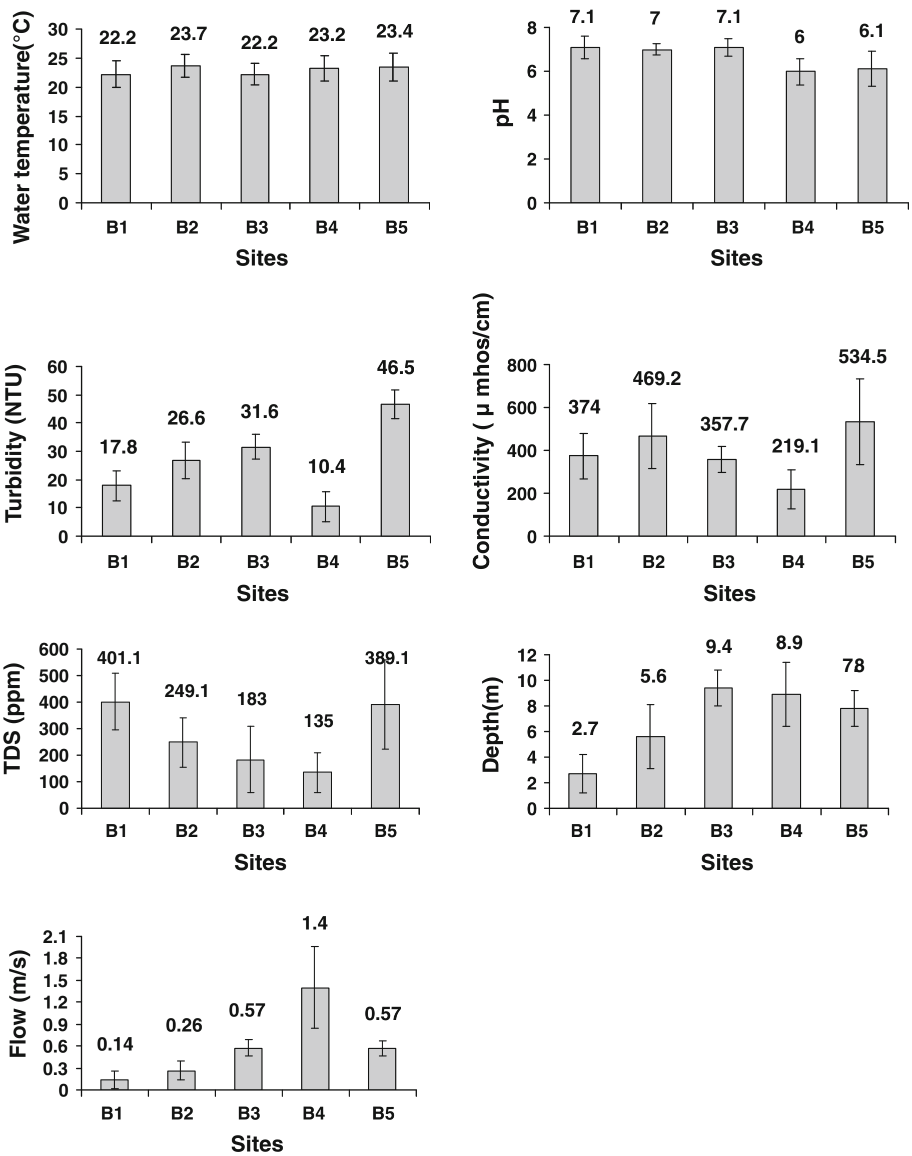

Fig. 2 Site wise variation of some habitat parameters of River Betwa

3 Result

3.1 Physico-chemical parameters

Among habitat attributes, pH, turbidity, total dissolved solid and conductivity, were varying considerably from site to site (Fig. 2), pH was normal at upper stretch, slightly alkaline in site B3 while become acidic in the downstream (B4 and B5). Turbidity, total dissolved solid and conductivity both showed were moderate at B1, high in B2 and B3, while it was very low in B4 and again high at B5 (Fig. 3).

Overall, water depths were averaging 5.5 m with a range from 2.7 to 9.4 m. Depth was high in middle and lower stretch while moderate at lower region of upper stretch (B2) and lower in extreme upper stretch (B1). Water velocity varied from slow (0.14 m s^{-1}) in upstream and lower stream to swift (0.57 m s^{-1}) with a fairly high average of 1.4 m s^{-1} in middle stretch. Substrate ranged from slightly coarser (≥6.5 mm) than pure sand (0.06–1 mm) to a mixture of largely pebbles (16–63 mm) and cobble (64–256 mm). Mean substrate was slightly larger than gravel. Water temperatures (12.1–26.8°C) varied as expected with seasonal climates and averaged 23.8°C. Water transparency varied seasonally and among all sites from highly turbid (46.5 NTU) to quite clear (10.4 NTU) with a moderate average (26.5 NTU).

Like water turbidity water conductivity was varied along all sites ranging from 219.1 μS cm^{-1} in middle stretch to 534.5 μS cm^{-1} in the lower stretch. The pH was ranged from 6.1 to 7.8, showing slightly alkaline to nearly neutral in the upper stretch, however slightly acidic in the middle and lower stretch. The total dissolved solid (TDS) was high

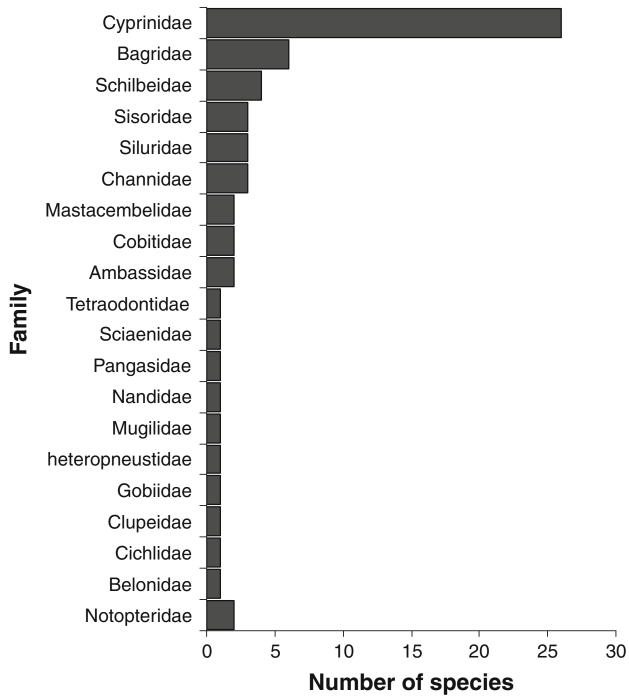

Fig. 3 Diagrammatic representation of the number of species occurring in each family

Table 2 Correlation coefficients (*r*) of fish species with selected hydrological parameters, River Betwa, India

Parameters	Sampling stations				
	B1	B2	B3	B4	B5
Water temperature	−0.66	−0.31	−0.18	−0.57	−0.14
pH	0.35	0.59	0.92	0.37	0.39
Turbidity	−0.99	−0.68	−0.40	−0.86	−0.35
Conductivity	0.75	0.86	0.53	0.34	0.13
Dissolved oxygen	0.96	0.64	0.41	0.89	0.43
Total dissolved solid	−0.74	−0.82	−0.20	−0.79	−0.10
Flow	−0.20	−0.05	−0.39	−0.57	−0.1
Depth	0.58	0.88	0.70	0.21	0.49

along the upper and lower stretch (389.1–401.1 ppm), but like turbidity total dissolve solid was low in the middle stretch. Statistical correlation between fish species richness with selected hydrological attributes (water temperature, pH, turbidity, total dissolved solid, conductivity, depth and flow) indicate that the faster current had negative impact on total number of fish species while depth, dissolved oxygen, and pH showed positive effect (Table 2). Based on the present study, eight major types of fish habitat have been identified along the entire stretch of river: slow water, fast water, riffle, deep pools, scour pool, shallow water, channel confluence and open river (Table 1).

3.1.1 Species diversity, abundance and distribution

The recorded 63 species belong to 7 order, 20 family, and 45 genera (Appendix 1). Cyprinidae is the most abundant family, contributing 41.3% of the fish fauna (Fig. 4) followed by Bagridae (6%) and Schilbeidae (4%), respectively. Cyprinidae, Notopteridae and Bagridae contributes the maximum species in each site (Fig. 5). Perciformes is the most predominated order, contributing to 40% of fish species; Siluriformes is second (30%) most abundant order of the total 7 orders.

The Shannon–Weiner diversity index of five different sampling indicated a strong relationship with overall species richness, showed considerable variation and ranged from 1.89 to 3.51 (Table 3). As expected maximum fish diversity index was observed in upper stretch as compared to lower stretch. The higher fish diversity was recorded from B2 followed by B1, B3, B5 and B4 (Table 3).

The similarity in species composition among the sites was analyzed using the Jaccard index for calculating the extent of similarity between pairs of data sets. The JI value between site B2 and B3 was the highest while it was the lowest for the comparison between site B2 and B4. The similarity in species composition across sites is shown as a dendrogram in Fig. 5, obtained from the JI coefficients of similarity using the average linkage method. B1 and B3 were found to be the least similar while B4 and B5 show the greatest similarity in species composition.

In our study, small indigenous fishes were dominated. At site B1, species like *Gudusia chapra* 7% (310), *Osteobrama cotio cotio* 5.21% (220), *Puntius ranga* 5.09% (215), *Puntius ticto* 4.97% (210) and *Eutropiichthys vacha* 4.7% (200) altogether comprised about 35% of the total. At site B2 *Gudusia chapra* 7.63% (315), *Rita rita* 6.49% (268), *Osteobrama cotio cotio* 6.06% (250) and *Puntius ticto* 5.33% (220) comprised 25.5% total. Similarly at site B3 *Puntius ticto* 10% (320) and *Gudusia chapra* 9.7% (320) both constituted 20.36% of the total fish species, while at site B4 the species were composed of *Osteobrama cotio cotio* 36.6% (205), *Gudusia chapra* 27.6% (155) and *Puntius ticto* 17.86% (460) comprised 82% of total and at site B5 *Gudusia chapra chapra* 13.96% (400), *Puntius ranga* 10.12% (290) and *Salmostoma bacaila* 5.23% (150) comprise 29.31% of total. The site wise relative abundance (RA) of all the species have been shown in Appendix 1. Among three Indian major carps, all were present in all sites except B 4 but the RA was varied. The RA of *Labeo rohita* was relatively higher (2.75%) as compared to *Catla catla* and *Cirrhinus mrigala* which ranged between 1.33% and 1.21%. The RA of medium carp *Labeo calbasu* was low (1%) among all sites. Among the eight endangered species as shown in Appendix 1, two (*E. vacha* and *Ompok bimaculatus*) showed relatively higher RA in sites B1 to

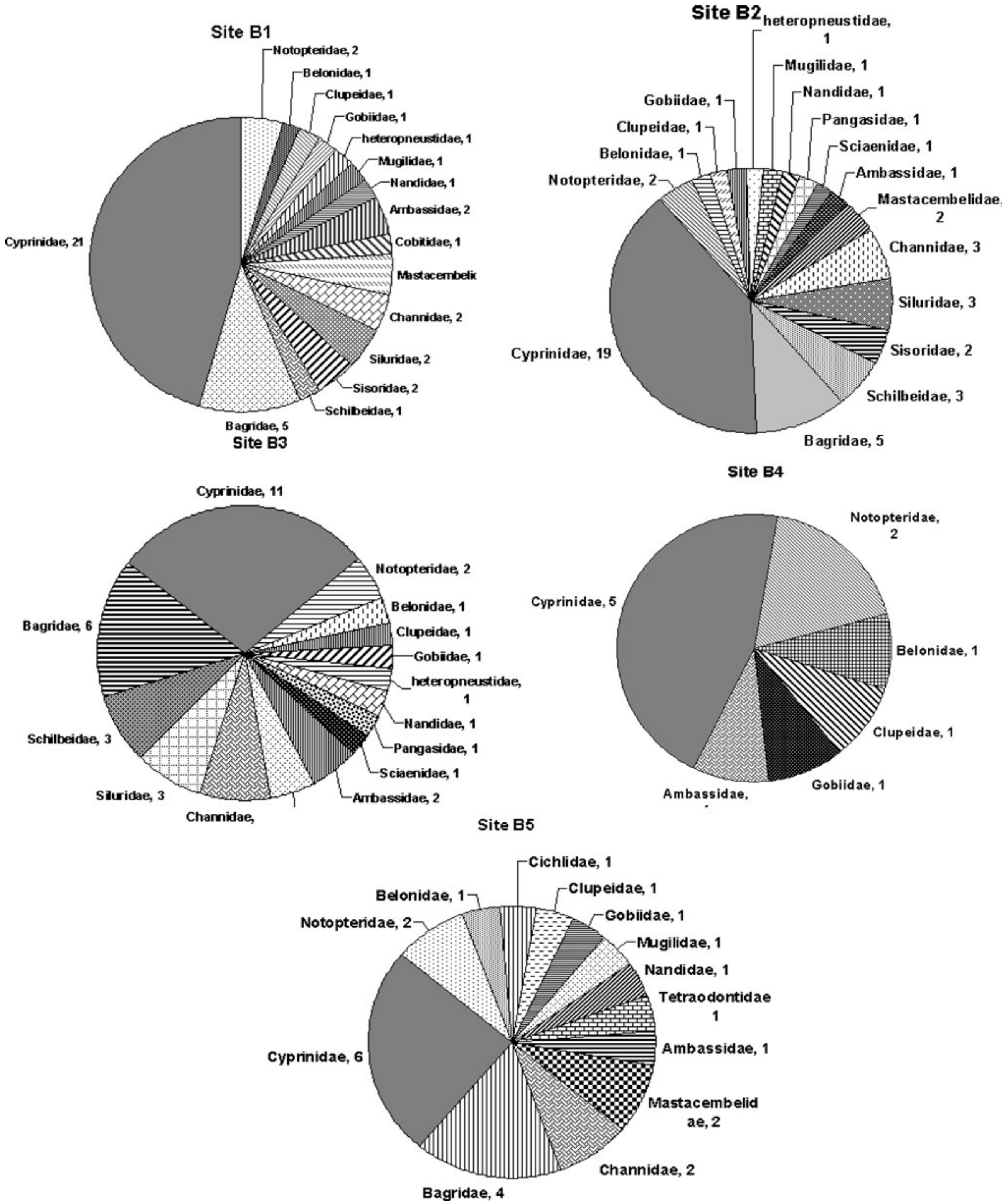

Fig. 4 Site wise representation (pie chart) of the number of species occurring in each family

B3. The RA of *Ompok pabda* was moderate (0.64–1.33) in upper stretch and selected site (B3) in middle stretch, while the remaining five species showed low RA and their accessibility was only confined in the upper and middle stretch. RA of some other conservational important species viz. *C. mrigala, Garra gotyla, Puntius sarana* and

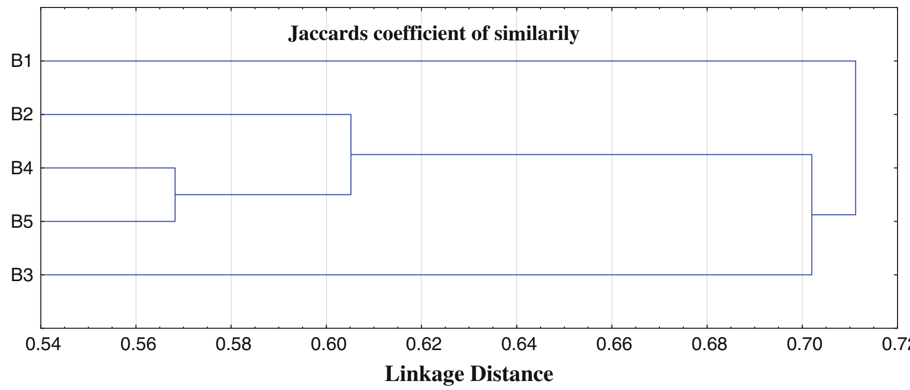

Fig. 5 Dendogram showing similarity in species composition across five sampling station based on Jaccard index

Table 3 Site wise of species diversity, Shannon–Weiner index and mean CPUE

Sampling station	Species diversity	Diversity index	c.p.u.e (kg/h)
B1	47	3.44	1.95
B2	50	3.51	3.1
B3	46	3.42	2.71
B4	11	1.87	0.62
B5	28	2.94	0.93

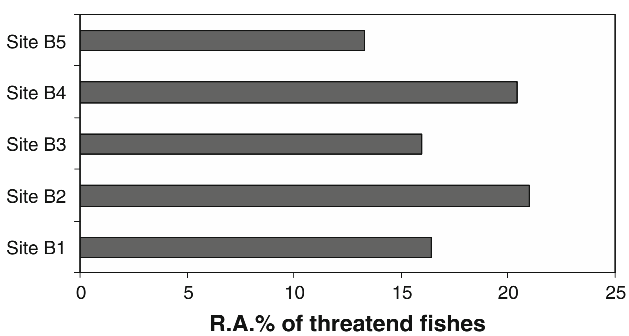

Fig. 6 Relative abundance of threatened fish across five sampling stations

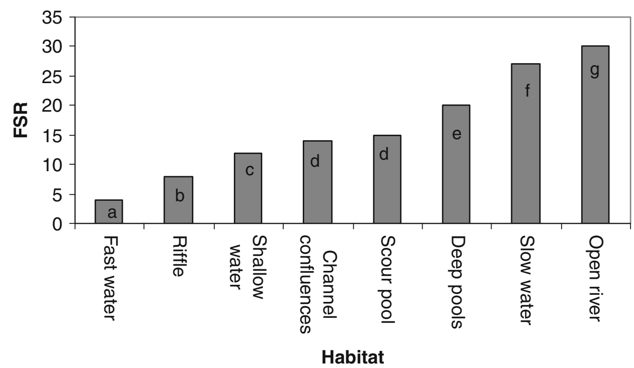

Fig. 7 Habitat wise fish species richness (FSR) in River Betwa. *Bars with different superscript letters* are significantly different ($P < 0.05$)

Clupisoma garua were medium and their distributions were restricted in the upper and middle stretch. The analyses of variance between RA of threatened species along the sites indicated no significant difference (Fig. 6). Among exotic species *Cyprinus carpio* and *Oreochromis mossambicus* was recorded only from the lower stretch with RA ranging 1.78–3.49% indicating threat to native species in this River.

In our study the species richness between different sites showed significant difference (95% CI of diff) except B1, B2, and B3. Maximum richness was recorded in upper stretch, followed middle stretch, while considerably low species richness was recorded from lower stretch. Maximum difference in richness was found between B2 and B4 (95% CI of diff 33.17 to 40.43) while least between B3 and B5 (95% CI of diff 13.57 to 20.83).

Considerable difference was noticed in the fish species richness (FSR) in different habitat classes (Fig. 7). Except two habitat classes (channel confluence and scour pool) the FSR of remaining habitat was significantly different ($P < 0.05$). Maximum FSR was obtained in open river ($n = 30$), slow water ($n = 27$) and deep pool ($n = 20$), respectively while very low FSR was recorded in fast water ($n = 4$) and in riffle ($n = 8$). Moderate FSR was observed in scour pools ($n = 15$). Among habitats, open river and slow water were home to a rich assemblage of cyprinids, silurids and notopterids. The domination of open River and slow water habitat were recorded mostly in the upper stretch and genera like *Labeo, Catla, Chitala, Ompok, Mystus, Wallago, Silonia, Bagarius, Notopterus* and *Puntius* were common in this habitat. Endangered fish *E. va*cha (a Schilbeid), *T. tor* (a Cyprinid) and *C. chitala* (a Notopterid) were mainly confined to only deep pools which was the most common habitat of site B2 of upper stretch and B3 of middle stretch. Fast water habitat represented very low FSR ($n = 4$).

The distribution of fish showed interesting pattern and only 7 species were found common in all the sites indicating long range of distribution (Appendix 1). However, some of the species (*Barilius bendelisis, Lepidocephalus guntae, Tor tor, Acanthocobitis botia*, *Glyptothorax brevipinnis* and

Chagunius chagunoi) showed very restricted distribution and collected only from single location. Among migratory fishes, a total of seven species were captured. The distribution of migratory fishes was varied along the stretch. *Tor tor, Bagarius bagarius, Pangasius pangasius, Silonia silondia* and *Sperata aor* were moved mainly in the upper and middle stretch of River (above dam) while *Chitala chitala* and *Notopterus notopterus* were recorded throughout the River.

Evaluation of the commercial utilization of fishes of River Betwa indicated that River Betwa is rich in supporting many food fish (89.47%), ornamental fish (49.12%) and sport fish (5.26%) as shown in Appendix 1. Among the fishes collected from entire stretch a uniform pattern of utilization of trophic ecology (feeding habit) was observed. Omnivorous fishes were dominated (58–70%), followed by carnivorous (18–28%), herbivorous (7–15%) and planktivorous (3–18%), respectively. The average c.p.u.e. (catch per unit effort) of all sites was ranging between 0.62 and 3.1 kg $h^{-1}man^{-1}$ with the highest value from B2 and lowest from B 4 (Table 3). Among fishing gears utilized by the local fisherman gill net, drag net and cast net of different mesh size was dominated.

3.1.2 Conservation status

Based on our study we have divided the threat status of the fishes of Betwa River into three categories: endangered (EN), vulnerable (VU) and low risk (LR) (Appendix 1). The threat status of River Betwa suggests that at least 34.92% of fish fauna is threatened by either being VU or CR. Out of 63 species, the status of 10 was not known due to data deficiency (DD), among the remaining fifty-three species 29 categorized as LR, 14 as VU, 8 as EN while the remaining two species were introduced (Appendix 1).

4 Discussion

The present study revealed that the physical habitat variables play key role in the distribution of fishes in River Betwa and the habitat alteration and fragmentation brought about significantly to the endangerment of freshwater fish fauna. We observed that among habitat attributes, water depth, dissolved oxygen and pH are key habitat features and positively correlated with the fish assemblages and found the most important variables in shaping fish distributions. The variations in the habitat attributes like pH, turbidity, total dissolved solids and conductivity across different sites was attributed to differences in land use pattern, which was responsible for variation of species diversity and distribution (De Silva et al. 2007). Similar pattern of habitat attribute has been observed by Lobb and Orth (1991); Aadland (1993) and Shahnawaz et al. (2010). Recently, the significance of habitat was endorsed by Peres-Neto (2004) with evidence suggesting species occurrence are driven more by relationship with abiotic factor than species interaction.

The present study is the first of its kind for the River Betwa on fish diversity and conservation priority in view of proposed interlinking. Our study depicted presence of 63 species contributing about 56.75% of total fish diversity published from Uttar Pradesh (Srivastava 1988), and about 45.65% icthyofauna from Madhya Pradesh (Lakra and Sarkar 2007). The diversity in terms of number (63 species) observed in the present study was 8 species greater than that reported by Adholia (1977) which might be attributed to very limited study areas covered in earlier report. The diversity recorded in the present study lesser than a recent report from other tributaries of River Ganga (Sarkar and Bain 2007; Sarkar et al. 2009). Due to lack of previous information on fish diversity from this river it is not possible to quantify the rate of decline in fish diversity but the present study would be useful as baseline data for any future assessment after interlinking. Most importantly, our study indicate considerable share in supporting fish biodiversity in the region despite alterations like damming and habitat degradations.

Fish communities in riverine system typically follow a pattern of increasing species richness, diversity and abundance from upstream to downstream (Welcomme 1985; Bayley and Li 1994; Granado 2000). However, the current pattern of species richness, diversity and abundance of fishes contrasts sharply with the typical pattern. Species diversity, species richness both were lowered in the lower area in this study compared with the upper area (Habit et al. 2006). This pattern is unlikely to result from sampling variation, because the same sampling gears were used in studies The pattern found in this river suggests cumulative temporal and spatial effects of habitat loss or environmental degradation in the lower zone (Scrimgeour and Chambers 2000; Wolter et al. 2000). Although the upper and middle stretch of the river is fragmented due to lack of water, damming, and multiple water use but supported more species as compared to downstream might be due to positive influence of reservoirs connected with the river in this region as well as due to existence of more open river, slow water and pool habitats along with macrophytes which might have importance in fish assemblage and aggregation (Growns et al. 2003; Raghavan et al. 2008a, b). Open river habitat were the most preferred habitat for fishes inhabited in the tropical rivers (Sarkar et al. 2010; Lobb and Orth 1991; Aadland 1993; Arunachalam 2000) was also evident in River Betwa. The reason of low species richness at site B4 and B5 might be due to effect of discharge from the thermal power plant, high water velocity degraded shore line habitat, high sedimentation rate, pollution, industrial west water discharge, illegal exploitation of fishes, and exotic species. Sreekantha and Ramachandra (2005) recorded the low fish richness due to degradation of breeding ground from Linganamakk reservoir on Sharavathi Rive, India. According to Bunn and Arthington (2002) many types of river ecosystem have been lost and populations of many riverine species have become highly fragmented due to human intervention. Values of Jaccard similarity indices were high among undisturbed sites (B1, B3 and B3) while low at disturbed sites (B4 and B5) (Specht and Paller 2004). High value of CPUE was recorded from upper and middle stretch which might be due to presence of more deep pools, low to moderate water velocity corroborating the reports of Boruah and Biswas (2002) from River Brahmaputra and Flores and others 2009 from a tributary stream of the Paranas River, Argentina.

The analysis of the trophic structure of the fishes indicate dominancy of omnivorous fishes in all sites followed by carnivorous herbivorous and planktivorous fish depicting similar findings as per Fu et al. (2003); Das and Chakrabarty (2007) reported from Yangtze River basin of China and two tropical river of India, respectively. Based on the study of trophic level of fishes it appears that omnivores are often the most tolerant of degradation or ecosystem dysfunction because they are able to consume food from a wide variety of sources in a changing ecosystem (Wichert and Rapport 1998) and this may be useful to assess quality of the fish habitat. Dominancy of carnivorous fishes was observed in the Western Ghats (Das 2007) and Ganga basin (Sarkar et al. 2010).

The threat of exotic species on the indigenous fish species of River Betwa was relatively low except in lower stretch (below dam). Sarkar et al. (2010) found that the higher relative abundance and distribution of exotic species indicate threat to the other local species due to their establishment in the River. This may cause difficulty to manage other species of conservation importance in the River and may become more challenging due to the interaction of climatic changes (Rahel et al. 2008). Corbacho and Sanchez (2001) reported that, threat of introduced species also increase along with the increment of canalization and regulation (dam) of river, both are directly proportional with each other in the Guadiana River (southwest Iberian Peninsula).

5 Conclusion

Variation in species diversity in different sampling sites indicated that altered habitat support less biological communities while less disturbed sites are characterized by a diverse fish fauna in a variety of habitat. Our habitat study

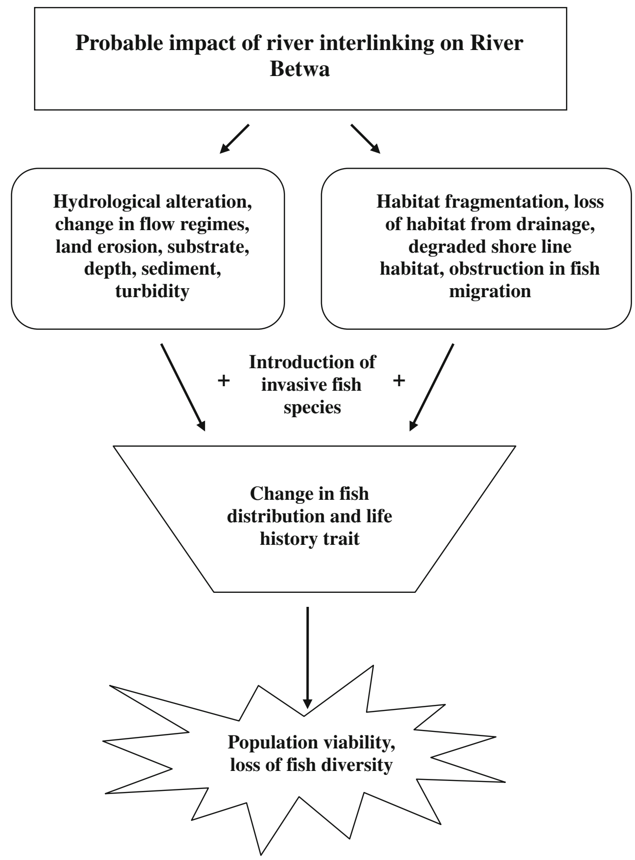

Fig. 8 Probable impact of river interlinking on the fish diversity of River Betwa

shows that open river, shallow water and deep pools are the primary habitats contributing to the maximum diversity, therefore, protection of these particular habitats is recommended for conservation and management of the fish biodiversity. As our data on the utilization of trophic ecology showed dominancy of omnivores fishes and more precisely in the lower stretches indicating that this model may be useful for assessing altered as well as less altered fish habitat of the tropical rivers. Habitat fragmentation by damming has serious consequences in terms of alternative life history strategies (Shaffer et al. 2009; Morita et al. 2009; Motita and Yokota 2002). Most fish in the dammed- off area do not migrate through out the river in search of suitable nursery ground and instead become resident forms. This loss of diadromous form negatively affects populations through decreased spawning biomass. Some other potential impacts of interlinking may be: change in flow regimes, substrate, depth, changes in sediment and nutrition transport, loss of habitat and many unknown consequences. Many of these effects of habitat fragmentation due to damming are not immediate but rather occur gradually over several generations (Yamamoto and others 2004; Fukushima et al. 2007). Here, we summarized the probable interlinking induced changes on the habitat as well as on fish population (Fig. 8).

Effective strategies can be taken up the conservation agencies for sustaining biodiversity. A more refined biotic assessment program is required for effective protection of freshwater fish resources. Our assessment showed uses of specific habitat classes across spatial scale related to species richness and diversity and also structuring of trophic ecology of the fishes at different spatial scales which could be useful to assess the integrity of an aquatic ecosystem. This study allows consideration of a long-term conservation strategy for icthyo fauna in the Betwa River. Our study suggests that Betwa is very important river for fresh water fish diversity in the region. Since this River will be interlinked in near future, our study may be beneficial for further environmental bioassessment.

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Appendix 1

See Table 4.

Table 4 Diversity of fish species, threat status, total mean length and relative abundance of fishes of River Betwa

Family/species[a]	Threat status[b]	Total nos.	Total length (cm)		RA (%)					
			Max	Min	B1	B2	B3	B4	B5	Total
Notopteridae										
Chitala chitala (Hamilton–Buchanan)[‡,†]	EN	50	83	24.2	0.35	0.48	0.18	0.89	0.14	0.33
Notopterus notopterus (Pallas)[‡,†]	EN	40	30.4	13.1	0.24	0.29	0.33	0.89	0.07	0.27
Clupeidae										
Gudusia chapra (Hamilton–Buchanan)[‡]	VU	1,500	13.9	5	7.34	7.63	9.72	27.68	13.96	9.95
Cyprinidae										
Aspidoparia morar (Hamilton–Buchanan)[†]	LRnt	12	18	12.7	0.14	0.19	00	00	00	0.08
Barilius bendelisis (Hamilton–Buchanan)[1,†]	LRnt	12	16.2	14	0.28	00	00	00	00	0.08
Catla catla (Hamilton)[†]	VU	200	45.7	28	1.42	1.33	2.58	00	00	1.33
Chagunius chagunio (Hamilton–Buchanan)[2,†]	DD	10	23	11.7	00	0.24	00	00	00	0.07
Cirrhinus mrigala (Hamilton–Buchanan)[†]	LRnt	182	44	18	1.18	1.57	2.04	00	00	1.21
Cirrhinus reba (Hamilton–Buchanan)[†]	LRnt	35	*22*	15.4	0.35	0.48	00	00	00	0.23
Cyprinus carpio[†]		51	*39*	21	00	00	00	00	1.78	0.34
Garra gotyla gotyla (Gray)[‡]	VU	275	9.4	5.6	1.89	2.42	2.89	00	00	1.82
Labeo bata (Hamilton–Buchanan)[†]	LRnt	309	33	13.8	2.37	2.91	2.70	00	00	2.05
Labeo boggut (Sykes)[†]	LRnt	250	9	29	4.61	1.33	00	00	00	1.66
Labeo calbasu (Hamilton–Buchanan)[†]	LRnt	150	58.1	12	0.95	1.09	1.28	00	0.8	1.00
Labeo dyochilus (Mc Clelland)[†]	VU	25	41	16.5	00	0.24	0.33	0.71	00	0.17
Labeo gonius (Hamilton–Buchanan)[†]	LRnt	200	29.2	14.3	1.47	1.57	1.06	1.33	00	1.33
Labeo pangusia (Hamilton–Buchanan)[3,†]	DD	15	26	21.8	00	00	0.46	00	00	0.10
Labeo rohita (Hamilton–Buchanan)[†]	LRlc	415	49.1	7.8	2.96	4.72	0.91	2.27	00	2.75
Osteobrama cotio cotio (Hamilton–Buchanan)[‡]	LRnt	905	14	7.3	5.21	6.06	6.99	36.61	00	6.00
Puntius amphibious (Valenciennes)[1,‡]	DD	430	15.2	14.8	1.18	00	00	00	00	2.85
Puntius chola (Hamilton–Buchanan)[‡]	VU	370	12.2	8.8	3.43	4.84	0.76	00	00	2.45
Puntius sarana sarana (Hamilton–Buchanan)[†,‡]	VU	370	21	5.2	2.15	2.42	2.13	00	00	2.45
Puntius sophore (Hamilton–Buchanan)[†,‡]	LRnt	170	9.3	6.1	0.83	00	1.52	3.57	2.27	1.13
Puntius ticto (Hamilton–Buchanan)[‡]	LRnt	1,158	8.7	4	4.97	5.33	10.64	17.86	9.7	7.68
Raiamas bola (Hamilton–Buchanan)[†]	DD	12	24.8	21.1	0.17	00	0.15	00	00	0.08
Rasbora daniconius (Hamilton–Buchanan)[†,‡]	LRlc	459	12.5	4.2	3.55	3.39	00	00	9.39	3.05
Salmostoma bacaila (Hamilton–Buchanan)[†]	DD	560	15.4	5.9	2.01	5.21	3.34	00	5.23	3.72
Securicula gora (Hamilton–Buchanan)[3,†]	DD	73	20.1	19.3	00	00	2.22	00	00	0.48
Tor tor (Hamilton–Buchanan)[2,†,‡,$]	EN	7	26.9	22.1	00	0.17	00	00	00	0.05
Balitoridae										
Acanthocobitis botia (Hamilton)[1,‡]	EN	35	8	4.3	0.83	00	00	00	00	0.23

Table 4 continued

Family/species[a]	Threat status[b]	Total nos.	Total length (cm)		RA (%)					
			Max	Min	B1	B2	B3	B4	B5	Total
Cobitidae										
Lepidocephalus guntea (Hamilton–Buchanan)[1,‡]	LRlc	110	7	4.6	2.60	00	00	00	00	0.73
Bagridae										
Sperata aor (Hamilton–Buchanan)[†,$]	LRnt	99	45	10.6	00	0.85	1.22	00	0.84	0.66
Sperata seenghala (Sykes)[†,$]	LRnt	82	73.2	15	0.24	0.87	0.79	00	0.35	0.54
Mystus cavacius (Hamilton–Buchanan)[†]	LRnt	115	22	11.3	1.18	0.97	0.76	00		0.76
Mystus tengara (Hamilton–Buchanan)[†]	DD	483	17.2	12.3	3.60	4.84	2.28	00	1.95	3.20
Mystus vittatus (Bloch)[†,‡]	VU	110	14.5	4.2	1.54	00	1.37	00		0.73
Rita rita (Hamilton–Buchanan)[†]	EN	559	24	7.4	3.55	6.49	0.36	00	4.5	3.71
Siluridae										
Ompok bimaculatus (Bloch)[†]	EN	250	36.4	8.7	2.6	1.96	1.79	00	00	1.66
Ompok pabda (Hamilton–Buchanan)[†]	EN	120	14.5	8.2	1.06	1.33	0.61	00	00	0.80
Walago attu (Bloch and Schneider)[†,$]	LRnt	105	75.9	22.8		0.97	1.98	00	00	0.70
Schilbeidae										
Ailia coila (Hamilton–Buchanan)[‡]	VU	30	12.8	8.4	00	0.48	00	00	00	0.20
Eutropiichthys vacha (Hamilton–Buchanan)[†]	EN	589	32.4	10.2	4.73	6.27	3.95	00	00	3.91
Clupisoma garua (Hamilton–Buchanan)[†,$]	VU	153	45	9.2	00	1.45	2.83	00	00	1.02
Silonia silondia (Hamilton–Buchanan)[3,†,$]	LRnt	78	46	32	00	00	2.37	00	00	0.52
Pangasidae										
Pangasius pangasius[†,$]	LRnt	11	62	41	00	0.17	0.12	00	00	0.07
Sisoridae										
Bagarius bagarius (Hamilton–Buchanan)[2,†]	VU	54	112.8	15	0.28	00	00	00	00	0.36
Gagata cenia (Hamilton–Buchanan)[†]	DD	113	10.1	6.1	1.18	1.53	00	00	00	0.75
Glyptothorax brevipinnis (Hora)[2,‡]	DD	25	7.2	6.7	00	0.61	00	00	00	0.17
Heteropnustidae										
Heteropneustes fossilis (Bloch)[†]	VU	65	28	14.2	0.62	0.36	0.73	00	00	0.43
Belonidae										
Xenentodon cancila (Hamilton–Buchanan)[†,‡]	LRnt	89	31.5	21.2	0.24	0.36	0.76	1.07	1.15	0.59
Ambissidae										
Chanda nama (Hamilton–Buchanan)[‡]	LRlc	785	10.2	3.8	3.43	4.84	3.34	1.79	7.33	5.21
Parambassis ranga (Hamilton–Buchanan)[‡]	LRlc	800	5.2	4.5	5.09	00	8.96	00	10.1	5.31
Sciaenidae										
Johinus coitor (Hamilton–Buchanan)[†]	DD	35	21.5	18.6	00	0.51	0.43	00	00	0.23
Nandidae										
Nandus nandus (Hamilton–Buchanan)[†,‡]	LRnt	116	18.2	15.1	0.83	0.48	0.97	00	1.01	0.77
Cichlidae										
Oreochromis mossambicus (Peters)[†]		100	22.1	18.4	00	00	00	00	3.49	0.66
Mugilidae										
Rhinomugil corsula (Hamilton–Buchanan)[†,‡]	VU	250	39	8.1	2.37	1.57	00	00	2.97	1.66
Gobiidae										
Glossogobius giuris (Hamilton–Buchanan)[†,‡]	LRnt	600	14.2	8.6	2.37	2.66	4.62	8.93	6.56	3.98
Chandadae										
Channa marulius (Hamilton–Buchanan)[†]	VU	225	56.9	15.3	1.06	1.21	1.98	00	2.27	1.49
Channa puntatus (Bloch)[2 †]	LRnt	104	26	16.2	00	1.11	1.76	00	00	0.69
Channa striatus (Bloch)[†]	LRnt	265	18	10.5	1.18	1.09	2.13	00	3.49	1.76
Mastacembelidae										
Macrognathus pancalus (Hamilton–Buchanan)[‡]	LRnt	120	21	9.4	1.06	0.85	0.30	00	0.17	0.80

Table 4 continued

Family/species[a]	Threat status[b]	Total nos.	Total length (cm)		RA (%)					
			Max	Min	B1	B2	B3	B4	B5	Total
Mastacembalus armatus (Lacepede)[†,‡]	VU	150	54	14.38	0.59	0.87	0.30	00	2.76	1.00
Tetraodontidae										
Tetrodon cutcutia[5,‡]	LR-nt	118	5.98	4.7	00	00	00	00	4.12	0.78

EN endangered, *VU* vulnerable, *DD* data deficient, *LRnt* lower risk near threatened, *Lrlc*, low risk least concern

[a] Taxonomic status adapted from Talwar and Jhingran (1991)

[b] Status adapted from Lakra and Sarkar (2007)

[1] Species found only in sampling station B1

[2] Species found only in sampling station B2

[3] Species found only in sampling station B3

[5] Species found only in sampling station B5

[†] Food fish, [‡] ornamental fish, [$] sport fish

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