DOI: 10.22092/ijfs.2018.118930.

Fish assemblages and habitat ecology of River Pinder in central Himalaya, India

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Received: January 2016 Accepted: November 2016

Abstract

Snow-fed River Pinder -a tributary of River Alaknanda in central Himalaya was explored for fish assemblages and habitat specificity. Altogether 27 fish species were reported from three orders, four families and nine genera. Cypriniformes order was dominating followed by Siluriformes and Salmoniformes. Shannon-Weiner diversity index (3.09 to 4.10) and Simpson index of diversity (0.81 to 0.92) of four sites specified strong relationship with species richness. The distribution of fish species showed interesting patterns, 33% species were common to all four sampling sites while 14.80% were restricted to single site and the remaining species were randomly distributed among two or three sampling sites. Habitat variability in the river significantly influenced the species assemblage structure. About 7.40% species were found common to all habitats while 3.70% species were restricted to only single habitat type. The remaining 88.90% of species were dwelling between two to three habitat types. Deep pools recorded maximum species richness followed by shallow pools, while least species richness was recorded in cascade habitats. The conservation status of fish fauna of the river was ascertained by CAMP (Conservation Assessment and Management Plan). Out of 27 species, the status of 8 species was not assessed due to data being deficient, 7 species were categorised as lower risk near threatened, 6 as vulnerable, 5 as endangered while 1 species was exotic.

Keywords: Fish assemblage, Habitat ecology, Fish diversity, Conservation, Himalayan River

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Introduction

The understanding of fundamental characteristics of biological assemblages is the first step toward the development of effective conservation policies. The assemblage composition pattern of fishes and their relationships to biotic and abiotic factors is very important. The distributional patterns of fishes are controlled by dispersal mechanism, historical factors (connecting pathways, dispersal barriers) and tolerance to environmental factors (Carter *et al*., 1980). The climatic conditions, geological vegetation, land use and topographic conditions in a basin determine the hydrology and chemistry of waters with direct effects on the stream organisms (Wiley *et al*., 1997).

Multiple factors are thus associated with distributional pattern and composition of fish assemblages. The river size (surface area and mean annual discharge of river) and availability of energy are two important factors influencing fish species richness patterns (Oberdorff *et al*., 1995). Some biological factors like competition and predation are also important dependable factors for species richness (Grossman, 1982; Moyle and Vondracek, 1985). Nevertheless, according to Gorman and Kar (1978) some physical factors like habitat heterogeneity is an important factor controlling species richness and distributional pattern. Along with these factors, some other important factors viz. physico-chemical attributes, water temperature, flow regime and channel morphology also play a crucial role in the distribution of fish species (Schlosser, 1982). The river continuum concept (Vannote *et al*., 1980) proposed that aquatic communities exhibit predictable variations according to their longitudinal position within a hydrographic basin. Unfortunately on the global scale over the last century, various riverine ecosystems have endured from intense human interventions and natural disasters resulting in habitat loss and degradation, alteration in hydro chemistry and river geomorphology. The riverine ecosystem of the upper Ganga River basin in central Himalaya is also degrading continuously as a consequence of human interventions and natural cataclysmic events in the past. This continuous degradation is proving highly detrimental for many of the inhabitant fish species (Agarwal *et al*., 2011). According to Kerr (1997), when anthropogenic manipulations result in threatening habitats, the understanding of species richness patterns is critical in facilitating the choice of species and habitats for their conservation.

The River Pinder, an important tributary of river Alaknanda of the Ganga river River system in the Himalayan region (Garhwal) of India is also affected by a number of alterations due to human intervention and natural cataclysmic events (land sliding, cloud bursting and flooding). The river characteristics governing the distributional patterns of aquatic fauna are thus altering. In fact these alterations may possibly distress the patterns of distributions of resident fish fauna of this river. Studies on the distributional pattern of fish assemblages have been conducted in the western Ghat (India) (Arunachalam, 2000; Bhat, 2004) while the upland of Garhwal remained unnoticed. However, River Pinder was explored three decades earlier only from the viewpoint of its fish diversity (Badola, 1979; Singh *et al*., 1987). Thus the present study on River Pinder has been conducted to understand the distributional patterns of fish fauna in the uplands of Garhwal Himalaya (India). Besides, the study also aimed to know the current status of fish fauna with information on important physico-chemical attributes of the river.

Materials and methods

Study area

The study was conducted on a snow-fed Himalayan River Pinder (latitude 30^0 15.48'N, longitude 79^0 13.10'E) - a major left bank tributary of River Alaknanda of the upper Ganga river system in India. It originates from the Pindari Glacier (5200 masl) lying between Nanda Devi and Nanda Kot peaks. Thereafter, the river maintains a east-west direction and travels ~124 km before merging with river Alaknanda at Karanprayag (760 m asl). It cuts a gorge in thick glacial deposits for nearly 10 km. In the upper reaches, the river has a steep gradient and flows through sedimentary rocks and large boulders, thereafter it meanders through quart schists. Important tributaries joining River Pinder are Kail Ganga, Pranmati, Meing, Kewar, Chopta and Ata Streams. Four sampling sites viz. S-1, S-2, S-3 and S-4 were selected covering the middle and lower stretches of the river (Table 1, Fig. 1) considering heterogeneity in habitat and substratum, altitudinal gradient and hydro chemistry.

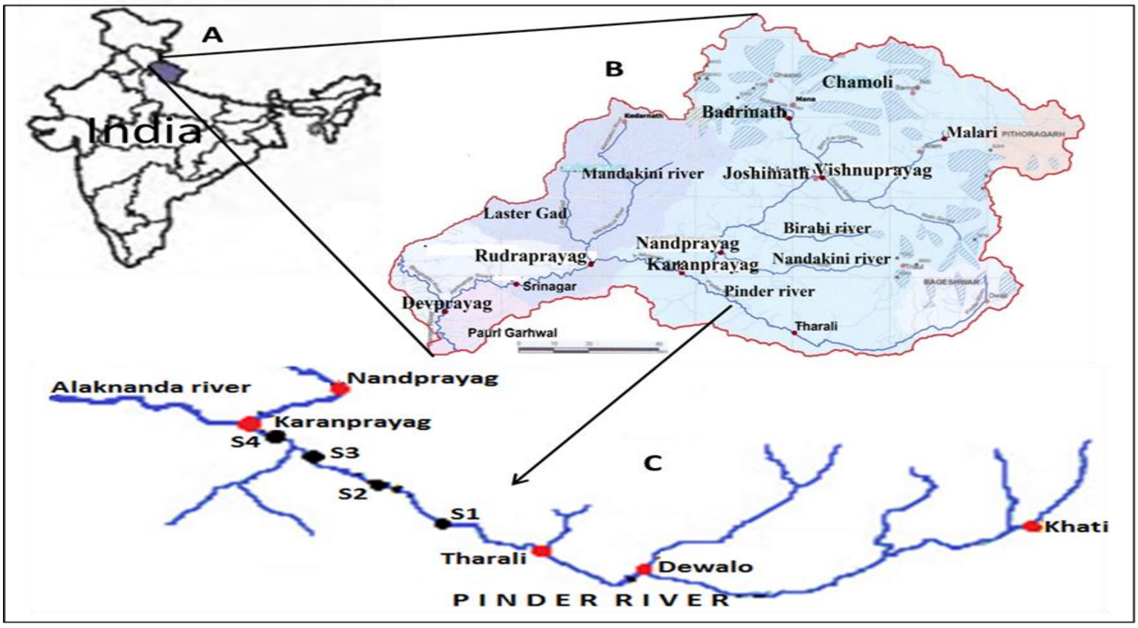

Figure 1: Geographical location of Pinder River and sampling sites, A) India map showing Uttarakhand state, B) Alaknanda river system in central Himalaya, C) Sampling sites located along the Pinder River.

Table 1: Description of sampling sites.

Sampling sites	Location	Altitude	Dominant Habitat types
S-1	Naryan bagar	846 m sl	Cascade and rapids
S-2	Nauli	820 m sl	Rapids and riffles
S-3	Simli	793 m sl	Riffles and runs
S-4	Karanprayag	762 m sl	Run, riffles and pools

Fish collection

Experimental fishing was done bi-monthly during the period 2011-2013. The fishing is performed by cast nets (dia 1-2 m and mesh size 1.8 cm) and gill nets (mesh size 1.2 x 1.2 cm, L x B, 12 x 1.0 m). The region specific traditional fishing methods viz. baur or phans, atwal, goda, hammering, hooks and hand picking, were also used (Singh and Agarwal, 2014). Fish samples from different study sites were preserved separately in 10% formalin for taxonomic identification based on morphometric, meristic and descriptive characteristics following Day (1958), Talwar and Jhingran (1991), Badola (2009) and Jayaram (2010).

Physico-chemical attributes and Habitat characteristics

For the analysis of physico-chemical attributes, water sample were analysed on the spot at each study site. Water temperature was measured using a mercury thermometer with a range of 0-50 ^{o}C. Water velocity was measured by the float method. pH was measured using a digital pH meter. Dissolved oxygen, free CO_2, total alkalinity, turbidity and TDS were analysed following APHA (2005). Substratum type at various sampling sites was classified into large boulders, small boulders, cobbles, coarse gravels, fine gravel and sand. The stream habitat was classified by following Armantrout (1999) as pool (shallow and deep pool), riffle, rapid, run and cascade type of habitat. Classification of habitat types and their description during the study is outlined in Table 2.

Table 2: Various habitat types with their description

Habitat Type	Description
Pools	A segment of the stream with reduced current velocity, depth exceeding than surrounding habitats.
Run	An area of swiftly flowing water with gradient over 4% with minor surface agitation and in which slope of the water surface is roughly parallel to the overall gradient of the stream.
Riffles	A relatively shallow area with gradient less than 4% with swift flowing water completely or nearly covering obstructions and substrate of smaller rock gravel or bedrock having surface or subsurface agitation.
Rapid	A relatively deep stream section with swift currents and gradient exceeding 4% resulting in series of short drops, considerable surface agitation, pocket pools and rock and boulders exposed at all but high flows
Cascade	An area of continuous stepping with low water depth and swiftly flowing water.

[DOR: 20.1001.1.15622916.2019.18.1.1.6]

Data analysis

The relative abundance (RA) of fish species across the study sites was worked out by the following formula.

RA = Number of samples of particular species×100/Total number of samples.

The fish species diversity indices at each site was calculated following Simpson (1949)

$$D = 1 - \sum \frac{ni(ni-1)}{N(N-1)}$$

Where, ni=the total number of individuals of a particular species; N= the total number of individuals of all species.

The Shannon and Wiener (1963) diversity index was also calculated for each sampling site.

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

Where H=Shannon- Wiener index of diversity; n_i=total numbers of individuals of species, N=total number of individuals of all species.

Bi-variant Pearson Correlation coefficient of various physico-chemical attributes with fish species richness was calculated by using statistical software SPSS version 10.0.

Results

Species diversity and abundance

Twenty seven fish taxa, representing four families and three orders were recorded. Cypriniformes was the dominating order which included 77.78% of fish species followed by Siluriformes with 18.52% and Salmoniformes with 3.70% of fish species. Among the families, Cyprinidae was the dominating family (15 species) followed by Cobitidae (6 species), Sisoridae (5 species) and Salmonidae with 1 species (Table 3). Maximum fish diversity was recorded from sampling site S-3 followed by S-4, S-2 and S-1, respectively. The Shannon-Weiner diversity index and Simpson diversity index of four different sites specified strong relationship with overall species richness and showed considerable variation. The Shannon Weiner diversity index ranged from 3.10 to 4.10 and Simpson diversity index ranged from 0.81 to 0.92 (Table 4). The fish assemblage of river was composed of mainly small-sized fishes (10- 25 cm) with few large sized samples of mahseer and snow trout (25-50 cm).

Table 3: Species richness, relative abundance (RA) and conservation status of fish fauna of River Pinder.

Order/family/species	Threat status	Relative abundance (%)				
		S-1	S-2	S-3	S-4	Average
Order Cypriniformes						
1. Family Cyprinidae						
Barilius barila	VU	0.00	3.40	2.74	1.79	2.03
B. barna	LRnt	0.00	2.04	1.71	0.00	0.85
B. bendelisis	LRnt	4.88	5.44	3.42	5.37	4.69
B. shacra	LRnt	1.83	4.76	0.00	2.39	1.92
B. vagra	VU	0.00	2.04	3.08	0.00	1.28
Crossocheilus latius latius	DD	0.00	0.00	3.42	4.48	2.67
Garra gotyla gotyla	VU	3.05	6.12	4.79	3.58	4.26

Table 3 continued:						
G. lamta	NA	4.88	0.68	3.42	0.00	2.03
Schizothoraichthys progastus	LRnt	4.27	0.00	2.74	5.97	3.73
Schizothorax plagiostomus	NA	21.3	23.8	13.7	13.4	16.5
S. richardsonii	VU	29.9	34.0	18.8	19.4	23.3
Tor chilinoides	NA	2.44	1.36	3.08	3.28	2.77
T. hexasticus	NA	0.00	2.04	2.40	0.00	1.07
T. putitora	EN	2.44	0.00	4.11	5.37	3.62
T. tor	EN	0.00	0.00	0.00	4.48	1.60
2. Cobitidae						
Noemacheilus bevani	NA	0.00	0.00	1.71	2.09	1.28
N. gangeticus	NA	0.00	2.04	2.74	0.00	1.17
N. montanus	EN	2.44	3.40	3.42	4.48	3.62
N. multifasciatus	EN	1.83	0.00	0.00	1.49	0.85
N. rupicola	LRnt	3.66	4.08	5.14	5.97	5.01
N. savona	NA	0.00	0.68	3.77	0.00	1.28
Order Salmoniformes						
1.Family Salmonidae						
Salmo gairdnerii gairdnerii	NA	6.1	0.00	0.00	0.00	1.07
Order Siluriformes						
1. Family Sisoiridae						
Glyptothorax cavia	EN	3.66	2.04	2.74	4.18	3.30
G. madraspatanum	VU	0.00	0.00	3.08	0.00	0.96
G. pectinopterus	LRnt	2.44	2.04	4.79	4.48	3.84
G. telchitta	LRnt	0.00	0.00	0.00	2.39	0.85
Pseudecheneis sulcatus	VU	4.88	0.00	5.14	5.37	4.37
Species Richness		**16**	**17**	**22**	**19**	

EN- endangered, VU- vulnerable, LRnt- low risk near threatened, NA- Not assessed

Table 4: Shannon-Weiner and Simpson diversity index at four study sites along River Pinder.

Diversity and diversity index	**Sampling sites**			
	S-1	**S-2**	**S-3**	**S-4**
Species richness	16	17	22	19
Shannon –Weiner Index	3.31	3.10	4.10	3.91
Simpson's index of Diversity	0.85	0.81	0.92	0.91

Distribution pattern along various study sites

The distribution of fish species showed interesting patterns by contributing varying percentages at different sites. Among the 27 species, nine species viz. *Schizothorax richardsonii* (23.3%) *S. plagiostomus* (16.5%), *Noemacheilus rupicola* (5.01%), *Barilius bendelisis* (4.69%), *Garra gotyla gotyla* (4.26%), *Glyptothorax telchitta* (3.84%), *N. montanus* (3.62%), *G. cavia* (3.30%), *Tor chilinoides* (2.77%) were present at all four sites with varying RA. However, four species viz. *Tor tor* (1.60%), *Salmo gairdnerii gairdnerii* (1.07%), *G. madraspatanum* (0.96%) and *G. telchitta* (0.85%) were found restricted to a single site only. All other species showed their random distribution among two or three sites, respectively.

Varying percentages of different species were also recorded at various sites however the major contribution at all sites was made by *S. richardsonii* and *S. plagiostomus.* At site S-1, *S. richardsonii* (29.9%), *S. plagiostomus* (21.3%), *S. gairdnerii gairdnerii* (6.1%) and *B. bendelisis*, *G. lamta*, *Pseudecheneis sulcatus* each (4.88%) made the major contribution. At site S-

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2, along with the major contribution of *S. richardsonii* (34.0%) and *S. plagiostomus* (23.8%), some other species viz. *G. gotyla gotyla* (6.12%), *B. bendelisis* (5.44%), and *B. shacra* (4.76%) showed considerable occurrence. At site S-3, *S. richardsonii* (18.8%), *S. plagiostomus* (13.7%), *N. rupicola (*5.14%), *P. sulcatus* (5.14%), *G. gotyla gotyla (*4.79%) and *G. pectinopterus* (4.79%) altogether comprised more than 50 % of the total catch. At site S-4, in the lower stretch, *S. richardsonii* (19.4%) and *S. plagiostomus* (13.4%) again made major contributions along with *Schizothoraichthys progastus* (5.97%), *N. rupicola* (5.97%), *B. bendelisis* (5.37%), *Tor putitora* (5.37%), and *P. sulcatus* (5.37%).

Pattern of species richness and abundance along the altitudinal gradient

The variation in altitude gradient among all four study sites was however less than 100 meters but in between this range species richness and abundance response was significant. From site S-4 to S-3 species richness was positively correlated with altitude gradient while upstream site S-3 towards site S-1, species richness and abundance were negatively correlated with altitude gradient. Except for site S-3, correlation (r) between the species richness and altitude gradient among the three sites was highly negative (r= -0.99). Abrupt fall in total species richness was observed from site S-3 to S-2 and further it was decreasing slowly.

Association of species composition to habitat ecology

Variation in species richness and abundance was observed with change in habitat (Table 5). Deep pool habitat recorded the maximum fish species richness (21 species) followed by shallow pool habitat (18 species). Least species richness (8 species) was recorded in cascade habitats. The habitat types (riffle and rapid) having comparatively high turbulence and high velocity showed minute variations with each other in species richness. All other habitats, pool, run and cascade showed the considerable differences with each other in species richness. Deep and shallow pool habitats were dominated in the lower stretch while rapids and cascade habitats were common in middle and upper stretch of the river. The present study observed the habitat preference of different species. The shoals of lesser barils (*Barilius* spp) preferred mostly the shallow pool habitat however they were occasionally reported from deep pool and run habitat. Small sized loach aggregations (*Noemacheilus* spp) preferred both the shallow and deep pool habitats and were accidently reported in the run and riffle habitat. Mahseer (*Tor* spp) preferred mostly deep pool habitats followed by shallow pools however was accidently reported in the run habitat type. Snow trout (*Schizothoraichthys* and *Schizothorax* spp) and exotic trout (*Salmo* spp) have been recorded commonly distributed in all habitat types but preferred mostly the swiftly flowing riffle and rapid habitats. Minor carp (*Crossocheilus* sp) was found

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common to all habitat types except the cascade habitat. The true hill stream cat fishes (*Glyptothorax*, *Pseudecheneis* and *Garra* spp) preferred mostly the riffle, rapid and cascade type habitat and were hardly ever reported in the run and pool habitats. They were totally devoid from shallow pools. Detailed preference of each species is depicted in Table 5.

Table 5: Habitat preference of different fish taxa of Pinder River.

Name of fish species	**Habitat type**					
	Shallow pool	**Deep pool**	**Run**	**Riffle**	**Rapid**	**Cascade**
Barilius barila	+	+	-	-	-	-
B. barna	+	-	+	-	-	-
B. bendelisis	+	+	+	-	-	-
B. shacra	+	-	-	-	-	-
B. vagra	+	+	-	-	-	-
Crossocheilus latius latius	+	+	+	+	+	-
Garra gotyla gotyla	-	+	+	+	+	+
G. lamta	-	-	+	+	+	+
Glyptothorax cavia	-	+	+	+	+	+
G. madraspatanum	-	-	+	+	+	+
G. telchitta	-	-	-	+	+	-
G. pectinopterus	-	+	-	-	+	+
Noemacheilus bevani	+	+	-	-	-	-
N. gangeticus	+	+	-	-	-	-
N. montanus	+	+	+	+	-	-
N. multifasciatus	+	+	-	-	-	-
N. rupicola	+	+	-	-	-	-
N. savona	+	+	+	-	-	-
Pseudecheneis sulcatus	-	-	-	+	+	+
Salmo gairdnerii gairdnerii	+	+	+	+	+	
Schizothoraichthys progastus	+	+	+	+	+	-
Schizothorax plagiostomus	+	+	+	+	+	+
S. richardsonii	+	+	+	+	+	+
Tor chilinoides	-	+	+	-	-	-
T. hexasticus	+	+	-	-	-	-
T. putitora	-	+	+	+	-	-
T. tor	+	+	-	-	-	-
Fish Species Richness	**18**	**21**	**15**	**13**	**12**	**08**

+= present, - =absent

Physico-chemical attributes and their correlation with species richness

Some important physico-chemical attributes were also analysed and were correlated with species richness to know the degree and significance of relationship between them (Table 6). All analysed attributes showed considerable variation from site to site (Table 7). Water temperature showed considerable variation among all respective sites than all other attributes. Linear decrease in temperature was recorded from the lower stretch (S-4) towards the upper stretch (S-1). A variation of 2.34 ^{o}C was observed from site S-4 to S-1. Similarly total alkalinity also showed the similar pattern of linear decrease from site S-4 to S-1. Apart from these parameters, all other attributes showed the random variation at various sites rather than a linear

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variation. Water velocity showed slight variation with swift flow (1.52±0.54 m s^{-1}) at site S-2 in the upper stretch and stumpy flow (1.24±0.49 m s^{-1}) at S-4 in the lower stretch of the river. pH was recorded alkaline at all the sites with maximum value at S-4 and lowest value at S-3 both in the lower stretch of the river. Total dissolved solids showed slight variation ranging from 80.5±13.35 mg L^{-1} at S-1 to 86.67±11.83 mg L^{-1} at S-2. DO contents recorded high values (>10 mg L^{-1}) throughout the river length with slight variation from site to site. Free CO_2 was 0.28 mg L^{-1} on average ranging from 0.25±0.10 at S-3 to 0.31±0.086 mg L^{-1} at S-1. Turbidity of the water (water transparency) revealed low variation from site to site but variation among different seasons. It was high during the summer season and low during the winter seasons. Water was found highly turbid (32.33±34.94 NTU) in the lower stretch (S-3) and less turbid (21.83±30.96 NTU) in the upper stretch (S-1). Lower stretch of the river (S-3 and S-4) was more highly turbid than the upper stretch (S-1 and S-2). Statistical correlation revealed that the fish species richness is dependent on the physico-chemical attributes of river water. At all the four study sites in river Pinder, species richness was positively correlated to water temperature, pH, total dissolved solids and total alkalinity while it was negatively correlated with water velocity, dissolved oxygen, free carbon dioxide and turbidity (Table 6).

Table 6: Correlation coefficient of various physico-chemical attributes with fish species richness at four study sites of River Pinder.

Physico-chemical parameters	Sampling sites			
	S-1	**S-2**	**S-3**	**S-4**
Water temperature (^oC)	0.33	0.21	0.1	0.18
Water velocity (m s^{-1})	-0.43	-0.56	-0.55	-0.23
pH	0.43	0.27	0.13	0.88
TDS (mg L^{-1})	0.1	0.14	0.16	0.12
DO (mg L^{-1})	-0.43	-0.77	-0.85	-0.78
Free CO_2 (mg L^{-1})	-0.02	-0.04	-0.48	-0.48
Total alkalinity (mg L^{-1})	0.48	0.14	0.17	0.15
Turbidity (NTU)	-0.64	-0.58	-0.61	-0.53

Table 7: Physico-chemical attributes (mean ± SD) of Pinder River at four sampling sites.

Physico-chemical attributes	Sampling sites			
	S-1	**S-2**	**S-3**	**S-4**
Water temperature (^oC)	12.75±2.09	13.17±2.18	14.42±2.93	15.09±2.81
Water velocity (m s^{-1})	1.37±0.56	1.52±0.54	1.28±0.51	1.24±0.49
pH	7.41±0.45	7.33±0.40	7.09±0.21	7.66± 0.25
TDS (mg L^{-1})	80.5±13.35	86.67±11.83	81.0±11.73	81.67±13.97
DO (mg L^{-1})	10.32±0.57	10.17±0.73	10.18±0.74	10.09±0.76
Free CO_2 (mg L^{-1})	0.31±0.086	0.29±0.093	0.25±0.10	0.28±0.09
Total alkalinity (mg L^{-1})	1.19±0.24	1.23±0.28	1.29±0.30	1.30±0.32
Turbidity (NTU)	21.83±30.96	25.67±29.02	32.33±34.94	31.17±35.05

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Conservation status of fish species of Pinder River

According to the CAMP (Conservation Assessment and Management Plan, 1998) fish species reported from Pinder River fall under different categories (Table 3). About 18.51% of total fish fauna of Pinder was under the endangered (EN) category while 22.22% of it was vulnerable (VU). Instead of this 25.92% of total fish fauna came under low risk near threatened (LRnt), however 29.62% of fish fauna was not assessed (NA) and at least 3.70% of its fish fauna was introduced.

Discussion

River Pinder was explored three decades earlier from viewpoint of documentation of its fish fauna (Badola, 1979; Singh *et al*., 1987) and was found rich in fish diversity. However, it has not so far been investigated with regards to distribution of fish species in relation to various ecological factors (physico-chemical attributes, habitat ecology and altitudinal gradient). Present study is first of its kind for such a Himalayan River in the uplands of Garhwal (India). Previously Badola (1979) had reported 38 fish species from the Pinder River while Singh *et al*. (1987) had reported 37 species from the same river. Earlier there were reports of *Balitora brucei*, *Clupisoma garua*, *G. prashadi, G. brevipinnis, G. conirostris, G. kashmirensis, G. trilineatus, Labeo dero*, *L. dyocheilus*, *N. denisoni*, *N. zonatus*, *S. sinuatus*, *Schizothoraichthys esocinus*, *S. intermedius*, *S. micropogon*, *S. longipinnis*, *S. curvifrons*, *S. Niger* and *S. planifrons*, which we could not find during the period of rigorous studies, while *N. gangeticus*, has been recorded for the first time from this river. The species composition in both earlier studies also varied. The species diversity in the reference river has been decreased with passage of time which may be assigned to various alterations in habitat ecology due to anthropogenic and developmental activities going on with fast pace. Such changes may result into the extermination of some of the native species (Agarwal *et al*., 2011).

Various environmental factors influence distribution of fish species richness differently and the relationship varies in magnitude (Bhatt *et al*., 2012). The present investigation revealed that habitat ecology, altitude gradient and physico-chemical parameters are the major factors influencing distribution patterns of fish species. About 33% fish species were common to all four sites (both upstream and downstream) showing a long migration range. Bhat (2004) also stated that large numbers of fishes are there which could be reported from both upstream as well as down steam. However, this study also reported that some fish species (14.80%) of River Pinder were restricted to a single site and the remaining were distributed randomly among more than one site, which is in conformity with Agarwal and Singh (2012).

The present study has reported that fish species richness was negatively correlated with increase in altitudinal gradient along the river length except

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site S-3. According to Welcomme (1985) species richness and abundance decreased from downstream to upstream. However, in the present study (from site S-4 towards S-3) species richness and abundance increased with increase in altitude. Low species diversity in the lower stretch of river (S-4) concords with Habit *et al*. (2006); Lakra *et al*. (2010). Along with altitude gradient, stream depth and width being complementary measures of stream volume may be one of the most efficient descriptors of species richness. Various environmental, geographic and topographic features are often described as determinants of species richness patterns along elevational gradients (Kerr and Packer, 1997). Grenouillet *et al*. (2004) and Suarez *et al*. (2011) have observed, a clear increase in species richness along a longitudinal gradient, but this pattern is not linear, with a strong spatial autocorrelation, associated with variation in stream size, stream depth and width.

Habitat structure of any river is another important factor responsible for the patterns of distribution of fish species. About 7.40% of species were found common to all habitat types while 3.70% of species were found restricted to only a single habitat type. Other species were recorded sharing two or three habitats. The present study revealed that the pool habitat (deep and shallow) was the most preferred habitat. A maximum fish species diversity of 21 species (77.78%) was recorded from the deep pool habitat and 18 species (66.67%) from the shallow pool habitat. The least species diversity 8 species (29.63%) was recorded from the stepping type cascade habitat with swiftly flowing water. Johal *et al*. (2002) working on the streams of the lower middle western Himalayas, similarly investigated that the pool habitat was the most preferred habitat for fishes inhabiting those streams. All these observations divulge that hill stream fishes are habitat specialists. There is a strong relationship between fish assemblage structure and habitat structure (Meffe and Sheldon, 1988; Lakra *et al*., 2010). Similarly, Galacatoes *et al*. (1996) have identified habitat as one of the primary criteria on which many biological communities are organized.

All analysed physico-chemical attributes showed considerable variation from site to site, which may be confined to various alterations caused by natural as well as anthropogenic activities taking place along the length of river and land use pattern, thereby controlling the distribution of various sections of fish species in the reference river. Hydrological variables act as environmental filters for the species and colonization of species in the each part of a basin is assigned to hydrological characteristics within the basin (Poff, 1997). The river continuum concept proposes that physical, chemical and biological alterations along a longitudinal gradient in a watershed network drive the rate of species loss or gain, by the change in the probability of cataclysmic events and processes of channel development (Suarez *et al*., 2011). The lower stretch of the river recorded higher species diversity confined to less stressful hydrological conditions compared to headwaters, Therefore such hydrological conditions favour higher change rate in species composition, explaining the larger total richness when compared to headwaters (Tondato and Suarez, 2010). Among all physico-chemical attributes, water temperature, pH, total dissolved solids and total alkalinity were positively correlated with species diversity, while water velocity, dissolved oxygen, free CO_2, and turbidity showed the negative correlation. The variations among all these physico-chemical attributes at four respective sites were responsible for variations in fish species diversity and distribution.

Acknowledgements

University Grant Commission (UGC), New Delhi, India is thankfully acknowledged for providing financial support in the form of major research project [no. 37-199/2009(SR)].

References

Agarwal, N.K. and Singh, G., 2012. Documentation of fishes and physico-chemical characters of a stream Indrawati- a spring fed tributary of River Bhagirathi at Uttarkashi (Central Himalaya, Garhwal) India. *Environment Conservation Journal,* 13, 117-124.

Agarwal, N.K., Singh, G. and Singh, H., 2011. Present status of Ichthyofaunal diversity of Garhwal Himalayan River Bhilangana and its tributaries with reference to changing environment. *Environment Conservation Journal*, 12, 101-108.

American Public Health Association (APHA), 2005. Standard methods for the examination of water and wastewater. 21th ed., Washington (DC).

Armantrout, N.B., 1999. Glossary of aquatic habitat inventory technology. American Fisheries Society, 150 P.

Arunachalam, M., 2000. Assemblage structure of stream fishes in the Western Ghats (India). *Hydrobiologia,* 430, 1-31.

Badola, S.P., 1979. Ecological studies on the Ichthyofauna of freshwater resources of Garhwal region (India). Ph.D. Thesis, submitted to HNB Garhwal University, Srinagar (Uttarakhand).280 P.

Badola, S.P., 2009. Ichthyology of the Central Himalaya. India: Transmedia Publication House, Srinagar (Uttarakhand), 206 P.

Bhat, A., 2004. Patterns in the distribution of freshwater fishes in rivers of central Western Ghats, India and their associations with environment gradients. *Hydrobiologia,* 529, 83-97.

Bhatt, J.P., Manish, K. and Pandit, M.K., 2012. Elevational gradients in fish diversity in the Himalaya: water discharge is the key driver of distribution patterns. *PLoS ONE,* 7, e46237. DOI:10.1371/journal.pone.0046237.

CAMP, 1988. Report of the workshop on ‘Conservation Assessment and Management Plan (CAMP) for freshwater fishes of India.’ Zoo outreach organization and NBFGR,

[DOR: 20.1001.1.15622916.2019.18.1.1.6]

Lucknow, 22-26 September, 1997, India, 156 P.

Carter, J.C.H., Dadswell, **M.J., Roff**, **J.C. and Sprules**, **W.G., 1980.** Distribution of zoogeography of planktonic crustaceans and dipterans in glaciated eastern North America. *Canadian Journal of Zoology*, 58, 1355-1387.

Day, F., 1958. The fishes of India: being a natural history of the fishes known to inhibit the seas and freshwater of India, Burma and Ceylon. London: William Dawson, and Sons Ltd. 778 P.

Galacatoes, K., Stewart, D.J. and Ibarra, M., 1996. Fish community patterns of lagoons and associated tributaries in the Ecuadorian Amazon. *Copeia*, 4, 875-894.

Gorman, **O.T. and Karr**, **J.R.**, **1978.** Habitat structure and stream fish communities. *Ecology*, 59, 507-515.

Grenouillet, G., Pont, D. and Herisse, C., 2004. Within-basin fish assemblage structure: the relative influence of habitat versus stream spatial position on local species richness. *Canadian Journal of Fisheries and Aquatic Sciences*, 61, 93-102.

Grossman, G.D., 1982. Dynamics and organisation of a rocky intertidal fish assemblage: the persistence and resilience of taxocene structure. *American Naturalist*, 119, 611-637.

Habit, E., Belk, M.C., Tuckfield, R.C. and Parra, O., 2006. Response of the fish community to human induced changes in the Biobio River in Chile. *Freshwater Biology,* 51, 1-11.

Jayaram, K.C., 2010. The fresh water fishes of the Indian region. India: Narendra Publishing House, Delhi, 616 P.

Johal, M.S., Tandon, K.K., Tyor, A.K. and Rawal, Y.K., 2002. Fish diversity in different habitats in the streams of the lower middle western Himalayas. *Polish Journal of Ecology*, 50, 45-56.

Kerr, J.T. and Packer, L., 1997. Habitat heterogeneity as a determinant of mammal species richness in high energy regions. *Nature*, 385**,** 252-254.

Kerr, J.T., 1997. Species richness, endemism and the choice of areas for conservation. *Conservation Biology*, 11, 1094–1100.

Lakra, W.S., Sarkar, U.K., Kumar, R.S., Pandey, A., Dubey, V.K. and Gusain, O.P., 2010. Fish diversity, habitat ecology and their conservation and management issue of a tropical river in Ganga basin, India. *Environmentalist*, 30, 306-319.

Meffe, G.K. and Sheldon, A.L., 1988. The influence of habitat structure on fish assemblage composition in south-eastern black water streams. *American Midland Naturalist*, 120, 225-240.

Moyle, P.B. and Vondracek, B., 1985. Persistence and structure of the fish assemblage in small Californian stream. *Ecology*, 66, 1-13.

Oberdorff, T., Guegan, J.F. and Hugueny, B., 1995. Global patterns of fish species richness in rivers. *Ecography*, 18, 345-352.

[DOR: 20.1001.1.15622916.2019.18.1.1.6]

Poff, **N.L.**, **1997.** Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society*, 16, 391-409.

Schlosser, I.J., 1982. Fish community structure and function along two habitat gradients in a headwater stream. *Ecological Monographs*, 52, 395-414.

Shannon, C.E. and Wiener, W., 1963. The mathematical theory of communication. Urbanna: University Illinois Press, 36 P.

Simpson, E.H., 1949. Measurement of diversity. *Nature*, 163, 688-688.

Singh, G. and Agarwal, N.K., 2014. Fish assemblage structure and habitat use of the snow fed stream Assiganga - a major tributary of River Bhagirathi in Central Himalaya (India). *International Journal of Aquatic Biology,* 2(**6**), 305-312.

Singh, H.R., Badola, S.P. and Dobriyal, A.K., 1987. Geographical distribution list of Ichthyofauna of Garhwal Himalaya with some new records. *Journal of Bombay Natural History Society*, 84, 126-132.

Suarez, Y.R., Souza, **M.M., Ferreira**, **F.S., Pereira**, **M.J., Silva**, **E.A., Ximenes**, **L.Q.L., Azevedo**, **L.G., Martins**, **O.C. and Junior**, **S.D.L.**, **2011.** Patterns of species richness and composition of fish assemblages in streams of the Ivinhema river basin, upper Parana River. *Acta Limnologica Brasiliensis*, 23, 177-188.

Talwar, P.K. and Jhingran, A.G., 1991. Inland fishes of India and adjacent countries. India: Oxford & IBH Publishing house, New Delhi, 1097 P.

Tondato, K.K. and Suarez, Y.R., 2010. Temporal changes in fish species composition of headwater streams of the upper Paraguay and Parana basins, Brazil. *Acta Scientiarum Biological Sciences*, 32, 279-284.

Vannote, R.L., Minshall, G.W., Sedell, J.R., Cushing, C. ., 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 130-137.

Welcomme, R.L., 1985. River fisheries. *FAO Fish Technical Paper*, 262, 318.

Wiley, M.J., Kohler, S.L. and Seelbach, P.W., 1997. Reconciling landscape and local views of aquatic communities: lessons from Michigan trout streams. *Freshwater Biology*, 37, 133-148.