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Correlations between fish assemblage structure and environmental variables of the Seti Gandaki River Basin, Nepal

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ABSTRACT

This paper addresses the relationship between fish and environmental variables from the Seti Gandaki River Pokhara, Nepal. The water bodies previously had higher abundance and distribution of fishes, which are declining probably due to deterioration of abiotic characteristics and degradation of habitat. Five study sites were: three along the main channel and two along the tributaries. Water sampling was conducted fortnightly and fish sampling was done monthly. Altogether 30 species of fishes belonging to 5 orders, 9 families and 24 genera were recorded. The redundancy analysis (RDA) revealed significant correlations between fish assemblage and environmental variables. The first two axes accounted for 44.15% of the variation of which RDA1 explained 30.32% and correlated with conductivity, pH, dissolved oxygen, free carbon dioxide, ortho-phosphate, nitrite and silicates; while RDA2 explained 13.83% and correlated with depth, width, discharge and nitrates. Likewise, RDA1 revealed a gradient from species that require more oxygenated waters of upstream sites (*Schizothorax richardsonii*, *Pseudecheneis eddsi*, *Naziritor chelynoides*, *Garra annandalei*, *Schistura rupecula* and *Lepidocephalichthys guntea*) to less oxygenated urban and downstream sites (*Puntius sophore*, *Pethia conchonius*, *Barilius bendelisis*, *Barilius vagra*, *Garra gotyla*, *Mastacembelus armatus* and *Channa orientalis*). RDA2 revealed the gradient from species inhabiting urban and downstream sites to upstream sites.

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Fish communities; abiotic parameters; relationships; lotic waterbodies; Central Himalaya

Introduction

There has been a growing global concern among freshwater biologists about the alteration of aquatic ecosystems, rapid deterioration of water quality, destruction of riverine environment, and significant decline in the species diversity and abundance of stream fishes (Shrestha 2008; Zhao et al. 2011). Most freshwater ecological studies have strongly suggested biological monitoring of waterbodies along with the environmental characteristics (Dudgeon 1999; Wetzel 2001; Wu et al. 2011). Spatio-temporal variations of abiotic characteristics such as dissolved oxygen (DO) and pH are often higher at upstream but lower at urban and downstream reaches in contrast to free carbon dioxide (F-CO_2), conductivity, and compounds of phosphorus (P) and nitrogen (N), which were lower at upstream reaches but higher at urban and downstream reaches due to environmental pollution (Osmundson et al. 2002; Kannel et al. 2008; Bu et al. 2010). Fish assemblage structure in several studies was best correlated usually with the environmental variables stream size, discharge and free carbon dioxide (Koel and Peterka 2003; Fernandez and Bechara-Conicet 2010; Negi and Mamgain 2013), with

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variables conductivity, DO, pH and alkalinity (Edds 1993; Kouamelan et al. 2003; Li et al. 2012), and with nutrients (phosphates, nitrates and silicates; Goldstein et al. 1993–1995; Rashleigh 2004; Lin et al. 2013). The above-mentioned environmental variables exhibit significant patterns with the fluvial gradient from upstream to downstream reaches influenced by urbanization with either an increase or decrease in abundance and species richness (Edds et al. 2002; Shrestha et al. 2009; Pease et al. 2012).

Multivariate analyses have been used in ecological studies for identification and interpretation of statistically significant correlations between fish assemblage structure and the environmental variables (Winemiller et al. 2000; Humpl and Pivnicka 2006; Fernandez and Bechara-Conicet 2010). Other studies such as Edds (1993) and Edds et al. (2002) have analyzed fish assemblage structure and their relationships with environmental variables in Gandaki and Narayani rivers of Nepal. The waterbodies in the Pokhara Valley, which had greater abundances and diversity of fishes 25–35 years ago (Ferrow and Badgami 1980; John and Dhewajoo 1989), are in decline, negatively impacting the livelihood of fishing communities. Such livelihoods will be difficult to sustain over time if the causes are not mitigated in time (Rai 2005; Bista et al. 2010). The present study was initiated with the main objective to investigate the relationships between the fish assemblage structure and the environmental variables of the Seti Gandaki River Basin in the Pokhara valley of Nepal. By either confirming or not that environmental variables are responsible for fish declines, environmental planning and management of waterbodies in Pokhara Valley will benefit. The specific objectives were to assess the species–environment relations, species–site relations and site–environment relations.

Methods

Study area

Pokhara Valley is located on the southern flank of the Annapurna Himalayan range in Western Nepal, with diverse physiographic features such as rivers, streams, lakes, ponds, river terraces, deep gorges, caves and steep slopes. It is bounded by the Mahabharat hills and high Himalayan ranges to the northern side and mid-hills in the eastern, southern and western sides. It is located between N27°50′ and N28°10′ latitude, and E83°50′ and E84°50′ longitude with altitudes from 540 to 1020 m above sea level (msl), covering an area of about 200 km^2 (Tripathi 1985). The lotic waterbodies running through the valley are the Seti Gandaki River and its tributaries. The river is snow-fed, has its origin near the base of the Mount Machhapuchhre (6997 m) and Mount Annapurna IV (7525 m).

This river receives several tributaries downstream as it runs through the middle of the valley. The total length and catchment area of the river are nearly 112.6 km and 600 km^2, respectively. The river joins the Trishuli River at Gaighat (Sharma 1977). Mardi and Vijaypur are the major tributaries of the river. Mardi, a snow-fed stream, has its origin from the Mardi Himal (5127 m), runs downstream about 25 km and joins the Seti Gandaki River near Lahachok, 12 km north from the Pokhara city. Vijaypur, a spring-fed stream, has its origin at the foot of the Mahabharat range situated northeast of the valley and runs about 15 km before joining the Seti Gandaki river at the Seti–Vijaypur confluence area, 13 km southeast of Pokhara City. These waterbodies constitute Himalayan lotic ecosystems having unique features such as high water velocity, low-to-moderate temperature and unstable bottom substrates. Five study sites (A to E) were selected representing upstream, urban and downstream sites from the Seti Gandaki River, Mardi stream and Vijaypur stream based on accessibility and minor human disturbances (Figure 1).

Site A (Lahachok in main channel) and Site B (Mardi stream or upper tributary) were upstream sites, 11.12 km from the urban site, had patchy forests, rural settlements and cultivated land in their catchment. Site C (Ramghat in main channel) was the urban site, about 2 km east of Pokhara city center with urban area and cultivated land in the catchment. Site D (Vijaypur stream or lower tributary) was 8.46 km downstream from the urban site, had cultivated land, poultry farms and human

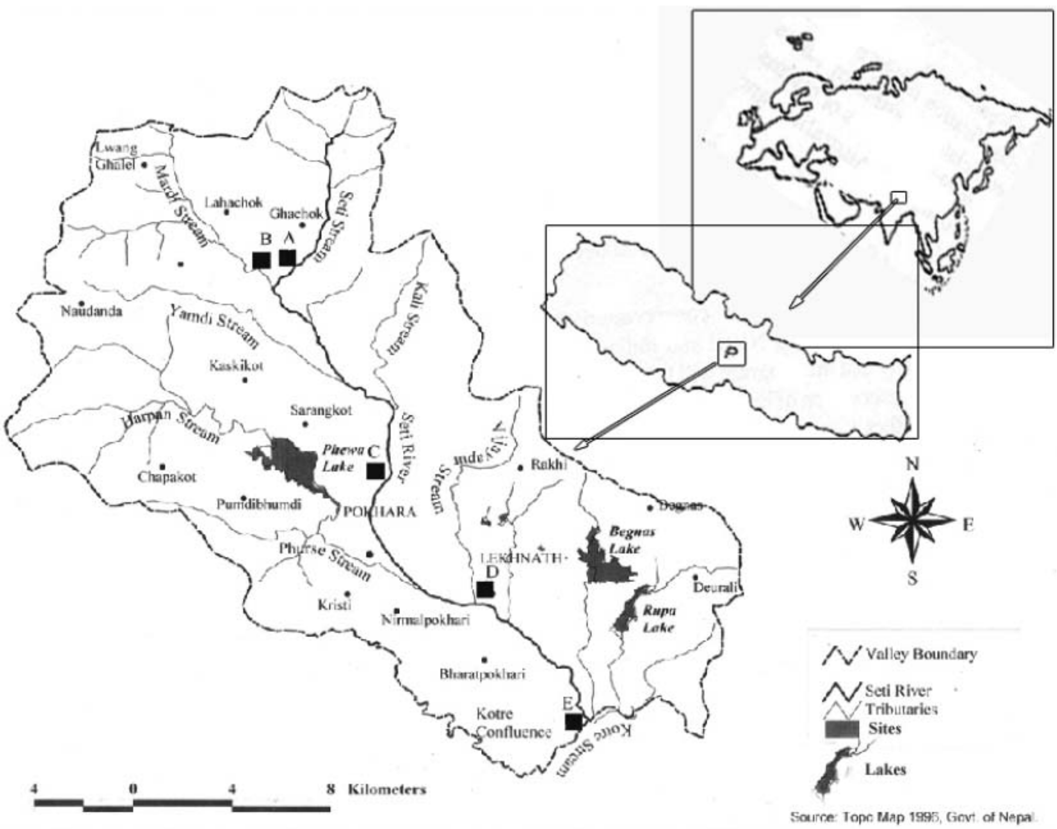

Figure 1. Location of study area and sampling sites.

settlement areas in the catchment. Site E (Kotre area in main channel) was the downstream site, along the main channel, about 15.39 km from urban site had cultivated land, patchy forests and human settlements in the catchment. The riverbed showed less sand and gravel, but more cobbles and boulders in the upstream sites than in the urban and downstream sites.

Sampling

Sampling was done fortnightly for environmental variables and the data were pooled and tabulated as monthly observations, while fish sampling was done monthly and were performed during July 2011 to June 2012. It started on the 15th and continued to the 22nd of every month. Four seasons were defined as summer, autumn, winter and spring which included the months June, July and August; September, October and November; December, January and February; and March, April and May, respectively.

Water samples were collected and analyzed following the standard methods of Golterman et al. (1978), Trivedy and Goel (1984), Das (1989) and American Public Health Association (APHA 1998). The variables such as depth, width, velocity, turbidity, transparency, conductivity, temperature, pH, dissolved oxygen (DO), free carbon dioxide (F-CO_2), alkalinity, hardness, calcium, magnesium and chlorides were recorded and determined/analyzed at the site (Water Test 4-in-one and Turbidity meter HI 93703, Hanna Instruments), while the samples for the variables phosphates (PO_4^{3-}); compounds of ammonia–N (NH_3-N), nitrite–N (NO_2–N) and nitrate–N (NO_3–N); and silicates (SiO_2) were carried to the laboratory and analyzed as soon as possible.

Fishes were sampled using a cast-net (433 cm in diameter, 252 cm in length and 6 mm mesh size) thrown by a fisherman and a portable backpack DC electro-shocker unit powered by a battery (8 volts) with two hand-held electrodes and two dip nets (mesh 6 mm) conducted by experienced sampling assistants (Vibert 1967; Ricker 1968, APHA 1998). For estimation of abundance, a two-pass removal method (Seber and Le Cren 1967) was used. Each removal pass included moving upstream and then downstream within a predetermined area of 0.1 ha during which both devices were used simultaneously to assess the fish diversity including depletion and data tabulated as sum of all catches. The surface area of river section was calculated by using width and length of the sampling area. Sampling was performed with equal effort (30 minutes) for each pass at each site. Fishes were caught, examined, counted, identified and released unharmed into the water. Fish samples which required taxonomic verification were collected, preserved in 10% buffered formalin and voucher specimens were deposited in the laboratory of Department of Zoology, Prithvi Narayan Campus, Pokhara. Fishes were identified following the taxonomic monographs/manuals of Day (1878), Shrestha (1981, 2001), Jayaram (1999) and Shrestha (2008). The abundance of fishes was expressed as number per 0.1 ha.

Data analysis

Redundancy analysis (RDA), a direct multivariate ordination method (ter Braak 1988a; ter Braak and Prentice 1988) based on a linear response of species to environmental gradients (Gauch 1982; ter Braak 1986; Palmer 1996), was applied by using *vegan* library in 'R' (Oksanen et al. 2015). The relative abundance and angular direction of each environmental variable in an ordination biplot space indicated by plots and arrows, respectively, were placed on the axes by 'R' (Hijmans and Elith 2013). The arrows pointed to the direction of maximum variation in the value of variables and the degree to which the variables were correlated with RDA axes was represented by the length of the arrows. The Species Distribution Modeling (SDM) was performed to determine patterns of fish species abundance with respect to environmental variables of each studied site as predictors (Hijmans and Elith 2013). All these statistical analyses were done in R (R Core Team 2015).

Results

Species–environmental variable relationships

A total of 30 fish species belonging to 5 orders, 9 families and 24 genera were recorded from the Seti Gandaki River Basin (Table 1). Biplot scores for constraining variables and the axes are given in Table 2. The first two axes (RDA1 and RDA2) accounted for 44.15% of the variation of 30 fish species (Figure 2). The first axis (RDA1) was more important, explaining 30.32% of variation, and was most strongly positively correlated with the variables conductivity, F-CO_2, phosphates (PO_4^{3-}), NH_3–N and SiO_2, and negatively with the variables DO and pH. The second axis (RDA2) explained 13.83% of variance and most strongly positively correlated with depth, width, chlorides and NO_3–N.

The positioning of 30 fish species in relation to environmental variables is shown in Figures 3–6. Several cyprinids including *Schizothorax richardsonii*, *Garra annandalei*, *Garra gotyla*, *Pethia conchonius* and *Neolissocheilus hexagonolepis* preferred negatively correlated pH values. Likewise, several cyprinids preferred positively correlated values of depth, width, conductivity, F-CO_2, chloride and SiO_2–Si, and negatively correlated values of DO and pH (Figure 3). Among balitorids and cobitids, *Lepidocephalichthys guntea* and *Schistura rupecula* preferred positively correlated higher DO and pH values, but negatively correlated lower values of conductivity, F-CO_2, chloride, SiO_2–Si, NH_3–N and O–PO_4 (Figure 4). Among sisorids and amblycipitids, *Pseudecheneis eddsi* and *Amblyceps mangois* preferred positively correlated higher values of DO and pH; while positively correlated lower values of depth, width, chloride and NH_3–N (Figure 5). Among channids and mastacembelids, *Channa orientalis* and *Mastacembelus armatus* preferred positively correlated high or above

Table 1. List of fishes recorded in the Seti Gandaki River Basin, with code, mean abundance and standard error (SE) of each species.

	Sites							
Taxa	A	B	C	D	E	Code	Mean	±SE
Family: Cyprinidae								
Neolissocheilus hexagonolepis	√	√	√	√	√	neol hex	4.0	0.07
Puntius sophore	√	√	√	√	√	punt sop	6.6	0.11
Pethia conchonius	√	√	√	√	√	punt con	9.38	0.i6
Tor putitora	–	–	–	√	√	tor put	2.1	0.04
T. tor	–	–	–	–	√	tor tor	1.2	0.02
Naziritor chelynoides	√	√	–	–	–	nazi che	8.6	0.14
Chagunius chagunio	–	–	–	–	√	chag cha	2.2	0.04
Barilius bendelisis	√	√	√	√	√	bari ben	12.3	0.21
B. vagra	√	√	–	√	√	bari vag	9.5	0.16
B. barila	–	–	–	–	√	bari bar	2.1	0.04
Opsarius barna	–	–	–	–	√	bari bar	1.4	0.23
Danio rerio	–	–	–	–	√	brac rer	3.5	0.06
Danio dangila	–	–	–	√	–	dani dan	8.2	0.14
Esomus danricus	–	–	–	√	–	esom dan	6.6	0.11
Garra annandalei	√	√	–	√	√	garr ann	14.8	0.25
G. gotyla	√	√	√	√	√	garr got	5.7	0.09
Schizothorax richardsoni	√	√	√	√	√	schi ric	8.6	0.14
Family: Balitoridae								
Acanthocobitis botia	–	–	√	√	√	acan bot	8.0	0.13
Turcinoemacheilus himalaya	√	√	–	√	√	shis bea	3.02	0.05
Schistura rupecula	√	√	–	–	–	shis rup	4.0	0.07
Family: Cobitidae								
Lepidocephalichthys guntea	–	√	–	–	–	lepi gun	2.01	0.03
Family: Sisoridae								
Pseudecheneis eddsi	√	√	–	–	–	pseu edd	5.5	0.09
Parachiloglanis hodgarti	√	√	–	–	–	euch hod	2.5	0.04
Glyptothorax pectinopterus	√	√	–	√	–	glyp pec	4.01	0.07
Family: Amblycipitidae								
Amblyceps mangois	√	√	–	–	–	ambl man	1.8	0.03
Family: Bagridae								
Mystus bleekeri	–	–	–	–	√	myst ble	3.7	0.06
Family: Belonidae								
Xenentodon cancila	–	–	–	√	√	xene can	5.32	0.09
Family: Channidae								
Channa orientalis	√	√	√	√	√	chan ori	3.9	0.07
C. punctata	–	√	√	√	√	chan pun	4.01	0.07
Family: Mastacembelidae								
Mastacembelus armatus	√	√	√	√	√	mast arm	3.5	0.06

Symbols: (√) = present and (–) = absent.

average values of depth, width, conductivity, F-CO_2, chlorides, SiO_2, NH_3–N, and PO_4^{3-}, while negatively correlated higher values of DO (Figure 6).

Species–site relationships

The first axis (RDA1) revealed the gradient from species requiring more oxygenated waters of upstream to less oxygenated urban and downstream sites. The upstream sites (Sites A and B) with more oxygenated water were dominated by the species *S. richardsonii, P. eddsi, Naziritor chelynoides, G. annandalei, S. rupecula, L. guntea, A. mangois, Parachiloglanis hodgarti, Glyptothorax pectinopterus* and *Schistura beavani*. The urban and downstream sites (Sites D and E) with less oxygenated water were dominated by the species *Puntius sophore*, *P. conchonius*, *Barilius bendelisis*, *B. vagra, G. gotyla, M. armatus, C. orientalis, Channa punctata, Xenentodon cancila, Acanthocobitis botia*, *Danio dangila*, *Esomus danricus*, etc. The second axis (RDA2) revealed the gradient from species inhabiting deeper, wider and high-flow urban and downstream sites to shallower, narrower and

Table 2. Biplot scores for constraining variables with code, mean and standard deviation (SD) of each variable.

Variable	Code	RDA1	RDA2	Mean	±SD
Depth	Dep	0.138980	−0.056888	00.90	00.30
Width	Wid	0.067861	−0.146857	32.30	13.00
Velocity	Vel	0.351387	−0.054590	01.10	00.30
Discharge	Disc	0.187960	−0.083192	40.00	37.00
Turbidity	Turb	0.197524	−0.110419	81.40	51.00
Transparency	Tran	−0.135567	0.065791	29.10	15.00
Conductivity	Cond	0.140278	−0.036674	166.00	80.00
Air temperature	Atem	0.067886	0.004198	20.00	05.00
Water temperature	Wtem	0.048596	0.055466	18.00	04.00
pH	pH	−0.085369	−0.003832	08.00	00.40
Dissolved O_2	DO	−0.086310	0.042520	08.00	02.00
Free CO_2	F-CO_2	0.096794	−0.058289	07.00	02.00
Total alkalinity	Talk	0.187033	−0.021652	98.00	22.00
Total hardness	Thar	0.065005	−0.018793	65.00	13.00
Dissolved Ca	Dca	−0.002300	0.003838	51.00	19.00
Magnesium	Mg	0.090860	−0.078479	13.40	08.00
Chloride	Cl	0.001241	−0.009065	24.30	05.00
Ortho-PO4	O-PO_4	0.163442	0.005067	00.005	00.002
Total- PO4	T-PO_4	0.176564	−0.008506	00.100	00.030
Ammonia	NH_3	0.125040	−0.081492	00.200	00.100
Nitrite	NO_2	0.128243	−0.090944	00.010	00.003
Nitrate	NO_3	0.142102	0.075632	00.130	00.040
Silicate	Sil	0.147266	−0.080200	00.020	00.020

with low-flow upstream sites. The former (Site E) was dominated by the species inhabiting less oxygenated water, while the latter, Sites A and B, were dominated by the species inhabiting more oxygenated water. Though the downstream site (lower tributary, Site D) was shallower, narrower and with lower flow, was also dominated by the species inhabiting less oxygenated water (Figure 7). Fish abundance was higher during spring and autumn seasons, and at downstream sites; while lower during summer and winter seasons and at upstream and urban sites.

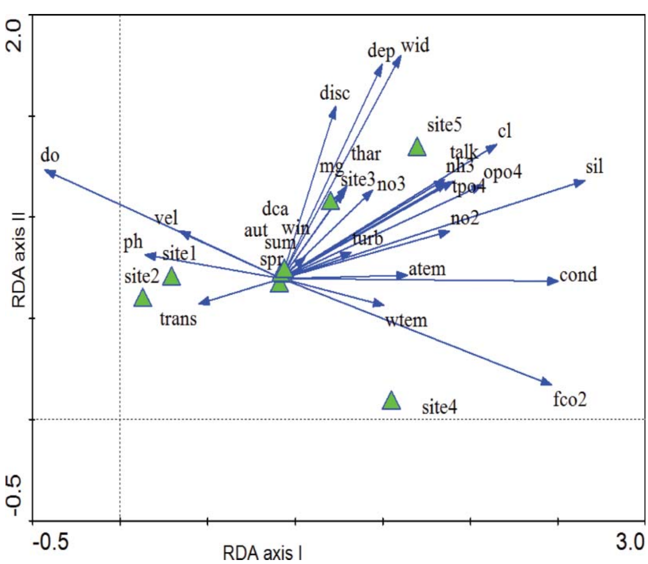

Figure 2. Redundancy analysis (RDA) ordination showing environmental variables correlated with RDA1 and RDA2 (aut = autumn, spr = spring, sum = summer, win = winter, site 1, 2, 3, 4 and 5 = site A, B, C, D and E). For variable codes, see Table 2.

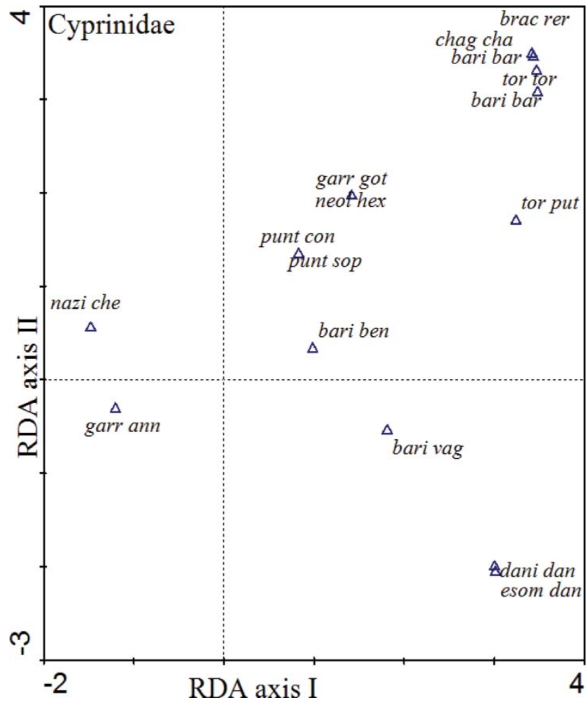

Figure 3. RDA ordination of cyprinid species in the Seti Gandaki River Basin. For species codes, see Table 1.

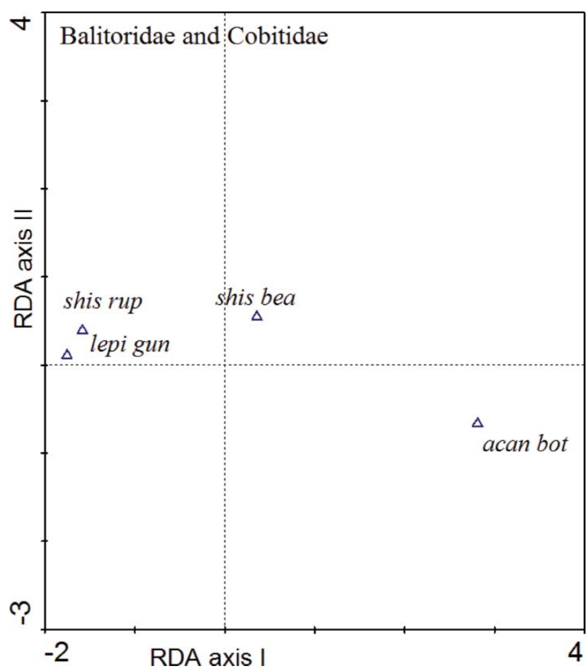

Figure 4. RDA ordination of balitorid and cobitid species in the Seti Gandaki River Basin. For species codes, see Table 1.

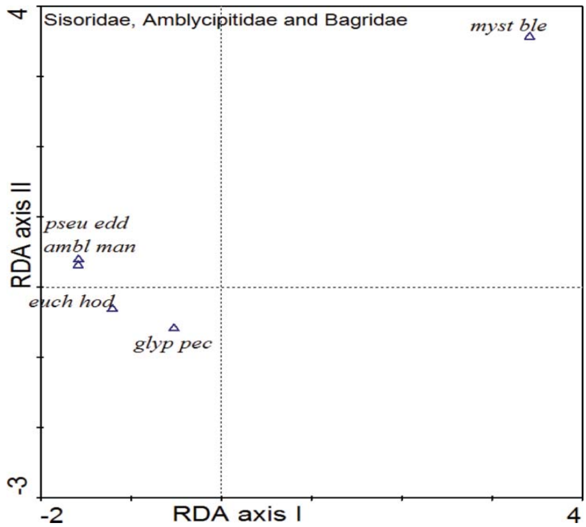

Figure 5. RDA ordination of sisorid, amblycipitid and bagrid species in the Seti Gandaki River Basin. For species codes, see Table 1.

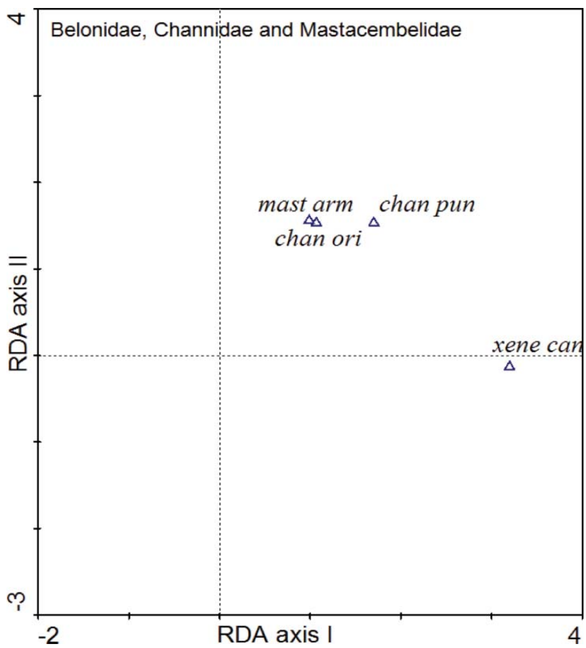

Figure 6. RDA ordination of belonid, channid and mastacembelid species in the Seti Gandaki River Basin. For species codes, see Table 1.

Site–environmental variable relationships

The positioning of study sites in relation to the environmental variables is shown in Figure 8. Sites A and B located in the upstream area are in the upper and lower left quadrants of the RDA plot to which the seasonal variables autumn and spring were also found aligned. These sites had higher than average pH and DO; near or below the average depth and width; while lower than average chlorides, NH_3–N, PO_4^{3-}, SiO_2, conductivity and F-CO_2. Among the above-mentioned variables, DO and pH had higher values during spring and winter seasons. Sites C and E located in the urban

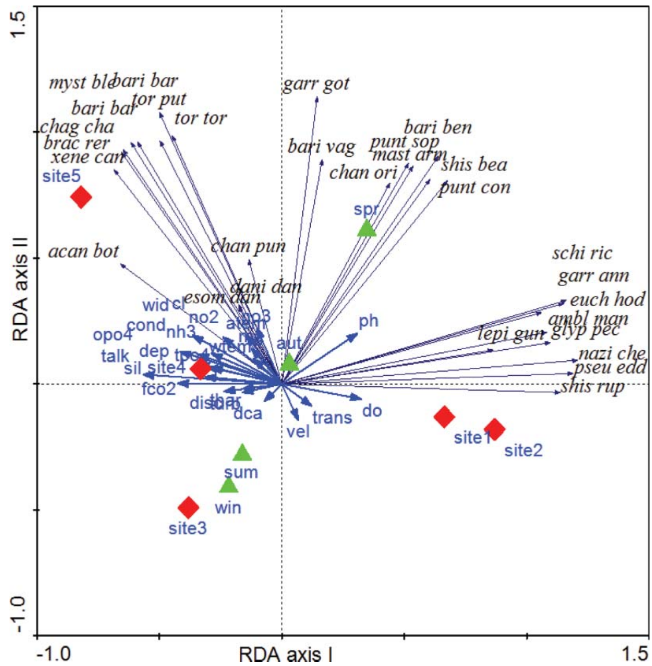

Figure 7. RDA ordination of fish species in relation to sites in the Seti Gandaki River Basin. (aut = autumn, spr = spring, sum = summer, win = winter). For variable codes, see Table 2 and for species codes, see Table 1.

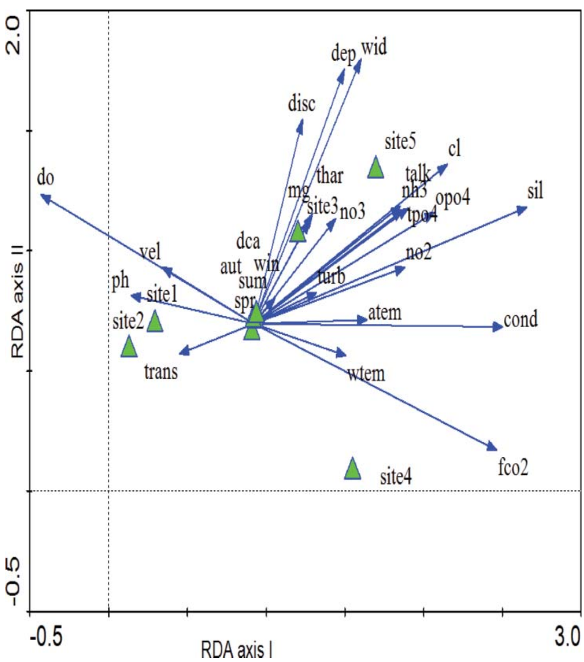

Figure 8. RDA ordination of sites in relation to environmental variables in the Seti Gandaki River Basin. (aut = autumn, spr = spring, sum = summer, win = winter, site 1, 2, 3, 4 and 5 = site A, B, C, D and E). For variable codes, see Table 2.

and downstream areas are in the upper right quadrant of the RDA plot. These sites had high or higher than average values of depth, width, chloride, NH_3–N, PO_4^{3-}, SiO_2, conductivity and F-CO_2. The above-mentioned variables had higher values during summer season. Likewise, Site D located in the downstream area is in the lower right quadrant of the RDA plot, had higher than average conductivity, F-CO_2, SiO_2, PO_4^{3-}, chlorides and NH_3–N; while lower than average pH, DO, depth and width. Among the above-mentioned variables conductivity, pH, DO and chlorides had lower; while F-CO_2, PO_4^{3-}, NH_3-N, SiO_2, depth and width had higher values during summer season.

An increasing trend of species richness from upstream Site A (17 species) to downstream Site E (21 species) was recorded exhibiting a longitudinal distribution pattern. Game fishes (*Tor tor*, *Tor putitora* and *Chagunius chagunio*), Zebra-fish (*Danio rerio)*, the hill-stream loach (*L. guntea*), and hill-stream catfishes (*P. hodgarti* and *A. mangois*) were not common in the study area (Table 1).

Discussion

Species–environmental variable relationships

Stream-size (channel depth and width), discharge and F-CO_2 have been mentioned as the most important habitat variables correlated with fish assemblage composition in Red River, USA, and North Tiaoxi River, China (Koel and Peterka 2003; Li et al. 2012). Likewise, Edds (1993) and Dubey et al. (2012) observed that the habitat variables such as conductivity, DO, pH, alkalinity, and salinity were most strongly correlated with the fish community composition of the Kali Gandaki River Basin, Nepal, and the Ganga River Basin, India. In other studies, phosphates, nitrates and silicates were significantly correlated with the fish assemblage structure of Red River North Basin, USA, and Upper French Broad River Basin, USA (Goldstein et al. 1993–1995; Rashleigh 2004). The most important environmental variables structuring the fish assemblage in the Seti Gandaki River Basin were depth, width, conductivity, DO, F-CO_2, SiO_2 and chlorides. Some other variables such as, pH, PO_4^{3-}, chlorides and NO_3–N were also important in structuring the fish communities.

Species–site relationships

Cold-water cyprinids were dominant, followed by balitorids and sisorids at the upstream sites as mentioned in the Tamor River and the Pokhara Valley, Nepal (Shrestha et al. 2009; Pokharel 2010). The downstream sites influenced by urbanization with some increase in depth and discharge were inhabited by the degraded habitat tolerant cyprinids followed by channids, mastacembelids and balitorids or by other tolerant groups having less oxygen requirements as reported from the Narayani River, Nepal; the Upper French Broad River Basin, USA; and the Seti Gandaki River, Nepal (Edds et al. 2002; Rashleigh 2004; Pokharel 2011). The further downstream sites having improvement in habitat degradation and with increased depth and discharge were inhabited by the cyprinids followed by balitorids, channids, mastacembelids and bagrids or by other groups which prefer deeper waters as mentioned in various studies in the Piedmont River, Argentina; in the Rio Grijalva Basin, Southern Mexico; and in the Tons River, India (Fernandez and Bechara-Conicet 2010; Pease et al. 2012; Negi and Mamgain 2013). Similarly, occurrence of species having higher oxygen requirements at the upstream sites, when compared with urban and downstream sites, in the present study, could be due to the physio-hydrological characteristics as well as human interference to the riverine environment.

An increasing trend of species richness from upstream to downstream sites can be attributed to increasing depth, width, discharge and capacity to tolerate higher levels of free carbon dioxide, alkalinity, conductivity, turbidity and nutrients. The lower species richness at the upstream site and middle urban site of main channel could be due to lower values of temperature, depth, width, discharge and nutrients (NO_3 and PO_4), and due to entrance of wastes into the river changing the abiotic characteristics at urban site. But it was higher at the downstream sites due to higher temperature, depth, width as well as improvement in the effects of urban influence.

Site–environmental variable relationships

Environmental variables such as DO and pH were higher, but F-CO_2, conductivity, chlorides, compounds of nitrogen (NH_3–N, NO_2–N and NO_3–N) and compounds of phosphorus (PO_4^{3-} and TP) were lower at upstream sites but higher at urban and downstream sites due to human impact on the riverine environment. Martin and Haniffa (2003), Kannel et al. (2008) and Bu et al. (2010) reported higher levels of DO and pH, but lower concentrations of F-CO_2, conductivity, compounds of nitrogen (NH_3, NO_2 and NO_3) and phosphorus (PO_4^{3-} and TP) at upstream sites with less human influence in the South Indian River Tamiraparani, the Bagmati River, Nepal, and the Jinshui River, China, respectively. In contrast, DO and pH were reported to be lower and F-CO_2, conductivity, compounds of nitrogen (N) and phosphorus (P) were found to be higher at the urban sites influenced by human activities in the Colorado River, USA; the Ramganga River, India; and the Bagmati River, Nepal (Osmundson et al. 2002; Pathani and Upadhyaya 2006; Kannel et al. 2008). Dieterman and Berry (1998), Osmundson et al. (2002) and Bu et al. (2010) mentioned the lower concentrations of DO and pH, but higher levels of F-CO_2, conductivity, compounds of nitrogen (N) and phosphorus (P) at downstream sites of the Big Sioux River; the Colorado River, USA; and the Jinsui River, China; though there may be some improvement in the deteriorated water quality while flowing downwards from the urban sites.

Harmful human activities observed in the study area such as deforestation and unscientific road construction in the watershed and the extraction of bottom substrata (sand, gravels, pebbles, cobbles and boulders) were leading to the destruction of habitat. Likewise, introduction of lethal chemical compounds/pesticides into the water for fishing and discharge of untreated wastes directly were deteriorating the natural characteristics of water. The above-mentioned activities certainly alter the abiotic habitat characteristics and in turn the biotic components of the riverine ecosystem.

To conclude, the important environmental variables in structuring the fish assemblage in the Seti Gandaki River Basin were conductivity, DO, F-CO_2, O–PO_4, NH_3, SiO_2–Si, depth, width, chlorides and NO_3. Redundancy analysis revealed the gradients from species requiring more oxygenated water of upstream sites to less oxygenated of urban and downstream sites, as well as those from species inhabiting deeper, wider and with higher flow urban and downstream sites to shallower, narrower and with lower flow upstream sites.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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