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

Kishor K. Pokharel a, Khadga B. Basnet b, Trilok C. Majupuria b and Chitra B. Baniya c

aDepartment of Zoology, Prithvi Narayan Campus, Pokhara, Nepal; bCentral Department of Zoology, Tribhuvan University, Kathmandu, Nepal; cCentral Department of Botany, Tribhuvan University, Kathmandu, Nepal

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, orthophosphate, 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.

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-CO₂), 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
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 km² (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 km², 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
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-CO₂, phosphates (PO₄³⁻), NH₃–N and SiO₂, 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 NO₃–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 Neolissoscheilus hexagonolepis preferred negatively correlated pH values. Likewise, several cyprinids preferred positively correlated values of depth, width, conductivity, F-CO₂, chloride and SiO₂–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-CO₂, chloride, SiO₂–Si, NH₃–N and O–PO₄ (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 NH₃–N (Figure 5). Among channids and mastacembelids, Channa orientalis and Mastacembelus armatus preferred positively correlated high or above
average values of depth, width, conductivity, F-CO₂, chlorides, SiO₂, NH₃–N, and PO₄³⁻, 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
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.

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  | 0.090| 0.30 |
| Width          | Wid  | 0.067861   | -0.146857  | 32.30| 13.00|
| Velocity       | Vel  | 0.351387   | -0.054590  | 0.110| 0.30 |
| 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| 0.05 |
| Water temperature| Wtem | 0.048596 | 0.055466 | 18.00| 0.04 |
| pH             | pH   | -0.085369  | -0.003832  | 08.00| 00.40|
| Dissolved O2   | DO   | -0.086310  | 0.042520   | 08.00| 02.00|
| Free CO2       | F-CO2| 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|
| Magnesium      | Mg   | 0.090860   | -0.078479  | 13.40| 08.00|
| Chloride       | Cl   | 0.001241   | -0.009065  | 24.30| 05.00|
| Ortho-PO4      | O-PO4| 0.163442   | 0.005067   | 00.005| 00.002|
| Total-PO4      | T-PO4| 0.176564   | -0.008506  | 00.100| 00.030|
| Ammonia        | NH3  | 0.125040   | -0.081492  | 00.200| 00.100|
| Nitrite        | NO2  | 0.128243   | -0.090944  | 00.010| 00.003|
| Nitrate        | NO3  | 0.142102   | 0.075632   | 00.130| 00.040|
| Silicate       | Sil  | 0.147266   | -0.080200  | 00.020| 00.020|

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.
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...

**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-CO₂, conductivity, chlorides, compounds of nitrogen (NH₃–N, NO₂–N and NO₃–N) and compounds of phosphorus (PO₄³⁻ 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-CO₂, conductivity, compounds of nitrogen (NH₃, NO₂ and NO₃) and phosphorus (PO₄³⁻ 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-CO₂, 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-CO₂, 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-CO₂, O–PO₄, NH₃, SiO₂–Si, depth, width, chlorides and NO₃. 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.

Acknowledgments

The authors are grateful to Dean’s Office, Institute of Science and Technology (IOST), Tribhuvan University, for approval to conduct the present work. Similarly, they are thankful to Mr R. G. Dhewajoo, Head of Department of Zoology, Prithvi Narayan Campus (PNC), Pokhara, for providing the laboratory facilities. Thanks are also due to Mr B. R. Pahari, Senior Lab Assistant, and Mr O. L. Jalari, Staff, PNC, Pokhara, for their assistance in the laboratory and field works.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Kishor K. Pokharel is a PhD scholar in fish biology at the Tribhuvan University in Nepal. His research focus is fish-environment relations and impact of human activities on riverine habitat.

Khadga B. Basnet is a professor at the Tribhuvan University in Nepal. His research focus is animal-environment relations and the impact of human activities on terrestrial and aquatic habitat.

Trilok C. Majupuria is a professor at the Tribhuvan University in Nepal. His research focus is Wildlife Biology and the impact of human activities on terrestrial and aquatic habitat.
Chitra B. Baniya is an associate professor at the Tribhuvan University in Nepal. His research focus is the study on Lichen Biology and multivariate statistical analysis.

ORCID

Kishor K. Pokharel http://orcid.org/0000-0002-1087-3871

References

APHA/AWWA/WEF. 1998. Standard methods for the examination of water and wastewater. 20th ed. Washington (DC): American Public Health Association (APHA), American Water works Association (AWWA) and Water Environment Federation (WEF).

Bista JD, Wagle SK, Nepal AP, Prasad S, Gurung TB. 2010. Scope of small-scale fisheries in natural resource management for livelihood enhancement of rural communities. Zoo J. 1(1):54–64.

Bu H, Tan X, Li S, Zhang Q. 2010. Temporal and spatial variations of water quality in the Jinshui River of the South Qinling Mountains, China. Eco-toxicol Environ Saf. 73(5):907–913.

Das SM. 1989. Aquatic pollution and fisheries in India. In: Khulbe RD, editor. Perspectives in aquatic biology. New Delhi: Papyrus Publishing House; p. 43–49.

Day F. 1878. The fishes of India, being a natural history of the fishes known to inhabit the seas and freshwaters of India, Burma and Ceylon (Volumes I and II). New Delhi: Today and Tomorrows Book Agency. (Reprint).

Dieterman D, Berry Jr CR. 1998. Fish community and water quality changes in the Big Sioux River. Prairie Naturalist. 30(4):199–224.

Dubey VK, Sarkar UK, Pandey A, Sani R, Lakra WS. 2012. The influence of habitat on the spatial variation in fish assemblage composition in an un-impacted tropical river of Ganga Basin, India. Aquat Ecol. 46(2):105–174.

Dudgeon D. 1999. Tropical Asian streams: zoobenthos, ecology and conservation. Hong Kong: Hong Kong University Press.

Edds, DR. 1993. Fish assemblage structure and environmental correlates in Nepal’s Gandaki River. Copeia. 1993 (1):48–60.

Edds, DR, Gillette DP, Maskey T M, Mahato M. 2002. Hot-soda process paper mill effluent effects on fishes and macro-invertebrates in the Narayani River, Nepal. J Freshw Ecol. 17(4):543–554.

Fernandez L, Conicet J AB. 2010. An assessment of fish communities along a Piedmont River receiving organic pollution (Aconquija Mountains, Argentina). Acta Biol Colombia. 15(2):79–100.

Ferrow W, Badgami PR. 1980. On the biology of the commercially important species of fish of the Pokhara Valley, Nepal. J Institute Sci. 3(1):237–250.

Gauch HG Jr. 1982. Multivariate analysis in community ecology. Cambridge: Cambridge University Press.

Goldstein RM, Stauffer JC, Larson PR, Lorenz DL. 1993–1995. Relation of physical and chemical characteristics of streams to fish communities in the red river of the North Basin, Minnesota and North Dakota.water resources investigations report. Minnesota (MN): National Water-Quality Assessment Program (NWQAP), U.S. Geological Survey.

Golterman HL, Clymo RS, Ohnstad M. 1978. Methods for physical and chemical analysis of freshwaters. IBP Hand Book No. 8. 2nd ed. Oxford: Blackwell Scientific Publishers.

Hijmans RJ, Elith J. 2013. Species distribution modeling with R. Available from: http://cran.r-project.org/web/packages/raster/vignettes/Raster.pdf

Humpl M, Pivnicka K. 2006. Fish assemblages as influenced by environmental factors in streams in protected areas of the Czech Republic. Ecol Freshw Fish. 15:96–103.

Jayram KC. 1999. The freshwater fishes of Indian region. New Delhi: Narendra Publishing House.

John A, Dhewajoo RG. 1989. Effect of ecological parameters on fishes of Pokhara Valley. A report. Kathmandu: Royal Nepal Academy of Science and Technology (RONAST).

Kannel PR, Lee S, Lee VS. 2008. Assessment of spatial-temporal patterns of surface and ground-water quality and factors influencing management strategy of ground-water system in an urban river corridor of Nepal. J Environ Manag. 86(4):595–604.

Koel TM, Peterka JJ. 2003. Stream fish communities and environmental correlates in the Red River of the North Minnesota and North Dakota. Environ Biol Fish. 67(2):137–155.

Kouamelan EP, Teugels GG, Douba VN, Goore G Bi, Kone T. 2003. Fish Diversity and its relationships with environmental variables in a West African basin. Hydrobiologia. 505:139–146.

Li J, Huang L, Zhou L, Kano Y, Sato T, Yahara T. 2012. Spatial and temporal variation of fish assemblages and their associations to habitat variables in a mountain stream of North Xiaoxi River, China. Environ Biol Fish. 93(3):403–417.

Lin S-J, Tsai S-T, Lin J-H, Jong K-J, Wang Y-K. 2013. Changes in structure and function of fish assemblages along environmental gradients in an intensive agricultural region of subtropical Taiwan. Pacific Sci. 68(2):1–33.
Martin R, Haniffa MA. 2003. Water quality profile in the South Indian River Tamiraparani. J Environ Prot. 23(3):286–292.

Negi RK, Mangaim S. 2013. Species diversity, abundance and distribution of fish community and conservation status of Tons River of Uttaranchal State, India. J Fish Aquat Sci. 8:617–626.

Osmundson, DB, Rayl RJ, Lamarr VL, Pittlick J. 2002. Flow-sediment-biota relations: Implications for river regulation effects on native fish abundance. Ecol Appl. 12(6):1719–1739.

Oksanen J, Blanchet FG, Kindr P, Legendre P, Minchin PR, Ohara RB, Simpson GL, Solymos P, Henry M, Stevens H, et al. 2015. vegan: Community ecology package. R package version 2.3-1. Available from: http://CRAN.R-project.org/package=vegan.

Palmer MW. 1996. The ordination gopher (online). Available from: gopher://bubha.unc.okstate.edu/oo/academis/bot any/ordinate

Pathani SS, Upadhyaya KY. 2006. An inventory of zooplankton, zoobenthos and fish fauna in the River Ramganga (W) of Uttaranchal, India. Envis Bull Himalayan Ecol. 14(2):37–46.

Pease AA, Gonzalez-Diaz AA, Rodiles-Hernandez R, Winemiller KO. 2012. Functional diversity and trait-environment relationships of stream fish assemblages in a large tropical catchment. Freshw Biol. 57:1060–1075.

Pokharel KK. 2010. Fisheries resources of Pokhara Valley, Nepal: sustainable use and conservation. In: Jha PK, Karma-charya SB, Balla MK, Chettri MK, Shrestha BB, editors. Sustainable use of biological resources in Nepal. Kathmandu: Ecological Society (ECOS); p. 188–190.

Pokharel KK. 2011. Study on fish ecology of the Seti Gandaki River, Pokhara, Nepal. II. Spatio-temporal variations in fish communities. Nepal J Sci Technol. 12:350–357.

Rai AK. 2005. Potential of indigenous riverine fish species in Nepal. Lalitpur: Fisheries Research Division. (Occasional Papers).

Rashleigh B. 2004. Relation of environmental characteristics to fish assemblages in the Upper French Broad River-Basin, North Carolina. Environ Monit Assess. 93(1–3):139–156.

R Core Team. 2015. R: A Language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Available from: http://www.R-project.org

Ricker WE. 1968. Introduction to methods for assessment of fish production in freshwater. In: Ricker WE, editor. Methods for assessment of fish production in freshwaters. Oxford: International Biological Program (IBP) and Blackwell Scientific Publications; p. 1–6.

Seber GAF, Le Cren FD. 1967. Estimating population parameters from catches large relative to the population. J Anim Ecol. 36:631–643.

Sharma CK. 1977. River systems of Nepal. Kathmandu: Ms Sangeeta Sharma.

Shrestha J. 1981. Fishes of Nepal. Kathmandu: Curriculum Development Center, Tribhuvan University.

Shrestha J. 2001. Taxonomic revision of fishes of Nepal. In: Jha PK, Baral, SR, Karmacharya, SB, Lekhak, HD, Lacoul P, Baniya CB, editors. Environment and agriculture: Biodiversity, Agriculture and Pollution in South Asia. Kathmandu: Ecological Society (ECOS); p. 171–180.

Shrestha J, Singh DM, Saund TB. 2009. Fish diversity of Tamor River and its major tributaries of eastern Himalayan region of Nepal. Nepal J Sci Technol. 10:219–223.

Shrestha TK. 2008. Ichthyology of Nepal. Kathmandu: Himalayan Ecosphere.

ter Braak CJF. 1986. Canonical correspondence analysis-a new eigenvector technique for multivariate direct gradient analysis. Ecology. 67(5):1167–1179.

ter Braak, CJF. (1988a). CANOCO: A FORTRAN Program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis, principal component analysis and redundancy analysis (Version 2.1). Wageningen: Agricultural Mathematics Group. (Report LWA-88-02).

ter Braak CJF, Prentice IC. 1988. A theory of gradient analysis. Adv Ecol Res. 18:271–317.

Tripathi MP. 1985. Ecology of Pokhara Valley. In: Majupuria TC, editor. Nepal – nature’s paradise. Bangkok: White Lotus Company; p. 438–452.

Trivedy RK, Goel PK. 1984. Chemical and biological methods for water and pollution studies. Karad: Environmental Publications.

Vibert R. 1967. Fishing with electricity: its application to biology and management. Proceedings of a symposium. London: European Inland Fisheries Advisory Committee, Food and Agricultural Organization (FAO). Fishing News Books Limited.

Wetzel RG. 2001. Limnology: lake and river ecosystems. 3rd ed. San Diego (CA): Academic Press.

Winemiller KO, Tarim S, Shormann D, Catner JB. 2000. Fish Assemblage structure in relation to environmental varia-
tion among Brazos river oxbow lakes. Trans Am Fish Soc. 129:451–468.

Wu J, Wang J, He Y, Cao, W. 2011. Fish assemblage structure in the Chisui River, a protected tributary of the Yangtze River. Knowl Manag Aquatic Ecosyst. 400:11 p 1–14.

Zhao J, Fu G, Lei K, Li Y. 2011. Multivariate analysis of surface water quality in the Three Gorges area of China and implications for water management. J Environ Sci. 23(9):1460–1471.