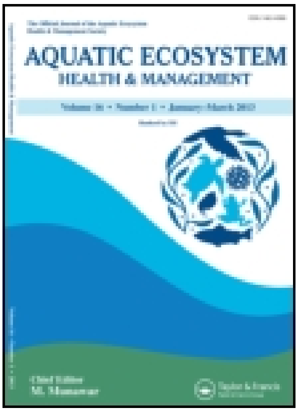

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Ecosystem health indicators in the Ganga Basin (Uttarakhand, India): Biodiversity, spatial patterns in structure and distribution of benthic diatoms, macro-invertebrates and ichthyofauna

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Ecosystem health indicators in the Ganga Basin (Uttarakhand, India): Biodiversity, spatial patterns in structure and distribution of benthic diatoms, macro-invertebrates and ichthyofauna

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This is the pioneering attempt to study the spatial patterns in structure of lotic ecosystems that form the Ganga River system in the Himalaya. The diversity of source (glacier-fed [GF], snow-fed [SN] and spring-fed [SF]) and stream-size (both interrelated) across the altitudinal panorama, create numerous habitats that contribute to structural diversity. The spatial patterns in richness, density and taxonomic composition and distribution of benthic diatoms are less affected by source compared with macro-invertebrates but shows strong influence on the distribution of fish fauna that are poikiliotherms, because a glacier-fed river carries ice-cold water (usually <20°C) in contrast to normal waters in spring-fed system (22°C near snowline, 32°C in foothills). The abundance patterns of biota of lower organisation grade (diatoms, macro-invertebrates) do not differ sharply even across distant river basins as they are more influenced by proximate factors; thus the sub-basins of the Alaknanda resemble more by virtue of one basin and there is notable resemblance between distant SF Bemunda (lower Ganga basin) and SF Gomti (East Rāmgangā basin) and even the farthest Yamuna and Rāmgangā. Fish are more sensitive to temperature and current velocities that are related to altitude and hence longitudinal rather than the spatial gradients in the mountains. The lotic ecosystem of Doon Valley harbour rich and diverse diatom flora, macroinvertebrate fauna and ichthyofauna. The examination of trophic, saprobic and ecological status shows that organic pollution, degradation and anthropogenic eutrophication are non-existent in the Lesser Himalayan rivers and streams, but the fragile Doon Valley is under severe anthropogenic stress. This and habitats fragmented by hydropower projects in the major rivers has threatened the iconic game fish Himalayan mahseer in the Ganga.

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[Supplementary materials are available for this article. Go to the publisher's online edition of *Aerosol Science and Technology* to view the free supplementary files.]

Introduction

An understanding of biodiversity distribution in relation to the abiotic environment enhances our predictive abilities in ecological studies and resource management. Vast riverine network of the Ganges (always referred to as holy Ganga in ancient and modern scriptures of Hindustan) in the Himalaya was politically hyped to be an enormous hydropower potential in the economy starved Uttarakhand State separated from the State of Uttar Pradesh in year 2000 (Joshi, 2007). The sister-rivers (Bhagirathi and Alaknanda) that unite to form the Ganga are already affected by urbanisation at major pilgrim destinations and are discharge-starved for long distances below the Maneri, Tehri and Vishnuprayag dams (Singh, 1988; Gaur, 2007; Rajvanshi et al., 2012). Sixty-nine hydro-electric projects (>25 MW) are envisaged (includes commissioned, under construction and proposed) in the Bhagirathi and Alaknanda River systems. Loss of torrential flows and ice-coldwater are the major threats to the specialised biota of the Gangetic riverine network in the mountains.

The streams and rivers of Doon Valley are also under immense stress, as Dehradun, the present capital city of Uttarakhand is located centrally in the valley. Phenomenal urbanization in last 12 years has transformed the agriculture landscape into residential, administrative and commercial zones. The Song system drains the eastern part of the Doon Valley into the Ganga. The Asan system drains the western part of the Doon Valley into the Yamuna. The climate, terrain, vegetation and geology of this valley and the mountains are different (Kandari and Gusain, 2001). As the valley lies at the junction of the Indo-Gangetic Plains and the Himalayas, it supports unique biotic communities such as the fish fauna (Hora and Mukerjee, 1936). Many of these species have declined in abundance. Major rivers (Song and Asan) of the Doon Valley are prime spawning-cum-nursery grounds of the mahseer (Nautiyal et al., 2008). The degradation in the mountain and valley is affecting the river ecosystems, habitats and the biotic diversity at all trophic levels; such as decline in density of benthic macro invertebrates and diatoms due to sewage influx (Singh et al., 1994; Nautiyal et al., 1996) and decline in the stock of Himalayan mahseer due to river regulation for hydropower and irrigation, respectively at Veerbhadra and Bheemgoda, where the congregation of migrating individuals including potential brooders in the shallow areas below the barrages become easy targets. Year after year, poaching of brood stock during the spawning period and indiscriminate juvenile fishing in the major breeding-cum-nursery grounds of the mahseer in the valley and Nayar (a tributary of the Ganga between Devprayag and Rishikesh in the Lesser Himalayas), has caused multifold decline in numbers (Nautiyal, 1996, 2006) and endangered the species (Jha and Rayamajhi, 2010).

Hence, there is an imminent need to organise information on the biodiversity and structure of major biotic communities in natural or near-natural conditions and their distribution in the glacier fed (GF), snow fed (SN) and spring fed (SF) tributaries of the River Ganga, both in the mountain terrain of the Himalayas and in the flatter sloping terrain of the Doon Valley. The network of GF, SN and SF streams offers a great diversity of habitats and ecological communities in the Gangetic basin. The Doon Valley has been treated separately with respect to these communities owing to its present demography, as it is a small area with concentrated human activity in the Gangetic basin. In this respect the predictive ability of diatom assemblages (Dohet et al., 2008) was used to determine the trophic and saprobic state of the rivers. Since the valley lies at the junction of Plains and West Himalayan ecoregions, the communities are expected to be diverse, that render value to the valley part of the basin. Substrate heterogeneity is another reason for the diversity of benthic communities, which increases from the source of rivers and streams in high mountains to the foothills (Doon Valley).

The benthic assemblages have been mostly studied at certain locations or river sections or longitudinally in the Bhagirathi (Singh et al., 1994), Alaknanda and Ganga Rivers (Nautiyal R et al., 1996; Nautiyal P et al., 1997; Nautiyal R et al., 2000). Studies have also been made at single (Nautiyal P et al., 2004a; Verma and Nautiyal, 2009) and multiple river basins (Nautiyal, 2005a, 2009) of the Ganga River system. The fish fauna and their distribution in the Gangetic drainage has also been extensively studied (Singh et al., 1987; Husain, 1995; Husain and Tilak 1995, Nautiyal, 2005b, Nautiyal et al., 2013). Studies on biodiversity and ecosystem are scarce for the Ganga on the Himalayan part/hill stream habitats of the Ganga (Nautiyal and Nautiyal, 1999; Nautiyal et al., 2004b; Nautiyal, 2010; O'Keeffe et al., 2012) compared with extensive literatures especially with respect to fish biodiversity and fisheries in the middle, lower and estuarine stretches of the Ganges (Anonymous, 1975–2006; Krishnamurti et al., 1991; Payne and Temple, 1996; Sinha et al., 1998; Rao, 2001; Payne et al., 2003; Vass et al., 2009, 2010).

Though much remains unknown, the scope of this study is restricted to the patterns of the taxonomic richness, composition and distribution of freshwater biota in the GF, SN and SF ecosystems of the Ganga River basin in the State. The relation of stream-source (GF and SF) with the diversity and spatial distribution of benthic communities and fish fauna in the basin has also been examined. The present study is an attempt towards the development of a framework that aims at predicting aquatic communities in order to assess quality of aquatic ecosystem, define river restoration and other such objectives to meet the challenges posed by hydropower development plans for the State.

Study area and methodologies

The Himalayan River Ganga originates in the State of Uttarakhand in India (see Appendix I in the online supplementary information [SI]). The entire drainage of State forms the basin of the Ganga. The River Ganga (including the Alaknanda and Bhagirathi River systems) lies centrally in the State. The Yamuna basin lies to west while the Kali-Sharda lies to east forming State border with Himachal Pradesh and International border with Nepal, respectively. The river has a dense network of glacier fed (GF), snow fed (SN) and spring fed (SF) tributaries of varying magnitudes from snowline to foothills, thus providing habitats defined by ice-cold (GF, SN) and normal (SF) temperature regimes (Nautiyal 2001), in addition to those created by flow conditions such as the rapids, runs, riffles and pools. The course of the Ganga moves in southwest direction throughout the mountains. The channels of the river and its tributaries in the mountains is divisible into; short stretches in the Greater Himalaya, long stretches through the Lesser Himalaya till Rishikesh and a small stretch of the Ganga through the Siwaliks along the left bank and Doon Valley along the right bank from Rishikesh to Hardwar. After the confluence of GF-Bhagirathi and GF-Alaknanda at Devprayag, the unified GF-Ganga flows for 87.7 km till Hardwar. The Nayar, Hinyul (north and south) and Song, are the major SF-tributaries in this stretch. The GF-Yamuna flows parallel to the Bhagirathi and then the Ganga in the Upper Ganga Plain. The west Rāmgangā flows across the Upper Ganga Plain into the Ganga before Kanpur. The Kali tilts further eastward and joins the middle segment of the Ganga. All major river basins were considered for the study and are demarcated in Appendix I, the locations of which are listed in Appendix II (in the SI). The climate, physiography, vegetation and land use of all basins are known (Singh et al., 1994; Nautiyal et al., 2004a,b; Gaur, 2007; Nautiyal, 2009; Nautiyal, 2010, O'Keeffe et al., 2012).

The physiography and geology of the Doon valley differs from the Himalaya (Wadia, 1983). The Doon region is a unique synclinal valley between the parallel ranges of lesser Himalaya and Siwaliks extending from Hardwar to Paonta Sahib. The valley is drained by Song and Asan in the eastern and western Doon, that have source in the lesser Himalaya and the Siwalik foothills near Chandrabani, respectively. Their channel is narrow and the banks are raised due to hills. Hard stony bottom is characteristic to both, but the Asan lacks large boulders conspicuous in the Song. Numerous streams and brooks join these arteries, some of which were considered in this study and had a mixture of hard and soft sediments on the bottom. Only Siwaliks are forested, especially in the Rajaji National Park. Tourism is a major activity by virtue of its proximity to the hill station Mussorie. The pharmaceutical industries are located in the Asan basin while the distilleries and sugar mills in the Song basin.

The water characteristics, benthic diatoms, macroinvertebrates and fish were examined for determining biodiversity and spatial patterns in community structure and distribution. Most of the GF and SF tributaries of the Ganga were sampled seasonally. Not all communities were sampled at same location and same time. They were sampled at different times during last 11 years from 2000 to 2011. The altitude of sampling location ranges from 2500 to 250 m asl (above sea level) of which Doon Valley ranged from 350–550 m asl (Appendix II). The diatom samples were obtained by scraping 3 × 3 cm surface of cobbles collected from river/stream bed, with the help of razor and brush. The benthic macroinvertebrates were sampled by lifting stones (boulder, cobble, pebble, gravel) and sieving clay and silt from 0.09 m^2 area. The substrate was washed to dislodge the fauna, which was preserved in 5% formalin for further analysis. Both communities were sampled in available habitats at each station. Other details of standard sampling, taxon identification and data analysis are described in Nautiyal et al. (2004a,b) and Nautiyal (2005a, 2009, 2010, 2012). The functional feeding groups occurring in the benthic macroinvertebrate community were ascertained according to Cotta Ramusino et al. (1995, http://www.riversource.net.pdf) to assess predominant feeding guilds and determine the state of the ecosystem (auto/heterotrophic).

Commercial landings are made from the Ganga below Hardwar only (Nautiyal et al., 2005b). Locally designed traps are used for fishing in GF rivers while cast nets are operated in SF tributaries (Nautiyal 1994). Fish were collected seasonally from fishermen in 2010–2011 from the locations of GF rivers and SF tributaries in Lesser Himalaya (LH) and the Doon Valley (DV) indicated in Appendix II. Present study details the abundance of the commonly occurring fish fauna recorded by Uniyal (2002, 2010) from 4 locations each in the Asan (Chandrabani, Baronwala, Jhajra, Dhalipur) and Song (Mothorawala, Lachhiwala, Nepali farm, Satyanarayan). The fish fauna was assessed for threat based on the Conservation Assessment of Management Plan (CAMP) (1998). The abundance pattern of the said communities in the GF and SF tributaries were also examined (Cluster Analysis Ward's method, Bray-Curtis Similarity, CAPS ver 4.0 [2007]).

The impacts of fast-paced urbanisation (growth of commercial and residential areas) during last one decade in the Asan and Song basins of the Doon Valley were assessed through benthic diatom and macroinvertebrate communities. A diatom based software (OMNIDIA ver. 5.3) that generates variety of indices from the diatom count data was used to compute the Van Dam Index, to explain the ecological (trophic and saprobic) state for some locations of the Doon Valley (Appendix II).

Salient observations

Physico-chemical characteristics

The water temperature (WT) is higher in the eastward basins compared to the westward basins and hence seems to decline slightly to west with increase in latitude. The GF are characterised by ice cold-waters and voluminous discharge where WT barely exceeds 20°C in GF compared with SF (22°C near snowline, 32°C in foothills) and high flows result in shooting current velocities (CV) compared with SF (Appendix III in the SI). The average WT (10–30°C) and CV (0.25–1.75 ms^{-1}) observed in 28 streams of Himachal Pradesh (Johal and Rawal, 2005) are comparable. WT and CV are detrimental to biota in mountain streams. In view of their ability to structure assemblages, Nautiyal (2001) classified the rivers into glacier fed turbulent- stenothermal and spring fed placid-eurythermal to account for differences in their biota. The air temperature (AT), WT, pH, conductivity, total alkalinity and total hardness are low in the Yamuna, Bhagirathi and Mandakini basins and higher in the Alaknanda, Ganga and Rāmgangā basins as also recorded in the Bhagirathi-Ganga (Vass et al., 2010). The CV is higher in the Yamuna, Bhagirathi and Mandakini basins while the dissolved oxygen is almost similar in all basins. The increase in water temperature and decrease in CV was observed in the Ganga River from source to foothills (Singh et al., 1994; Joshi, 2005). GF and SF differ more in physical than the chemical features (Appendix III). Except for relatively higher total alkalinity and chloride in the SF basins, the water chemistry GF and SF does not differ notably, because geology is largely similar in sub-basins and even across the sub-basins. The nutrients; nitrate, phosphate and silicate do not show any trend as streams and rivers are in oligotrophic conditions. The concentration of phosphates and nitrates is relatively higher in the GF.

Ecosystem structure

Diatoms are one of the most abundant and diverse components of stream and river algal communities (Stevenson and Pan, 1999), this was also observed in the Alaknanda-Ganga as they account for 87.9 to 100% of phytobenthos density (Nautiyal et al., 1997; Badoni et al., 1997). Nautiyal (2001) observed that the diatom density is low in the GF ($<$1000 cells mm^{-2}) compared with SF (1000–3000 cells mm^{-2}). Density peaked in winter, in both GF and SF in all basins because high transparency during lean flows from October to February results in accumulation of producer biomass. The snow-melt in GF causes decline in density compared with SF where density is relatively higher.

Table 1. Diatom flora of the Yamuna, Bhagirathi, Mandakini and Alaknanda basins in Lesser Himalaya (LH) and Doon Valley (DV; A/S = Asan/Song).

	No. of Species			No. of Species			No. of Species	
Family Genera	LH	DV A/S	Family Genera	LH	DV A/S	Family Genera	LH	DV A/S
CENTRALES			MONORAPHID			*Gomphonema*	38	15/14
Thalassiosiraceae			Achnanthaceae			*Gyrosigma*	5	2/2
Aulacoseira	1		*Nupela*	1		*Geissleria*	1	
Cyclotella	3	1/3	*Planothidium*	2		Naviculaceae		
Melosiraceae			*Achnanthidium*	61	14/14	*Hippodonta*	1	
Melosira	1		*Cocconeis*	7		*Luticola*	1	
PENNALES			Naviculaceae			*Navicula*	50	35/18
ARAPHID/			*Adlafia*	3		*Neidium*	4	1/0
Fragilariaceae			*Amphipleura*	1	1/0	*Pinnularia*	12	4/3
Meridion	1		*Anomoeoneis*		0/1	*Placoneis*	2	
Diatoma	9	5/6	*Amphora*	6	3/1	*Reimeria*	3	
Fragilariforma	1		*Brachysira*	1		*Sellaphora*	5	4/4
Fragilaria	9	3/1	*Caloneis*	9	5/2	*Stauroneis*	7	1/0
Hannae	3		*Craticula*	4		Epithemiaceae		
Staurosira	4		*Cymatopleura*	1	1/1	*Epithemia*	4	
Staurosirella	3		*Cymbella*	29	5/3	*Rhopalodia*	4	1/0
Synedra	21	10/6	*Cymbopleura*	8		Bacillariaceae		
Tabellaria	1		*Delicata*	2	1/0	*Denticula*	1	
Peronia	1		*Diploneis*	4	2/3	*Hantzschia*	5	2/1
Eunotiaceae			*Encyonema*	13	2/2	*Nitzschia*	34	26/15
Eunotia	13	1/0	*Encyonopsis*	5		Surirellaceae		
Rhoicosphenia	3		*Frustulia*	1	1/1	*Surirella*	10	2/2
			Fallacia	1	1/0			

The diatom flora consists of 420 taxa from Yamuna, Bhagirathi and Alaknanda-Ganga River systems (Table 1). Compared to these basins of LH, the DV is very rich in diatom flora (358 diatom taxa). The diversity and evenness vary from 4.32–4.69 and 0.19–0.39, respectively. Most speciose genera (in order of richness) were *Achnanthidium* and *Navicula*. *Achnanthidium* species dominated assemblages in torrential mountain streams and rivers. Assemblages in the headwaters of SF streams closer to the snowline (*A. minutissimum* — *D. hyemale*) differ from those in mid hills (*A. minutissimum* — *Cymbella excisa*). The assemblages barely differ among the basins. The diversity and evenness was similar in GF and SF. The richness, however, seems to be greater in GF, which may be related to highly variable flows in a larger area and hence greater number of microhabitats in a river than in a stream. This is explained by the observation that 193 taxa occurred at one station in GF Alaknanda, 252 taxa from 13 stations in the Alaknanda-Ganga (Nautiyal et al., 2004b) compared with 116 taxa from 4 stations in a SF stream in LH, while 182 taxa and 139 taxa respectively, in the Asan (16 stations) and Song (13 stations) basins in DV. Similarly, 200 taxa were recorded from 29 varied locations (2 GF, 5 SN, 22 SF locations from 18 streams) of the Mandakini basin.

The density of macroinvertebrates was low in the GF compared with SF (Table 2). The maximum density declined from the Yamuna to Alaknanda (includes Pindar) basin, being least in the Bhagirathi (attributed to Maneri and Tehri dams) and increased eastwards in the SF Rāmgangā basins, which relates to phytobenthos densities, possibly due to decreasing latitude. The density varies seasonally; peak in winter and fall during monsoon floods. The benthic macroinvertebrates belong to 3 phyla, 12 orders and 31 families, primarily Trichoptera, Ephemeroptera, Diptera and occur in both the GF and SF streams. Trichoptera was the most family-rich order in GF (Alaknanda, Yamuna, East Rāmgangā basin) and SF streams (Mandakini, West Rāmgangā) of lesser

Table 2. Taxonomic richness (families) and FFG of the benthic macroinvertebrate fauna in the GF and SF streams/rivers of the various river basins in the Lesser Himalaya and its comparison with the Doon Valley.

Rivers/Stream	LH	Y	Y	B		M	Al	Al	G	ERG	WRG	DV	As	S	T
Source	GF & SF	GF	SN	GF	SF	SF	GF	SF	GF	GF	SF	SF	SF	SF	SF
Richness (No. of taxa)	9–33	31	31	30	30	31	31	30	9	31	31	4–12	16	7	14
Density (indiv. m^{-2})	11–1062	948.5–970.9	1016.5	106.7–539	209–502.7	529.8–687.5	585–877.9	761	11–550	710	913.5–1062	167–3585	414« 2680$^{\psi}$	891« 3585$^{\psi}$	167† 935«
Ephemeroptera	6	6	6	6	6	6	6	6	2	6	6	6		1	6
Trichoptera	8	8	8	7	7	8	8	7	2	8	8	4	3	1	3
Diptera	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2
Plecoptera	2	2	2	2	2	2	2	2		2	2	1	—	—	1
Coleoptera	3	3	3	3	3	3	3	3	1	3	3	1	1	—	1
Odonata	2	2	2	2	2	2	2	2	1	2	2	—	—	—	—
Lepidoptera	1	1	1	1	1	1	1	1		1	1	—	—	—	—
Hemiptera	1	1	1	1	1	1	1	1	1	1	1	1	1	—	—
Neuroptera	1	—	—	—		—	—	—	1	—	—	–	—	—	—
Platyhelminthes	1	—	—	—		—	—	—	1	—	—	—	—	—	—
Megaloptera	2	2	2	2	2	2	2	2		2	2				
Gastropoda	2	2	2	2	2	2	2	2	—	2	2	—	—	—	—
Arhynchobdellida		—	—	—		—	—	—	—	—	—	1	1	1	1
Basomatophora		—	—	—		—	—	—	—	—	—	2	2	2	—
FFG															
Shredder	1–19	3	3	1	1	2	2	1	19	3	2	—	—	—	—
Scraper	22–30	30	28	22	22	23	25	25	–	25	28	2–54	2–45	4–54	10–23
Gathering Collectors (GC)	26–74	35	34	44	42	35	40	43	74	27	26	28–85	28–58	35–85	59–65
Filtering Collectors (FC)	2–24	15	16	18	24	17	15	23	2	22	21	10–49	27–49	10–11	15–21
(GC + FC)	47–76	50	50	62	66	52	55	66	76	49	47	46–98	55–98	46–95	74–86
Predators	5–24	19	21	14	10	22	16	11	5	24	21	1–7	0–1	0–5	2–7

Acronyms: Al: Alaknanda; M: Mandakini; B: Bhagirathi; G: Ganga; Y: Yamuna; ERG: East Rāmgangā; WRG: West Rāmgangā; DV: Doon Valley; As: Asan; S: Song; T: Tawa; GF: Glacier fed; SN: Snow fed; SF: Spring fed. FFG: Functional feeding groups symbols: $^{\psi}$Winter, «Summer, †Monsoon.

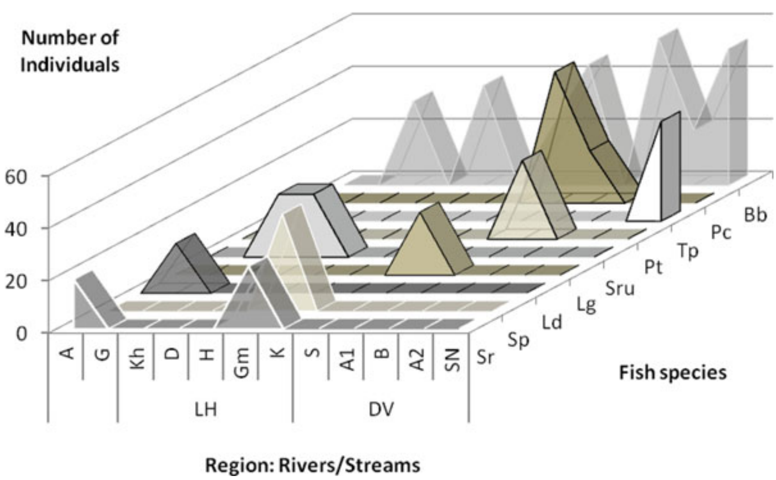

Figure 1. Highly abundant fish species (species with highest number of individuals among all rivers/streams) in Lesser Himalaya (LH) and Doon Valley (DV). Bb: *Barilius bendelisis*; Lg: *Lepidocephalicthys guntae*; Ld: *Labeo dero*; Pc: *P. conchonius*; Pt: *Puntius ticto*; Sr: *Schizothorax richardsonii*; Sp: *S. plagiostomus;* Sru: *Schistura rupecola*; Tp: *Tor putitora*. (Color figure available online.)

Himalaya. The collectors (gathering, filtering) predominate (>50%) in most of the GF and SF, and scrapers form the second important functional group (22 to 33%) in Lesser Himalaya (Table 2).

Singh et al. (1987) reported 69 fish species from the Garhwal region, Husain (1995) reported 126 species from west Himalaya. Based on these and other works Nautiyal (2005b) listed 133 species from the State. The commonly occurring fish fauna consisted of thirty four species from the GF and SF tributaries of Lesser Himalaya (LH); 10 species are common to GF and SF rivers/streams, 7 species occur only in the GF rivers/streams and 17 only to SF rivers/streams (Appendix IV). Snow Trout (*Schizothorax* spp.) occur abundantly (40 to 60%) in all GF rivers, except in the Tehri reservoir on the River Bhagirathi due to accidental introduction of *Cyprinus carpio*. The Snow-Trouts were abundant in the Ganga (G) and Gomti (Gm), while loaches in the Dhundseer Gad (D) and Kosi (K). *Barilius bendelisis* is abundant in both LH and Doon Valley (DV), but attains highest abundance in DV, where *Puntius* and *Tor* spp. also occur in abundance (Figure 1).

Effect of stream/river source on large-scale distribution patterns

The composition of diatom flora was more similar within the stem of Bhagirathi River than the adjacent GF Yamuna basin (Appendix V in the SI). Their resemblance with the Alaknanda is weaker. Composition of the epilithic diatoms is entirely different in the major GF rivers Alaknanda (partly), Yamuna and Bhagirathi (isolated small cluster at bottom) compared to other GF and SF streams (large cluster containing 2 sub-clusters each). The smaller cluster on the top also separates GF Alaknanda and its tributaries (Nandakini, Pindar, lower Mandakini and its high altitude GF and SN tributaries). The similarity among these GF rivers is attributed to similar source (glacier) and because they are part of the Alaknanda basin. Similarity with SN tributaries of Mandakini basin is due to their proximity to the snowline thus mimicking GF conditions for which reason the abundance of diatoms is similar in them. The larger middle cluster includes all SF streams of Mandakini, Alaknanda, East and West Rāmgangā (Gaula, Kosi) and lower Ganga (Khoh) basins, besides the GF Mandakini and Nandakini. Probably abundance of diatoms in high-order GF rivers tends to be similar to low-order SF streams. Similarity elevation range among these SF and GF sites may also govern abundance. The smaller cluster is distinct from others (large group) as it represents similarity among the E. Rāmgangā sites.

The benthic macroinvertebrate assemblages clearly segregate the Bhagirathi-Ganga from the rest. The remaining locations were grouped into three clusters; the uppermost GF Alaknanda, Nandakini, East Rāmgangā and SN/SF Mandakini basin streams (Appendix VI in the SI). The two small clusters are GF Yamuna and SF West Rāmgangā basin, and other sub-basins of the Alaknanda and Bhagirathi. There is notable similarity of distant GF Yamuna to SF West Rāmgangā basin.

For the fish assemblages, the GF and SF rivers are classified into two clusters; one exclusively of GF Alaknanda and its sub-basins the Nandakini, Pindar and Mandakini while the other of SF locations mixed with GF E. Rāmgangā/Sharda, Alaknanda, Bhagirathi and lower Ganga, possibly because some species are common among them (Appendix VII in the SI). Within the Alaknanda basin the SF Dhundseer Gad forms an exclusive cluster. This suggests a clear cut demarcation of the GF fauna as they prefer ice-cold waters and cannot tolerate water temperature of SF streams except in younger stages or during monsoon floods. While the GF fauna is widespread in the main river of each basin, some SF fauna is restricted to certain basins viz. Kosi (*Balitora*). Within the SF cluster there is no specific trend and even distant streams resemble each other (e.g. SF Bemunda of lower Ganga basin and SF Gomti of East Rāmgangā basin, Bhilangana of Bhagirathi with Sharda). The GF (East Rāmgangā; Sarju and Bhagirathi; Balganga) basins are also similar with Alaknanda and Mandakini basin. The Ganga basin shows similarity with the Bhagirathi basin because Bhagirathi is the founder tributary of the Ganga River basin and therefore fish fauna is similar (Appendix IV in the SI).

Distribution is also restricted by altitude and hence fauna of SF streams at higher elevation is very different from mid and lower sections as observed in SF tributary of the Alaknanda basin that formed a totally separate cluster owing to entirely different fish fauna. In SF the stream order also governs the fauna and its composition. The highest elevations are inhabited by snow trout, catfish and occasional loach species. The fauna gets diversified in the foothills in the main rivers as well in the SF streams/basins. Snow Trout (*Schizothorax* spp.) dominates catches (40 to 60%), in major GF rivers only (Figure 1). The SF streams and basins have diversified fish fauna. The SF Nayar and Khoh (lower Ganga), and the Kosi and West Rāmgangā are spawning grounds of the mahseer. Capture fishery is limited to the reservoirs. Fish production (including aquaculture) of the State is estimated to be 3000 tonnes per year which is meagre compared with the national value of 267 lakh tonnes. The diatom community in all the SF streams/rivers is largely alkaliphilous (pH 7), saprobity is medium (β-mesosaprobous) and trophic status ranges from mesotraphentic to eutraphentic. The organic pollution, degradation and anthropogenic eutrophication are non-existent in the Lesser Himalayan river basins of the Ganga River system but exist in the Doon Valley (Nautiyal, 2009).

Structure of lotic ecosystems of the Doon Valley

The water temperature (WT), current velocity (CV), dissolved oxygen, total alkalinity and total hardness were similar in Asan and Song Rivers; while pH and conductivity were considerably higher in the Song as compared to that in the Asan River (Appendix III). Diatom flora consists of 77 to 109 taxa at 3 locations in the Asan basin and 19 to 123 taxa in the Song basin. Shannon Diversity is relatively higher in the Asan basin (4.12 to 4.94; 0.71 to 0.8) compared with the Song basin (3.28 to 4.92; 0.73 to 0.95), but Evenness is higher in the latter, respectively. As a rule *Cymbella* sensu stricto (Cy) is the most speciose genus at 2 out of 3 locations in the Asan basin and at 2 locations in the Song basin, with *Navicula* sensu stricto (Na) at 4 out of 6 locations in the Song basin. Either genus dominates at remaining locations. Thus, *Cymbella-Navicula* or *Navicula-Cymbella* combination is common at all locations of the Asan compared to some in the Song basin. *Cymbella* and *Nitzschia* (Ni) are speciose at Baldi (receiving Sulphur springs) in the Song basin. *Navicula - Achnanthidium* (Ac) and *Navicula - Nitzschia* are speciose at one location each in the different ecosystems of the Song basin. *Gomphonema* (Go) is speciose though to a lesser extent in both basins except in streams under severe anthropogenic influence where *Synedra* (Sy) is speciose (Figure 2).

Species richness and diversity of diatom community is relatively higher in the Asan compared with variable richness in the Song basin (19 to 55 taxa at 3 locations, 95–123 at rest 3 locations). The eutraphentic and β-mesosaprobic conditions relates to relative severity of organic pollution, degradation and anthropogenic eutrophication in the Song compared to the Asan basin, but ecosystems around habitations are highly degraded in both basins. Asan drainage show lesser degradation and anthropogenic eutrophication (Appendix VIII in the SI). pH, salinity, nitrogen uptake and moisture class are identical in both basins of the Doon Valley but O_2 requirements vary. Water abstraction for agriculture and

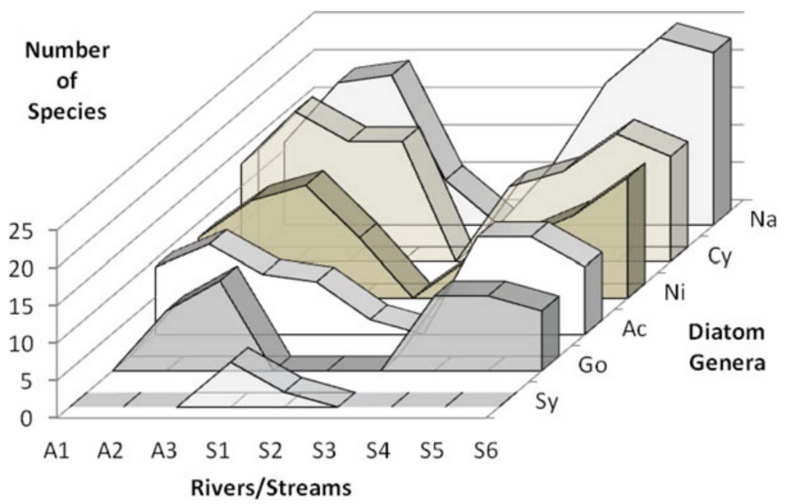

Figure 2. Speciose diatom genera in some lotic ecosystems of the Asan and Song (Doon Valley). (Color figure available online.)

domestic use has disturbed the natural hydrological regimes of the stream ecosystems and caused instability. The stability of the Asan basin is also supported by the prevalence of *Cymbella-Navicula* and vice-à-versa. The *Cymbella-Nitzschia* in the sulphur rich Baldi is in contrast to various combinations of species-rich genera like *Achnanthidium* and *Nitzschia* with *Navicula*. More combinations are also due to flows of various magnitudes in rainfed streams, natural and sulphur springs, shallow slow moving brooks with soft-sediments and with stony bottoms in the Song basin. This also influences the water chemistry causing variations in the flora as well as associations. *Nitzschia* tolerates pollution and prefer phosphate rich waters (Jüttner et al., 1996).

Benthic macroinvertebrate fauna comprised 18 taxa, primarily insect larvae-nymphs, highest in the Asan (16 taxa) and lowest in Suswa (7 taxa; Table 2). Total density is higher in the Asan (414–2680 individuals/m^2) and Suswa (891–3585 individuals/m^2) compared with the Tawa (167–935 individuals/m^2), draining agriculture and forest land representing near natural condition. The richness and density varies seasonally. Peak density occurs in winter coinciding with least temperature but shows summer peak in the Tawa. Baetidae and Chironomidae were most abundant families in forested areas of Asan and Tawa while Chironomidae in the sewage-enriched Suswa (Table 2). Both families are functionally collectors, depicting predominance of detritus food-chain and heterotrophic state of observed ecosystems in the Doon Valley, sewage and forest being the source of detritus. Thus, municipal wastes impact macroinvertebrate composition in the headwater itself and lower sections as expected were severely impacted, as assessed from diatom community.

A total of 41 fish species are known from the Asan River (Uniyal, 2002) and 34 species from Song River (Uniyal, 2010). The fauna is dominated by carps. The fauna of Asan consists of 28 genera, 12 families and 4 orders. The fauna of Song consists of 25 genera, 9 families and 4 orders. The fauna is common in both rivers but some fish species besides new records are restricted to the Asan only (*Ompok padba, Wallago attu, Mystus vittatus, Heteropneutes fossils*). *Colisa fasciatus* and *Nandus nandus* is new record for Dehradun district. There is high diversity of *Puntius* spp. (6 species) followed by barils and loaches. Few genera are represented by two species while rest by single species only. Threat assessment shows that 6 species (15%) each are Endangered (EN) and Not Evaluated (NE), while 11 (27%) are Vulnerable (VU) and rest are LRnt (Low Risk near threatened) except one Data Deficient (DD) (AppendixIV). *Barilius bendelisis* is most abundant in Burhi Tons (74%) and Asan (72%) and in the Asan basin, while *Barilius vagra* is abundant in the Song and *Puntius conchonius* in Suswa River (Ganga drainage) of Song basin (Figure 1).

Hora and Mukherji (1936) described 36 fish species from the eastern Doon, while Singh (1964) described 21 species from the western Doon. Husain (1995) described 79 species from Dehradun district, boundaries of which extend beyond the valley into the lesser Himalaya. Husain and Tilak (1995) recorded 49 species from the part of Rajaji National Park in Dehradun district of which 13 are common to the Ganga. The present study shows that the fish fauna of Asan and Song basins is a mixture of some essential mountain (with hillstream modifications *Schizothorax*, *Garra, Glyptothorax, Schistura*) and Gangetic plain elements (where clupid, sisorid, balitorid, cobitid, gobid, mugilid and many other genera are added besides minnows)[1] and ornamental foothill elements of subfamily Rasborinae. Besides the disruption and modification of the food chain due to degradation of lotic ecosystems, indiscriminate and overfishing has endangered 15% of the ichthyofauna, particularly the Golden mahseer and *Raiamas bola*. Both are typically foothill residents, but the mahseer occupies the glacial channels of the Ganga and Yamuna while the *bola* in the streams/rivers like Asan and Song. Further, these major rivers of the valley are the breeding grounds of mahseer. Fish mortality was recorded in the Asan at number of places due to pharmaceutical industries while the Song is now deprived of its discharge and fauna is limited to pockets, in protected area (Rajaji National Park), because the fish fauna has been impacted adversely after Dehradun became Capital of the State. *Tor putitora* (EN), *Puntius ticto* (LRnt) and *P. conchonius* (VU) prevail in the Song basin while *Barilius* spp. in the Asan most of which are not so threatened (LRnt) except *Barilius vagra* (VU).

Conclusions

Knowledge of ecology helps predictive abilities for resource management. In the mountain river ecosystems of the Ganga, the flora (diatom) and fauna (benthic macroinvertebrate, fish) of the major rivers, Yamuna, Bhagirathi and Alaknanda are distinct from its GF and SF tributaries. The SN and high elevation streams resemble more among themselves and with GF sub-basins of the Alaknanda by virtue of one basin and proximity to the snowline. With few exceptions the SF streams at mid and low elevations (e.g. SF Bemunda of Ganga and SF Gomti of E Rāmgangā basin) support considerably similar richness and abundance of flora and fauna across the basins, but no definite trend is evident. The epilithic diatom abundance segregates the GF and SF, suggesting the variation in composition caused by source of the river. Since a large cross section of SF streams was sampled in all basins, a better picture of the diatom abundance emerges with respect to similarity among the SF basins; e.g. Rāmgangā, Alaknanda and lower Ganga and within the adjoining basins lower Ganga (Nayar, Khoh), Rāmgangā W, Kosi, Gaula. Their similarity with the Mandakini near the snowline is notable, just as the distant SF Rāmgangā and the Yamuna basin. For the fish the demarcation is pronounced among the GF and SF basins.

High similarity among the adjoining basins compared to the distant basins is attributed to their location within a biome, as explained by biome dependency hypothesis (Ross, 1963). The present study shows that despite same biome the basins differ depending on the source of its tributaries (glacier and spring fed), a major factor in mountain river ecology. Thus, even if the environmental conditions appear very similar, as they do in mountain streams almost everywhere, communities that are assembled from distantly different species pools are not identical. Further, the lotic ecosystems in Lesser Himalaya differ from those in the Doon Valley; especially in respect of different diatom assemblages. The macroinvertebrate and fish fauna are similar, but vary in abundance. Their response to the stress of rapid urbanization differs. Producers (diatoms) that lie at the base of food chain and are direct users of nutrients show that the magnitude of organic pollution, degradation and anthropogenic eutrophication are high in the valley ecosystems and non-evident in the Lesser Himalayan rivers and streams. The macroinvertebrate community indicates heterotrophic state of lotic systems in Doon Valley, attributable partially to forested landscape and mainly to the organic pollution (contributing coarse and fine particulate matter) in the streams of urbanised Doon Valley. Considerable number of threatened and vulnerable fish species supports the observation that degradation and anthropogenic eutrophication is rampant in Doon Valley.

Hydropower potential is an important strategic asset for the economic development of Uttarakhand (World Bank, 2011), endowed with assets for good hydro power potential (Joshi, 2007). Thus,

[1]The minnows (family Cyprinidae) dominate the fish fauna of India. The proportion of minnow species is much higher in the mountain compared with the plain section of the Ganga. However, the proportion of Cyprinidae to other families in the mountain section is lower (8) than the Upper Plains (24), which increases further till estuarine zone. Elements other than Cyprinidae increase fish diversity at family level in the Plains thus diminishing the proportion of minnow to other families (Nautiyal et al., in press).

multiple HEP's are planned on major tributaries of the Ganga, but the HEP's are assessed as individual development projects and when assessed for its potential to impact, produce local impacts that are ecologically and socially acceptable, but when the effects of the numerous individual developments are combined, impacts may become larger, additive, or even new and therefore significant (Rajvanshi et al., 2012). The immediate concern is to prevent the death of the River Ganga. In past major dam proposals have been withdrawn in India; the Silent Valley (Gaur, 2007). There should be a limit on number of tributaries on which HEP's can be developed. The environmental flows (required for the maintenance of the ecological integrity of the rivers) should be determined for existing HEP's. The issues of Doon Valley are different from the Lesser Himalaya. The needs of the capital resulted in the massive urbanisation by irregular expansion without proper planning suddenly generated large volume of organic toxic wastes, soil erosion accounting for high pollution load and degradation. All discharges ultimately reach the major rivers of each basin, threatening the habitats and their biodiversity.

References

Anonymous, 1975–2006. Annual Reports. Central Inland Fisheries Research Institute, Barrackpore, India.

Badoni, K., Nautiyal, R., Bhatt, J.P., Kishor, B., Nautiyal, P., 1997. Variation in the epilithic diatom community structure due to river valley project on the Ganga between Rishikesh and Hardwar. Proc. Indian Natn. Sci. Acad. B63(6), 523–536.

CAMP, 1998. *Report on workshop "Conservation Assessment of Management Plan for freshwater fishes of India" Zoo Outreach organisation*, Coimbatore/CBSG and NBFGR, Lucknow, India.

CAPS Ver. 4.0 2007. Community Analysis Package Ver. 4.0. Pisces Conservation Ltd. Hampshire, U.K.

Cotta Ramusino, M., Villa, S., Calamari, D., 1995. River continuum concept and correspondence analysis to study Alpine stream macroinvertebrate assemblage. Mem.Ist. ital. Idrobiol. 53, 101–114

Dohet, A., Ector, L., Cauchie, H.M., Hoffmann, L., 2008. Identification of benthic invertebrate and diatom indicator taxa that distinguish different stream types as well as degraded from reference conditions in Luxembourg. Anim. Biol. 58, 419–472.

Gaur, R.D., 2007. Biodiversity and river valley project in Uttrakhand. Proc. Natn. Sci. Acad. 77(B III), 253–262.

Hora, S. L., Mukerjee, D. D. 1936. Fish of the Eastern Doon United Provinces. Rec. Indian Mus. 38, 133–146

Husain, A., 1995. Pisces. In: Director, Zoological Survey of India (Ed), *Fauna of Western Himalaya (U.P.) Himalayan Ecosystem Series: Part I*, pp.117–150. Computer World, Salt Lake, Calcutta.

Husain, A., Tilak, R., 1995. Fishes (Pisces). In: Director, Zoological Survey of India (Ed), *Fauna of Rajaji National Park*, pp.115–193. Jnanodaya Press, Calcutta.

Jha, B.R., Rayamajhi, A., 2010. *Tor putitora*. In: *IUCN Red List of Threatened Species*. Version 2011. 2. <http://www.iucnredlist.org/>. Accessed, 03 May 2012.

Johal, M.S., Rawal, Y.K., 2005. General ecology of some hill streams of Himachal Pradesh with special references to fish communities. In: P. Nautiyal, J.P. Bhatt, O.P. Gusain, A.K. Dobriyal (Eds.), *Biological Diversity in the Freshwater Environments*, pp. 36–56, Transmedia, Srinagar, Uttarakhand.

Joshi, B.D., 2005. Studies on the Eco-Biology of tributaries of river Ganga between Devprayag and Rishikesh. In: P. Nautiyal, J.P. Bhatt, O.P. Gusain, A.K. Dobriyal (Eds.), *Biological Diversity in the Freshwater Environments*, pp. 19–35 Transmedia, Srinagar, Uttarakhand.

Joshi, M.C., 2007. Hydro Power Potential in Uttarakhand. International Conference on Small Hydropower - Hydro Sri Lank a, 22–24 October 2007. Accessed, 15th May 2011.IIT, 2011.

Jüttner, I., Rothfritz, H., Ormerod, S.J., 1996. Diatom as indicators of rivers quality in the Nepalese middle hills with consideration of effects by the habitat - specific sampling. Freshwat. Biol. 36, 475–486.

Kandari, O.P., Gusain, O.P. (Eds.), 2001. *Garhwal Himalaya, Nature Culture and Society.* Transmedia, Srinagar, Uttarakhand.

Krishnamurti, C.R., Bilgrami, K.S., Das, T.M., Mathur, R.P. (Eds.), 1991. *The Ganga-A Scientific study.* Northern Book Centre, New Delhi for Ganga Project Directorate, New Delhi.

Nautiyal, P. (Ed.), 1994. *Mahseer - The Game Fish [Natural History, Status and Conservation practices in India and Nepal].* Jagdamba Prakashan, Dehradun.

Nautiyal, P., 1996. Conservation of mahseer in India: Research, a priority. Fish. Chim. 15(12), 27.

Nautiyal, P., 2001. Ecology of mountain streams and rivers in Garhwal Himalaya. In: Kumar A. (Ed.) *Ecology and Conservation of Lakes, Reservoirs and Rivers*, pp. 393–417. A B D Publishers, Jaipur.

Nautiyal, P., 2005a. Spatial and microdistribution of benthic macroinvertebrate community in tropical mountain streams of Garhwal region. Final Technical Report (Project No. SP/SO/C-42/98; 22.07.1999), DST New Delhi

Nautiyal, P., 2005b. Taxonomic richness in the fish fauna of the Himalaya, Central Highlands and Western Ghats (Indian subcontinent). Inter. J. Ecol. Environ. Sci. 31(2), 73–92.

Nautiyal, P., 2006. Rising awareness and efforts to conserve the Indian mahseer. Curr.Sci. 91(12), 1604.

Nautiyal, P., 2009. Benthic diatom assemblages as biological indicators of trophic status (water quality) in the streams impacted by different landuse in Uttarakhand. Final Technical Report (Project No.UCS&T/R&D/LS-33/06-07), UCOST, Dehradun.

Nautiyal, P., 2010. Food Chains of Ganga River Ecosystems in the Himalaya. Aquat.Ecosyst. Health Mgmt. 13(4), 362–373.

Nautiyal, P., 2012. *Utilization of mountain fishery resources - A partnership mode.Final Technical Report*. Directorate of the Coldwater Fisheries (ICAR), Bhimtal, Uttarakhand.

Nautiyal, P., Bhatt, J. P., Kishor, B., Rawat, V. S., Nautiyal, R., Badoni, K., Singh, H. R., 1997. Altitudinal variations in phytobenthos density and its components in the coldwater mountain river Alaknanda-Ganga. Phykos 36, 81–88.

Nautiyal, P., Kala, K., Nautiyal, R., 2004a. A preliminary study of the diversity of diatoms in streams of the Mandakini basin (Garhwal Himalaya). In: M. Poulin (Ed.) *Proceedings 17 International Diatom Symposium*. Ottawa, Biopress Ltd, Bristol.

Nautiyal, P., Nautiyal R., Kala, K., Verma, J., 2004b. Taxonomic richness in the diatom flora of the Himalayan streams (Garhwal, India). Diatom 20, 123–132.

Nautiyal, P., Rizvi, A.F., Dhasmana, P., 2008. Life history traits and decades trends in the growth parameters of Golden mahseer *Tor putitora*(Hamilton) from the Himalayan stretch of the Ganga river system. Turk. J. Fish. Aquat. Sci. 8, 125–131.

Nautiyal, P., Mishra, A.S., Singh, K. R., Singh, U., 2013. Longitudinal distribution of the fish fauna in the river Ganga from Gangotri to Kanpur. J. Appl. &Nat. Sci. 5(1), 63–68.

Nautiyal, R., Nautiyal, P., 1999. Altitudinal variations in the pinnate diatom flora of the Alaknanda-Ganga river system in the Himalayan stretch of Garhwal region. In: S. Mayama, M. Idei, I. (Eds.), *Proceedings of fourteen International Diatom Symposium.* Koeltz Scientific Books, Koenigstein.

Nautiyal, R., Nautiyal, P., Singh, H. R., 1996. Impact of sewage on the diatom communities of the river Alaknanda (Srinagar Garhwal) Ecol. Env. Sci. 22(3), 289–296.

Nautiyal, R. Nautiyal, P., Singh, H.R., 2000. Species richness and diversity of epilithic diatom communities on different natural substrate in the coldwater river, Alaknanda. Trop. Ecol. 41(2), 255–258.

O'Keeffe, J., Kaushal, N., Bharti, L., Smathkin, V., 2012. *Assessment of Environmental Flows for the Upper Ganga Basin.* World Wide Funds(WWF), India.

Payne, A.I., Temple, S.A., 1996. *River and floodplain fisheries in the Ganges Basin.Final Report*. DFID Fisheries Management Science Programme R 5485, London, MRAG Ltd.

Payne, A. I., Sinha R., Singh H.R., Huq, S., 2003. A review of the Ganges Basin: its fish and fisheries. In: R.L. Welcomme, T. Petr (Eds.) *Proceedings of the Second International Symposium of Management of Large Rivers for Fisheries, Vol. 1.* RAP Publication, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Rajvanshi, A., Roshni, A., Mathur, V. B., Sivakumar, K., Sathyakumar, S., Rawat, G.S., Johnson, J.A. Ramesh, K., Dimri, N. K., Maletha, A., 2012. Assessment of Cumulative Impacts of Hydroelectric Projects on Aquatic and Terrestrial Biodiversity in Alaknanda and Bhagirathi Basins, Uttarakhand. Wildlife Institute of India, Technical Report, plus Appendices.

Rao, R.J., 2001. Studies on Biological Restoration of Ganga River in Uttar Pradesh: An indicator species approach. Hydrobiologia 458, 159–168.

Ross, H. H., 1963. Stream communities and terrestrial biomes. Archiv für Hydrobiol, 59, 235–245.

Singh, H.R., 1988. Pollution study of the Upper Ganga and its tributaries. Final Technical Report Project No. J- 13013/20/83 RE (EN-I) under Ganga Action Plan, Ministry of Environment and Forests New Delhi.

Singh, H.R., Nautiyal, P., Dobriyal, A.K., Pokhriyal, R.C., Negi, M., Baduni, V., Nautiyal, R., Agrawal, N.K., Nautiyal, P., Gautam, A., 1994. Water quality of River Ganga (Garhwal Himalaya). Acta Hydrobiol. 36(1), 3–15.

Singh, H.R., Badola, S.P., Dobriyal, A.K., 1987. Geographical distributional list of ichthyofauna of the Garhwal Himalaya with some new records. J. Bombay Nat. Hist. Soc. 84, 126–131.

Singh, P.P., 1964. Fishes of Doon Valley. Ichthyologica 3(1–2), 86–92.

Sinha, M., De, D.K., Jha, B.C., 1998. *The Ganga-Environment and Fishery*, Central Inland Fisheries Research Institute, Publication Barrackpore.

Stevenson, R. J., Pan, Y., 1999. Assessing environmental conditions in rivers and streams with diatom. In: E.F. Stoermer, J.P. Smol (Eds.), *The Diatoms: Applications for the Environmental and Earth Sciences*, pp. 11–40, Cambridge University Press, Cambridge.

Uniyal, D.P., 2002. Eco-Taxonomical studies of Ichthyofauna of the Amlawa and Asan River of Western Doon Valley. D. Phil. Thesis, H.N.B. Garhwal University, Srinagar.

Uniyal, D.P., 2010. Pisces. In: Director, Zoological Survey of India (Ed), *Fauna of Uttarakhand, State Fauna Series, 18 (Part-1)*, pp. 533–621 Kolkata.

Vass, K. K., Das, M. K., Srivastava, P. K., Dey, S., 2009. Assessing the impact of climate change on inland fisheries in river Ganga and its plains in India. Aquat.Ecosyst. Health Mgmt. 12(2), 138–151. DOI: 10.1080/14634980902908746.

Vass, K. K., Mondal, S. K., Samanta, S., Suresh, V. R., Katiha P. K., 2010. The environment and fishery status of the River Ganges. Aquat Ecosyst Health Mgmt. 13(4), 385–394, 2010. DOI: 10.1080/14634988.2010.530139.

Verma, J., Nautiyal, P., 2009. Longitudinal patterns of distribution of epilithic diatoms in a lesser Himalayan streams. J. Hill Res. 22(2), 105–109.

Wadia, D.N., 1983. *Geology of India.* Tata McGraw Hill, Bombay.

World Bank, 2011. Uttarakhand. http://go.worldbank.org/FE04IF2IP0. Accessed 16th May 2011. http://riversource.net/docmanfiles/River_Source_flyer_0906.pdf