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Food chains of Ganga River ecosystems in the Himalayas

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The river ecosystems from the headwaters to the foothills in the upper mountain reach of the Ganga (Bhagirathi River) were characterized by increasing temperature, pH, total alkalinity, nutrient and BOD and decreasing current velocity, turbidity and DO. The biotic communities included benthos (phytobenthos, zoobenthos) and nekton (fish). The headwaters at Gangotri were heterotrophic and lacked fish (both grazers and predators). Functionally, the detritus and grazing chains operate in headwaters of the upper Ganga. The food chain was short and the web simple. In the middle and lower stretches, the macroinvertebrate assemblages functioned as filtering collectors and scrapers, representing detritus and grazing food chains. The abundance of scrapers indicated transition from heterotrophic to autotrophic state. The food chains and the food web became complex from the middle to lower stretches.

Keywords: Bhagirathi–Alaknanda, communities, trophic levels, heterotrophic, detritus feeders, grazing chain

Introduction

Much of our knowledge regarding food webs has been derived from small temperate forest streams of the northern hemisphere (Odum, 1971; Allan, 1996) and compared with the tropical streams (Dudgeon, 1999; March and Pringle, 2003; Mantel et al., 2004). Food webs highlight the linkages between streams and their riparian zones (Cummins, 1974; Gregory et al., 1991). As interactions change, these linkages are affected by longitudinal gradients and river networks (Power and Dietrich, 2002; Hoeinghaus et al., 2008). Though India has numerous rivers flowing through varied terrain and climatic zones ranging from high rainfall to arid conditions, there is a paucity of knowledge about the food chains and food webs even for important and sacred rivers like the Ganga, the cradle of Indian civilisation. A dip in this holy river on religious occasions is believed to wash away all sins and attain 'moksha' (salvation), and pilgrimage to the shrine of Goddess Ganga at Gangotri, close to its source at Gaumukh, has divine value. Hence, the vision of river conservation is ancient and central to Hindu philosophy. However, the spiraling needs for domestic water supply, agriculture, industry and hydropower have led to water abstraction and erection of dams and barrages hindering the natural flows, while fisheries go unnoticed. As hydroelectric power projects (HEP) are an easy proposition in mountains compared to the Plains, a large number of HEP are planned, three of which are functional, some are nearing completion and many more are awaiting implementation, Environmental Impact Assessment and preparation of Environmental Management Plans. This will adversely impact the integrity of the Ganga River ecosystem in the Himalayan zone. Presently, three dams, two barrages and continuous discharge of municipal effluents from the towns located near the banks in midst of hills and cities (Hardwar and Dehradun) in the foothills, cremation activities all along its banks and non–point sources of pollution have impaired its water quality, affecting the food chains and food webs.

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It may also be noted that though the Himalayan stretch is small, there are numerous rivers emerging from these mountains in India and Nepal compared to just one River Ganga on the Plains. Some information on the physical, chemical and biological characteristics of Ganga has been generated under the Ganga Action Plan in the mid 1980's by Indian Universities in the middle and lower stretches of the river in the States of Uttar Pradesh, Bihar and West Bengal (Krishnamurti et al., 1991). Institutes like the Central Inland Fisheries Research Institute, Barrackpore, West Bengal and its centers have a mandate for developing riverine fisheries (Ghosh and Pooniah, 2008; Vass et al., 2009). The food chains and webs are known from the lower freshwater stretch of the Ganga on the Plains (Krishnamurti et al., 1991), but not in the Himalayan stretch.

Gaps still occur in the knowledge of ecosystem structure and function, especially the functional food chains and webs in the Himalayan stretch of the Ganga and those of its tributaries in mountains of India and Nepal. The major developmental needs of the thickly populated Indian subcontinent depend on water, primarily for domestic use, irrigation and hydropower. Himalaya, the source of Ganga, Brahmaputra and Indus Rivers and their numerous tributaries, is under immense stress to meet the ever–growing demands of geometrically increasing human population and their livestock. The knowledge of ecosystem structure and function and operational food chains is obviously important for determining environmental flows in the impacted zones and undertaking management, conservation and river restoration measures for developing fisheries, enhancing recreational value, providing ecosystem services, and above all maintaining the ecological integrity of the Ganga River ecosystems.

In light of these issues, food webs were constructed for the upper (close to source), middle and lower (foothill) zones of the mountain stretch because the benthic and fish communities gradually change as the river flows through different altitudinal zones, resulting in different food chains and food webs. The latter will serve as a model for other glacial rivers in the adjoining areas of India and Nepal. The existing knowledge on the ecosystem structure of the Rivers Bhagirathi and Alaknanda and some recent observations were used to create food webs.

Study area

The Ganga arises as the Rivers Bhagirathi and Alaknanda from the Gangotri glacier at Gaumukh and from the confluence of the Bhagirathi Kharak and Satopanth glacier in the Greater Himalaya, respectively. Both flow in opposite directions; the Bhagirathi for 196.1 km from Gaumukh and the Alaknanda for 179 km from Badrinath, before they finally converge at Devprayag and flow down as the Ganga for 87.7 km to the foothills at Haridwar, and continue through the Gangetic Plains to reach the Bay of Bengal. The Alaknanda→ Ganga spans 266.7 km and the Bhagirathi → Ganga spans 283.8 km of the total Himalayan stretch (Mathur, 1991a). The Alaknanda and Bhagirathi are river systems in themselves, as a large number of streams and rivers join them directly and their tributaries (Figure 1) draining a large cross section of the lesser Himalaya in India. Important tributaries of Ganga drain the rest of the Himalaya in India and Nepal.

Climate, vegetation and landuse

The lengths of dry and wet periods vary in the Himalayan cross section. Thus, in the upper catchment close to the snow line, the dry period ranges from 3–4 months in the alpine/highest montane zone and 2–3 months in the montane and sub montane zone. These zones experience snowfall, and 100–250 cm of annual rainfall, the number of rainy days being 100–150. The air temperature varies from <10–20°C. The alpine zone is characterised by *Rhododendron campanulatum* and *Juniperus*, while the high montane by *Quercus semecarpifolia*, *Betula utilus* and *Rhododendron arboreum*, the montane by *Quercus incana*, *Cedrus deodara* and *Pinus wallichiana* and the sub–montane by *Q. incana* and *Myrica* species (Sundriyal, 1995). Pine forest occurs below 1500–1200 m. Forest, agriculture and settlements are the major landuse. Human settlements of larger magnitude occur below 1000 m elevation. In the upper stretch two hydropower projects are proposed on the Bhagirathi between Bhaironghati and Harsil, while two projects have been initiated between Harsil and Gangnani. A 23–yr–old dam exists at Maneri and the Tehri dam has been commissioned recently. Another dam is nearing completion at Koteswar below Tehri, while another was recently completed on the Alaknanda at Vishnuprayag in its

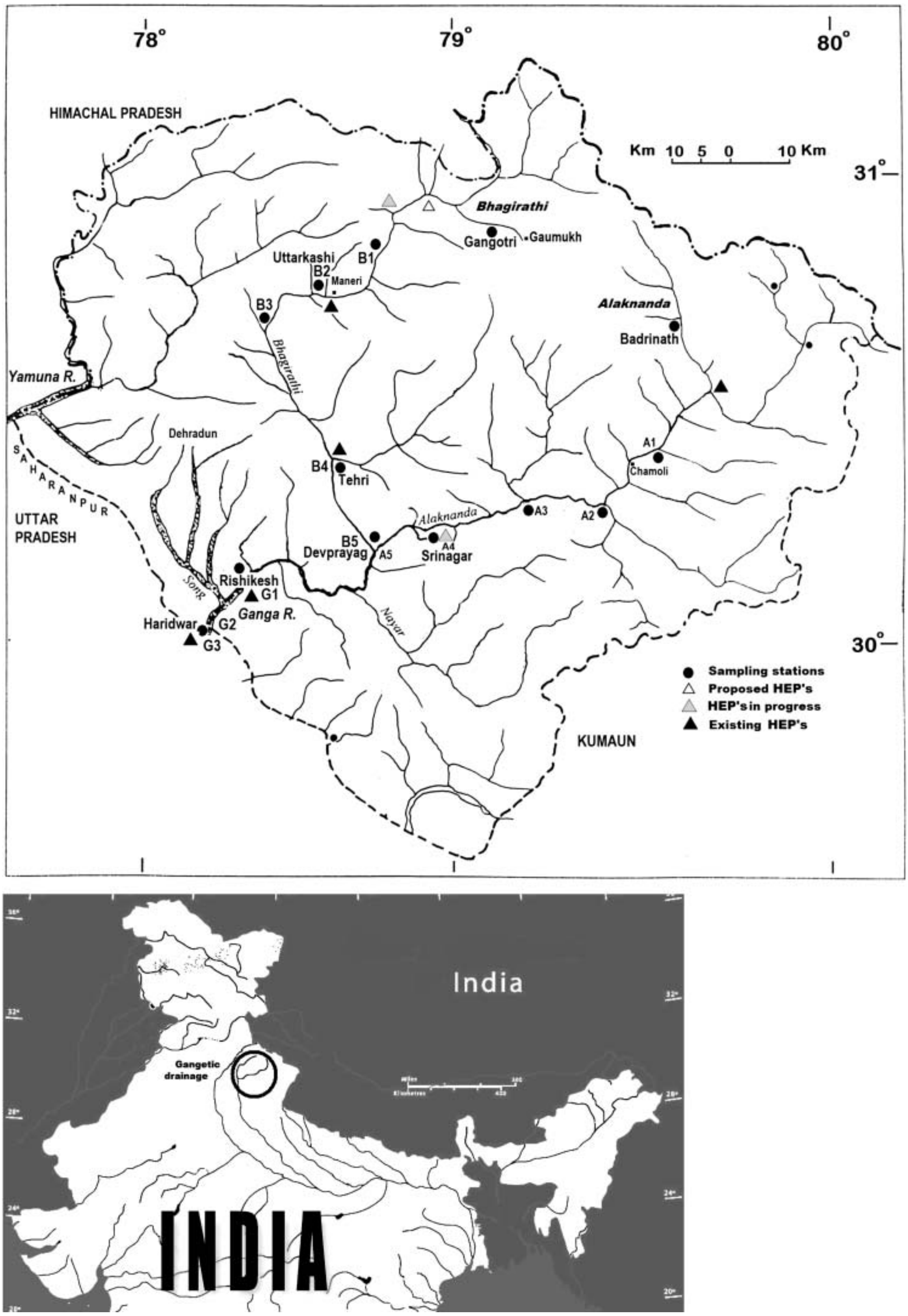

Figure 1. Below: Regional map to highlight the Himalaya portion of the Ganga drainage in India. Above: The site map showing source rivers of the Ganga in Himalaya: the parent rivers Bhagirathi and Alaknanda originate from glacier, and flow considerable distance before meeting at Devprayag to form the Ganga. The sampling stations and other places of importance have been located on the map, B1 to B5 for the Bhagirathi, A1 to A5 for the Alaknanda and G1 to G3 for the Ganga.

upper stretch. Work on another is in progress at Srinagar.

Physiography

In the upper section the river flows through narrow channels and rocky gorges except for small valleys such as Harsil in case of the Bhagirathi and Badrinath (near the origin) in case of the Alaknanda (Table 1). Uttarkashi is a wider valley at ca. 1100 m asl in the Bhagirathi basin. The particle size of the substrate decreased from boulders ($>$250 mm) to predominantly boulders and cobbles. The slope was high in the upper section; Bhagirathi 22.1 m km^{-1} from Gangotri to Gangnani, 15.4 m km^{-1} to Uttarkashi, Alaknanda 41.5 m km^{-1} from Badrinath to Bhimtala, upstream of Chamoli. In the middle and lower section, the mountain slopes are gentler except for wide valley at Tehri in the Bhagirathi and Srinagar in the Alaknanda. The slope was approximately 5 m km^{-1} in the Bhagirathi and the Alaknanda, compared with 1.9 m km^{-1} in the Ganga. The particle size of the substrate gradually decreases from predominantly boulder and cobble to cobble, pebble and gravel in this stretch. The mountain slopes near the river are mostly devoid of forest except in the headwaters. The flooding zone lacks any vegetation, beyond which grasses, herbs and shrubs appear. The trees are scarcely found along the banks and thus the reaches are devoid of shading.

Materials and methods

Various components of the food chain have been studied over a period of two decades (1985 to 2005) in the Himalayan zone. The Bhagirathi has been studied for various components of the ecosystem structure from almost near its origin to the confluence (Singh, 1988). To describe the food-webs, the data of from six major locations (includes Devprayag) was used (Figure 1). These stations are ca. 40–50 kms apart. The Alaknanda has also been studied at number of stations (Nautiyal, 1996, 1997; Nautiyal and Nautiyal, 1999) except the upper stretch from Badrinath to Chamoli. Of the five stations indicated in Figure 1, the station A1 is ca. 50 km below origin. The first three stations are ca. 22, 16 km apart, while the fourth and the fifth 63 km and 29 km apart, respectively. The Ganga has been studied at three locations between Devprayag and Rishikesh (Singh, 1988) and at six stations between Rishikesh and Hardwar with respect to river regulation (Nautiyal, 1996, 1997). However, the data for three major locations was used for the Ganga (Figure 1). All stations on the Bhagirathi and Ganga except Gangotri (accessible in summer only) have been sampled at monthly intervals, while the Alaknanda has been sampled during winter, summer and monsoon. Thus data has been summarized based on 12 and seasonal samples, respectively.

The autotrophic component of the food–web was sampled by scraping 3 $\times$ 3 cm^2 area of the substrate at 30–40 cm depth and filtering 100 litres of water through plankton net (20 bolting silk). Since the filtered water contained only some of the algae and diatoms found on the bottom attributed to scouring (Allan, 1996), the plankton community did not exist in the river tract sampled for this study. The current velocity varied from 1.31 $\pm$ 0.19 to 2.19 $\pm$ 0.64 m sec^{-1} (Singh and Nautiyal, 1990). The heterotrophic benthic macroinvertebrates were sampled using a Square foot Surber sampler (mesh size 0.595 mm) and information on the fish fauna was obtained from published sources (Singh et al., 1987) as well as a survey of fish catches along the river. The periphyton and benthic macroinvertebrate community were analysed for density and percentage composition according to standard methods described elsewhere (Singh et al., 1994; Nautiyal, 1996, 2001a). The physico–chemical data are reproduced as minimum – maximum and annual means, while the data on phyto and zoobenthos density and percentage composition are based on yearly averages of counts. The benthic invertebrates were classified by their function in the ecosystem according to Dudgeon (1984) and Ramusino (1995). The functions of fish were based on the published records on their food habits from the Ganga and its tributaries (Nautiyal, 1994; Nautiyal and Nautiyal, 1998; Kishore et al., 1998) and examination of the food habits of catfishes by the author. The food web for the headwaters was based on data generated for the above stated components at the station Gangotri (Gt). The food webs were developed for the remaining stretches of the river on the basis of altitudinal differences in the community composition and their functional role in the ecosystems (Singh, 1988; Nautiyal, 1996, 1997, 2001a; Nautiyal, 2005) and some present observations made by the author.

Table 1. The physiographic details of the stations sampled along the Bhagirathi, Alaknanda and Ganga.

River/Stations	Bhagirathi						Alaknanda					Ganga		
Parameters	Gt	B1– G	B2– U	B3– Dh	B4– T	B5– D	A1– B	A2– NP	A3– KP	A4 –SR	A5 –D	G1 –R	G2 –H	G3 –A
Approx. distance from source (km)	18		Ca. 100			196					179	242	266	276
Altitude (m)	3048	1855	1100	800	630	460	980	880	700	500	480	325	286	273
Fall in gradient station (m km^{-1})	22.1	16.4	16.4	8.6	4.0	3.8	29.3	4.9	11.0	3.2	0.7	2.0	1.5	1.4
Width of river (m)	20	20	50	60	70	30	–	–	–	–		150	500	>500
Substratum – Major type; Shape	B-M	B-P	B-M	B-M	B-M	B-M	R-P	B-M	B-M	B-M	B-M	B-M	B-M	C-P-M
Others	S	–	–	C–Pb–G	C–Pb–G–S–St	–	–	–	–	–	–	C–P–G–S–St	–	G–S–St

Abbreviations used in Tables 1 to 3:

Gt	Gangotri	G2-H	Hardwar	R	Rock
B1-G	Gangnani	G3-A	Ajeetpur	B-M	Boulders-Maturing
B2-U	Uttarakashi	A1-B	Bhimtala	B-P	Boulders-Prismatic
B3-Dh	Dharasu	A2-N	Nandprayag	S	Silt
B4-T	Tehri	A3-KP	Karnpryag	C-Pb–G	Cobble-Pebble-Gravel
B-5D	Devprayag	A4-SR	Srinagar	C-Pb–G–S–St	Cobble-Pebble-Gravel-Sand-silt
G1-R	Rishikesh	A5.D	Devprayag	na	Not analysed

Results

Physicochemical characteristics

The temperature, pH, conductivity, total alkalinity, nutrient and BOD levels increased while the current velocity, turbidity and DO levels decreased downstream (Singh, 1988; Mathur, 1991b; Nautiyal, 1996, 2001b). Turbidity and conductivity respectively, decreased and increased drastically compared to others (Table 2).

Close to origin the periphyton density is low; 131 cells mm^{-2} at Gangotri to 187 cells mm^{-2} at Harsil in October 2006 (373 cells mm^{-2}in February 2007, Nautiyal et al., 2007) compared to downstream stations where it ranged from 313 to 509 cells mm^{-2}. The periphyton density is little higher in the Alaknanda (440 to 1045 cells mm^{-2}). The benthic macroinvertebrate density ranges from 327 to 1053 indiv. m^{-2} in the Bhagirathi and 125 to 1357 indiv. m^{-2} in the Alaknanda and 169–612 indiv. m^{-2} in the Ganga (Figure 2). No fish has been recorded in the headwaters of the Bhagirathi at Gangotri or the Alaknanda at Badrinath. Some snow trout species such as *Schizothorax richardsonii* (Gray), *S. plagiostomus* Heckel, and *S. sinuatus* Heckel populate the upper stretch. The resident cyprinid fish primarily *Schizothorax*, *Garra*, *Crossocheilus* spp. increase in diversity and density in the middle stretch (Gangnani to Tehri). Other resident fish of this stretch include sisorids (catfish) *Glyptothorax* and *Psudecheneis* spp. Loaches are rare. The lower sections of this stretch are visited by the migratory Himalayan mahseer, in both parent rivers. Only few species snow trouts occur in the Ganga, primarily *S. progastus* (Singh et al., 1987; Nautiyal 2001b). In the foothills from Rishikesh to Hardwar, the resident fish include the Himalayan mahseer *Tor putitora*, along with an array cyprinids, bagarids, schilbids other catfish, and few other fish).

Food chains and food web

In the headwaters the autotrophs (primary producers) consist mainly of diatoms, few desmids and green filamentous algae as periphyton. The heterotrophs comprise benthic macroinvertebrates only as fish are absent. The heterotrophs functioning as primary consumers include scrapers (Ephemeroptera – Heptageniidae) and detritus feeder (Diptera, Coleoptera, Ephemeroptera – Baetidae, Ephemerillidae). Those functioning as secondary consumer are predator (Plecoptera). Though both, the grazing and detritus food chains exist in the headwaters, the former are represented by Heptageniidae only which relates with low density of periphyton. Hence the chain is short and simple (Figure 3). The remaining invertebrates are detritus feeders, consisting mainly of the collecting gatherers and a few shredders (T). In the upper stretch itself the taxonomic composition of this community changes downstream of the headwaters at Gangnani (Table 3). Functionally, a qualitative increase occurs in the primary consumers (scrapers and collectors of both types). Snow trout (fish), which scrape the periphyton from stony substrate, also get incorporated in the web.

A change occurs in the web further downstream as the diversity of autotrophs increases along with its density thus enhancing primary production. Simultaneously, primary consumers from both the benthic macroinvertebrate (mostly Trichoptera) and nekton (fish) community increase in diversity. Among Trichoptera very few function as scraper. Majority of them process all forms of detritus (shredder, collecting gatherers and filtering collectors). Besides, there is a qualitative increase in the scrapers as compared to only Heptageniidae in the headwaters (Figure 4). Cyprinid fish (primarily *Schizothorax*, *Garra*, *Crossocheilus* spp.) increase in diversity downstream. They feed largely on periphyton and take a small amount of detritus, thus functioning as primary consumers. The predators are few, consisting of invertebrates (Plecoptera, Odonata, Coleoptera) and vertebrates (catfish). The fish Himalayan mahseer function as predator when young, feeding on the benthic macroinvertebrate community and small herbivore fish. The older fish function as grazer and detritus feeder (Figure 4). The web hence, becomes more complex.

In the foothill section the autotrophs increase in diversity and density as do the members of the grazing chain with insects, molluscs and fish. The shredder and filtering collectors in this stretch differ taxonomically compared to the middle stretch but there are few taxa in these two categories (Figure 5). A lot of aquatic birds, some reptiles and mammals, function as consumers at secondary and tertiary trophic levels. This renders more complexity to the web in the foothills. The benthic macroinvertebrate community changes functionally compared to the taxonomic composition.

Table 2. The limnological characteristics of the rivers at stations sampled along the Bhagirathi, Alaknanda and Ganga. The first row for each parameter contains minimum-maximum values and the row below it the annual means.

River/Stations		Bhagirathi					Alaknanda					Ganga		
Parameters	Gt	B1-G	B2-U	B3-Dh	B4-T	B5-D	A1-B	A2-NP	A3-KP	A4-SR	A5-D	G1-R	G2-H	G3-A
Water temperature (°C)	6–6.5	4.3–9.8	8.8–14.7	9.5–15.5	11.2–15.7	11.8–16.3	8–14	6–16.5	8–17.5	10 –21	11.8–17.9	11–21.5	16–24	10.5–24
		7.24 ± 2.7	11.6 ± 2.7	12.8 ± 3.0	13.2 ± 2.3	15.5 ± 3.3	11.25 ± 0.59	13.92 ± 2.97	14.08 ± 1.38	16.54 ± 0.81	15.6 ± 3.2	17.13 ± 0.99	19.8 ± 0.67	18.8 ± 1.1
Current velocity (m s^{-1})	1.9–2.9	2.0–3.3	1.0–2.6	1.5–2.7	1.3–2.0	1.7–2.4	1.8–3.9	2.1–3.7	0.6–2.8	0.9–1.8	1.5–2.3	0.18–1.6	0.27–1.6	0.14–1.0
		2.76 ± 0.6	2.13 ± 0.6	1.72 ± 0.4	2.07 ± 0.3	2.24 ± 0.6	3.02 ± 027	3.1 ± 0.2	1. 5 ± 0.5	1.2 ± 0.4	1.9 ± 0.38	0.61 ± 0.14	0.87 ± 0.15	0.56 ± 0.08
Turbidity (NTU)	420–1320	15.6–251	8.9–341	6.5–237	10.3–279	14.5–224	2–375	77–166	5–168	3–265	4.3–486	6–72	1–85	4–119
		172 ± 135	168 ± 166	158 ± 161	151 ± 135	139 ± 110	88.5 ± 37.1	131 ± 27.6	84.6 ± 35.8	47.8 ± 18.9	225 ± 243	16.5 ± 5.7	13.0 ± 7.3	19.4 ± 10
Conductivity (mho cm^{-1})	20–75	59–88	98–125	60–99	74–119	115–161	70–140	na	na	150–310	108–146	130–210	140–210	120–220
		88 ± 20	110 ± 13.5	87 ± 23.7	101 ± 23	126 ± 30.6	114.54 ± 8.2	–	–	–	122 ± 20.6	156 ± 6.5	175 ± 6.6	167 ± 8.8
pH	7.07–7.25	7.0–7.21	7.0–7.3	7.2–7.6	7.3–7.6	7.5–7.6	na	na	na	na	7.4–7.7	na	na	na
		7.2 ± 0.16	7.25 ± 0.15	7.51 ± 0.18	7.5 ± 0.19	7.58 ± 0.0					7.6 1 ± 0.9			
DO (mg l^{-1})	10.5–11.6	8.5–10.8	8.3–9.5	8.2–10.7	8.6–10.7	9.1–9.88	7 –14.5	8.9–14	9.4–14.3	4.9–12.8	8.5–10	6.5–8.8	2.7–9.3	3.2–9.0
		9.34 ± 1.2	9.08 ± 0.6	9.46 ± 1.2	9.42 ± 1.2	9.54 ± 0.4	10.68 ± 0.74	11.18 ± 0.86	10.71 ± 0.74	8.9 ± 0.46	9.5 ± 0.99	7.4 ± 0.2	6.8 ± 0.5	6.6 ± 0.4
BOD (mg l^{-1})	0.6–2.2	1.0–1.8	2.4–4.4	1.6–3.8	1.6–3.5	1.9–3.51	na	na	na	na	1.6–3.5	na	na	na
		1.3 ± 0.3	3.31 ± 1	2.68 ± 1.0	2.6 ± 1	2 ± 1	na	na	na	na	2.3 ± 1.03	na	na	na
Total alkalinity (mg l^{-1})	10–15	20– 38.4	29.8–45.6	32–46.5	34.5–45.7	31.7– 42.5	na	na	na	na	39–52	70–125	65–100	65–110
		31.5 ± 10.4	36.9 ± 7.9	38.3 ± 7.4	38.5 ± 6.2	38.3 ± 5.8	na	na	na	na	45.3 ± 6.7	100 ± 6	95 ± 5	85 ± 4.5
Silicate ($\mu g\ l^{-1}$)	10	5.9–52.3	4–70	8.9–73	6–28	7–40	4–20	10–20	6 –60–	8–21	0–41	12–24	16–23	12–20
		34.8 ± 14.5	41 ± 19.5	32.9 ± 20	9 ± 1	20 ± 16	13 ± 14.8	14.4 ± 11. 9	20.17 ± 14	12 ± 5	14 ± 0.23	15 ± 0.1	18 ± 01	16 ± 0.1

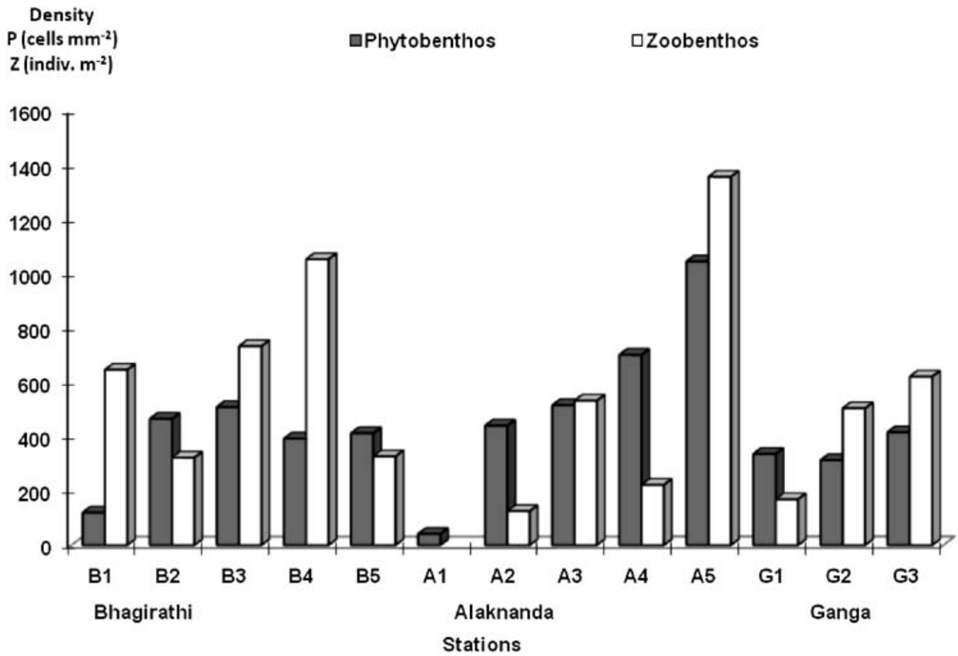

Figure 2. Longitudinal changes in the density of phytobenthos (periphyton) and zoobenthos (benthic macroinvertebrate) in the Bhagirathi, the Alaknanda and the Ganga.

Discussion

Every organism has a trophic role. In the headwaters of the Bhagirathi, periphyton functions as the autotrophs. Their density is low. The diatoms constitute 80–95% of the total density (Nautiyal et al., 1997). The heterotrophs functioning as primary/secondary/tertiary consumers consist of insect only (larvae, nymph, adult). Heptageniidae is the only primary consumer (scraper, feeding

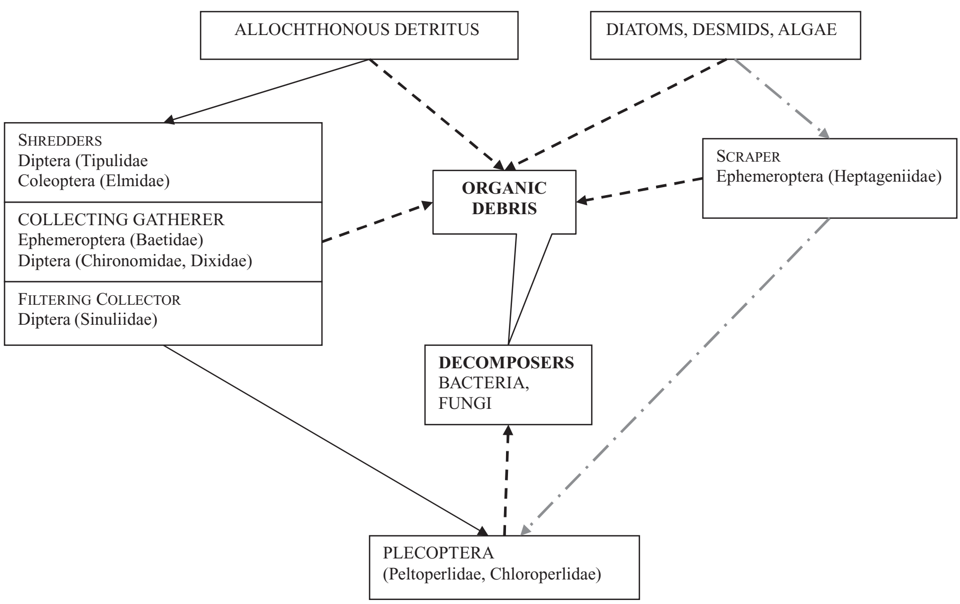

Figure 3. Food web in the uppermost section of the Ganga R. The black arrows indicate detritus food chain, gray dashed-dotted arrows the grazing chain and black dashed arrows indicate death and decay.

Table 3. Longitudinal changes in the composition of benthic macroinvertebrates in the Bhagirathi-Ganga.

Taxa	Gt	B1-G	B2-U	B2-J	B3-Dh	B4-T	B5-D	G1-R	G2-H
Plecoptera	52	2			3	1		2	
Ephemeroptera	38	60	17	22	38	31	43	49	14
Trichoptera			1	17	17	29	43	12	54
Diptera	8	36	83	51	42	31	14	36	20
Coleoptera	2	2		6		8		1	4
Odonata				4					
Mollusca and Nematode									8

on autotrophs) as the headwaters are devoid of fish. Other primary consumers are detritus feeders, largely collecting–filtering gatherers and very few shredders. This suggests the prevalence of FPOM over CPOM (Fine and Coarse Organic Particulate Matter, respectively) form of detritus in the torrential upper zone of the headwaters. This stretch of the river is hence, heterotrophic. Plecoptera function as predator constituting the next trophic level. The web is thus simple and food–chain is short in the headwater zone.

Below headwaters the composition of benthic macroinvertebrates changes considerably (Singh et al., 1994). This stretch is inhabited by fish, mostly primary consumers owing to herbivorous diet. Although more macroinvertebrate taxa function as grazing primary consumers in this stretch, the presence of many fish species in this functional group increases their number in this trophic level. The share of grazers and detritus feeders becomes almost similar in this stretch, a clear indication of increase in the autotrophic state in the middle compared to the upper stretch. At next trophic level (secondary and tertiary consumers) few benthic macroinvertebrates and some catfish function as predator. Due to an increase in the species diversity at autotrophic level there is a qualitative increase in grazers. More chains are added to the ecosystem which

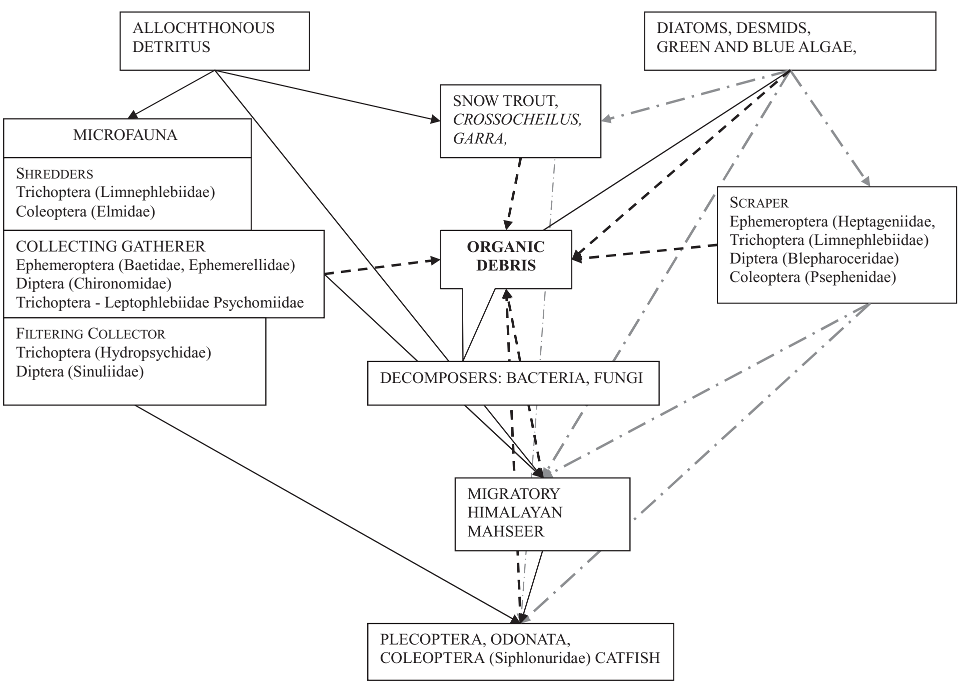

Figure 4. Food web in the middle section of the Ganga R. The black arrows indicate detritus food chain, gray dashed-dotted arrows the grazing chain and black dashed arrows indicate death and decay.

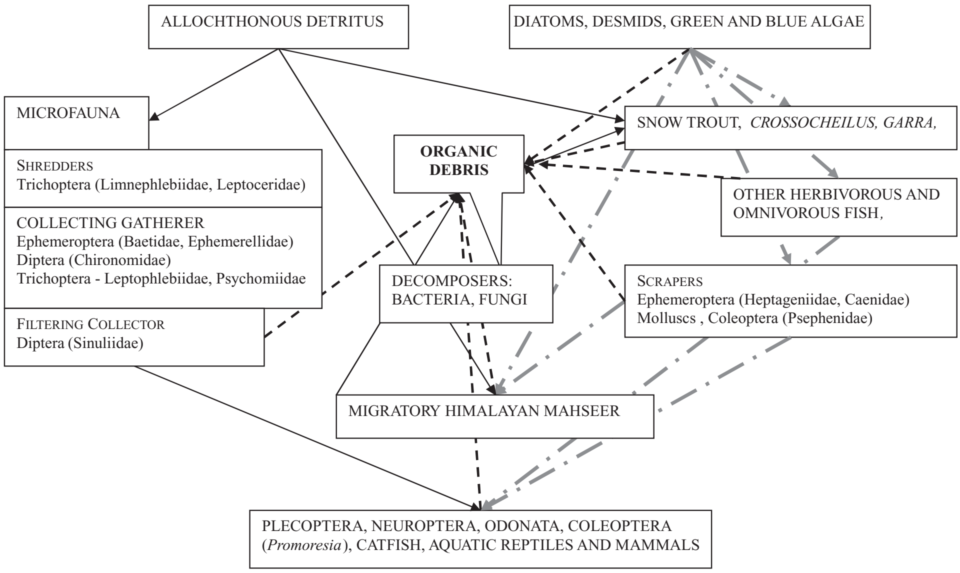

Figure 5. Food web in the lower section of the Ganga R. The black arrows indicate detritus food chain, gray dashed-dotted arrows the grazing chain and black dashed arrows indicate death and decay.

enhances complexity of the food web. In contrast there is a marginal addition to the detritus feeders.

A general trend of downstream increase in the density of macroinvertebrate and periphyton was apparent in the Alaknanda, Bhagirathi and the Ganga. However, the density of these communities was quite low in the foothill Ganga (Figure 2). The density of macroinvertebrate will increase even in low densities of periphyton if detritus has sizeable presence as observed in the headwaters of the Bhagirathi. The longitudinal changes in the composition of benthic macroinvertebrate community (Table 3), however, shows relationship with periphyton increase, as most of the ephemeroptera and trichoptera are scrapers and collectors, while a bulk of diptera are collectors which feed on detritus of smaller particle size.

Three food webs were found to operate in the mountain stretch of the Ganga from the headwaters to the foothills. In the middle stretch more food chains come into existence with increase in fish diversity. In the lower stretch further increase in the diversity of biota generates more autochthonous material increasing the complexity of the food web. The food web is influenced by life–cycle patterns of instream organisms, which are synchronized to monsoon and dry season flows. Summer snow–melt and the monsoon floods are unfavourable conditions for most organisms in the glacier rivers, but higher temperatures in this period suit their reproductive needs. During this period some links of food web are not functional. In India the dry season extends from winter (October) to summer (June), except for winter rains and seasonal disturbances. The generalizations presented herein apply from the beginning of winter to at least end of April and hence a large part of the year.

The large number of HEP's proposed in the Himalaya will starve the river of environmental flows and will not only alter food chains and food webs but will also erode the ecological integrity and affect recreational and religious value of the Ganga River along with its ecosystem services.

Conclusions

Three food webs operate in the mountain stretch of the Ganga from near the source to the foothills. Few and simple food chains exist in the upper stretch and the web is thus simple and the food chain short in the headwaters. The number of chains increases in the middle stretch, while the complexity of the food web increases in the foothill stretch. Both detritus and grazing chains operate in this mountain part of the river; the detritus chain prevails in the headwaters and hence is heterotrophic. The share of grazers and detritus feeders becomes almost similar in the middle and foothill stretch, a clear indication of an increase in the autotrophic state as compared to the upper stretch.

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