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Stream regulation: Variations in the density, composition and diversity of benthic macroinvertebrates occurring in the up and downstream sections of the impounded zone of the river Ganga in the foothills

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Abstract: Variations in the density, composition and diversity of the benthic macroinvertebrates were studied in the up and downstream sections of the impounded zones (Veerbhadra and Bhimgoda barrage) of the river Ganga in the foothills. In these sections differences in the benthic density were found to be insignificant ($P<0.05$). The sections differed in terms of composition and relative abundance of different taxa. The regulated stretch was found to harbour only Ephemerotera, Diptera, Trichoptera and Mollusca. Plecoterans were absent while Coleopterans were very rare in the regulated stretch as compared with the upstream pristine stretch studied earlier. The predominance of Heptageniidae and fragmented occurrence exhibited by other taxa are attributed to fluctuations in the flow regimes and loss of substrate diversity. The diversity of benthic community was lower in upstream sections being least in UVB (0.1348 – 1.1319). However, the differences were not significant. Similarity index indicated lack of similarity in the community at impounded locations.

Resumen: Se estudiaron las variaciones en la densidad, composición y diversidad de los macroinvertebrados bénticos en secciones río arriba y río abajo de la zona confinada (presa Veerbhadra y Bhimgoda) del río Ganga en las estribaciones de las montañas. En estas secciones se encontró que las diferencias en la densidad del bentos fueron insignificantes. Las secciones difirieron en términos de la composición y la abundancia relativa de los diferentes taxa. La porción confinada alberga sólo Ephemerotera, Diptera, Trichoptera y Mollusca. Los plecópteros estuvieron ausentes y los coleópteros fueron muy raros en la porción confinada, en comparación con la porción prístina río arriba estudiada con anterioridad. La dominancia de Heptageniidae y la distribución fragmentada exhibida por otros taxa fueron atribuidas a las fluctuaciones en los regímenes de flujo y la pérdida de diversidad del sustrato. La diversidad de la comunidad béntica fue más baja en las secciones río arriba que tenían menos UVB (0.1348 – 1.1319). Sin embargo, las diferencias no fueron significativas. El índice de similitud indicó una falta de similitud en la comunidad en las localidades confinadas.

Resumo: As variações na densidade, composição e diversidade nos micro invertebrados bênticos foram estudadas nas secções de montante e jusante de zonas represadas (Barragem de Veerbhadra e Bhimgoda) no rio Ganga no sopé das colinas. Nestas secções as diferenças encontradas na densidade bêntica foram insignificantes. As secções diferiam, contudo, em termos de composição e abundância relativa dos diferentes taxa. Encontrou-se que o curso regulado abrigava unicamente Ephemerotera, Diptera, Trichoptera e Mollusca. Os Plecoterans encontravam-se ausentes enquanto os Coleopteraneos eram muito raros no curso regulado em comparação com o curso virgem a montante e estudado anteriormente. A dominância dos Heptageniidae e a ocorrência fragmentada exibida por outros taxa são atribuídos às flutuações nos regimes do caudal e à perda da diversidade do substrato. A diversidade da

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comunidade bêntica era menor nas secções a montante sendo a menor em UVB (0,1348 – 1,1319). Contudo, as diferenças não eram significativas. O índice de semelhança indica a falta de semelhança na comunidade nos locais represados.

Key words: Benthic fauna, community structure, stream regulation, temporal variations.

Introduction

Stream regulation whether for the purpose of irrigation, hydroelectricity generation or flood control involves creation of a physical barrier across the stream. Consequently, the flow patterns tend to be altered. The stretch upstream of the barrier gets inundated while the downstream section gets a meagre to reduced discharge. This alters the habitat of the existing aquatic biota. The species thus existing may either get reduced in number or totally vanish owing to habitat destruction, thus influencing the biodiversity for long distances in the downstream section.

The lotic system and stream organisms have evolved in response to heterogeneous environmental conditions. Both predictable (e.g. annual temperature pattern) and unpredictable (e.g. major flood events) variations are important in maintaining the structure and functions of stream ecosystems. Stream regulation tends to reduce environmental heterogeneity and temporally disrupt natural biotic and abiotic patterns in the receiving streams. Intragravel flow may be reduced as substrate interstices accumulate fine materials thus reducing the hyporheic zone which provides an important habitat for benthic species as well as incubation sites for fish eggs and larvae. Reduced flow may result in extreme temperatures detrimental to the benthos. The degree of flow constancy appears to largely determine macroinvertebrate abundance in regulated streams (Ward 1976; Ward & Stanford 1979).

The benthic macroinvertebrate community contributes immensely to the functioning of the stream/river ecosystem. It serves not only as a major source of food for fishes but also helps in processing relatively large amounts of organic matter. Further, they are more of resident nature because they are not as mobile as fishes so as to exhibit avoidance behaviour. Owing to their bottom dwelling habit, they are better indicators of changes in the system because all extraneous matter coming into the system tends to settle on the bottom. Their diversity and composition at an particular time can give a picture of the nature of disturbance in the system (Stanford & Ward 1983).

According to various authors the groups favoured by altered conditions below the dams include dipterans (Lehmkuhl 1972) and blackflies (Spence & Hynes 1971), whereas plecopterans were greatly reduced or absent immediately below reservoirs. Trichoptera may be enhanced (Pfitzer 1954) or reduced (Ward 1974) below dams. Ephemeroptera, depending on the taxa may be either favoured or reduced below dams (Ward 1976; Ward & Stanford 1990). Heptageniids and other species with holdfast organs may be predominant species in streams with rapid current velocities (Radford & Hartland-Rowe 1971), but may be reduced or absent under other conditions (Trotosky & Gregory 1974).

The present study was conducted with a view to know how the density, percentage composition and diversity of the benthic macroinvertebrate community of the Ganga was influenced by stream regulation in the foothill sections between Rishikesh and Hardwar. The study was designed with a view to assess quality of the riverine habitat.

Materials and methods

The present study was conducted on the river Ganga between Rishikesh (30°7′ N latitude; 78°18′ E longitude, 325 masl) and Hardwar (29°56′ N latitude; 78°10′ E longitude, 286 masl). Since, the river is glacierfed in origin, lean flow occurs during winters as evidenced by velocity profile (0.01-0.37 m s^{-1}). The glaciers receive snowfall in this period. From March-April flooding starts due to melting of snow coinciding with rise in the ambient temperatures. More flooding occurs during monsoon as a result of increased surface run-off (velocity 0.016-3.0 m s^{-1}). The flow of the river is thus largely governed by the source and influenced seasonally by the rainfall.

The Himalayan region (Garhwal) experiences, two dry and wet periods alternatively. The major wet period (monsoon) extends from July to September followed by a dry period till December. Winter rains during December to February constitute the second wet period. The summer, March to June and post monsoon October to mid December constituted the dry period with occasional showers of local rains. Annual rainfall in these areas was about 1100 mm during 1994 (maximum rainfall in August and minimum in December).

The river channel is characteristically mountainous as it opens out at Rishikesh. The channel widens as the hills become restricted to the left side only. The embankments are low along the right bank of the river. The channel tends to spread out in a fashion similar to those of the alluvial plains. *Dalbergia sissoo* and *Acacia catechu* were the dominant components of vegetation on hill slopes along the left bank of the river Ganga. The ground vegetation included *Murraya koenigii, Adhatoda vasica, Lantana camara, Cassia tora, Clerodendrum viscosum, Saccharum spontaneum*

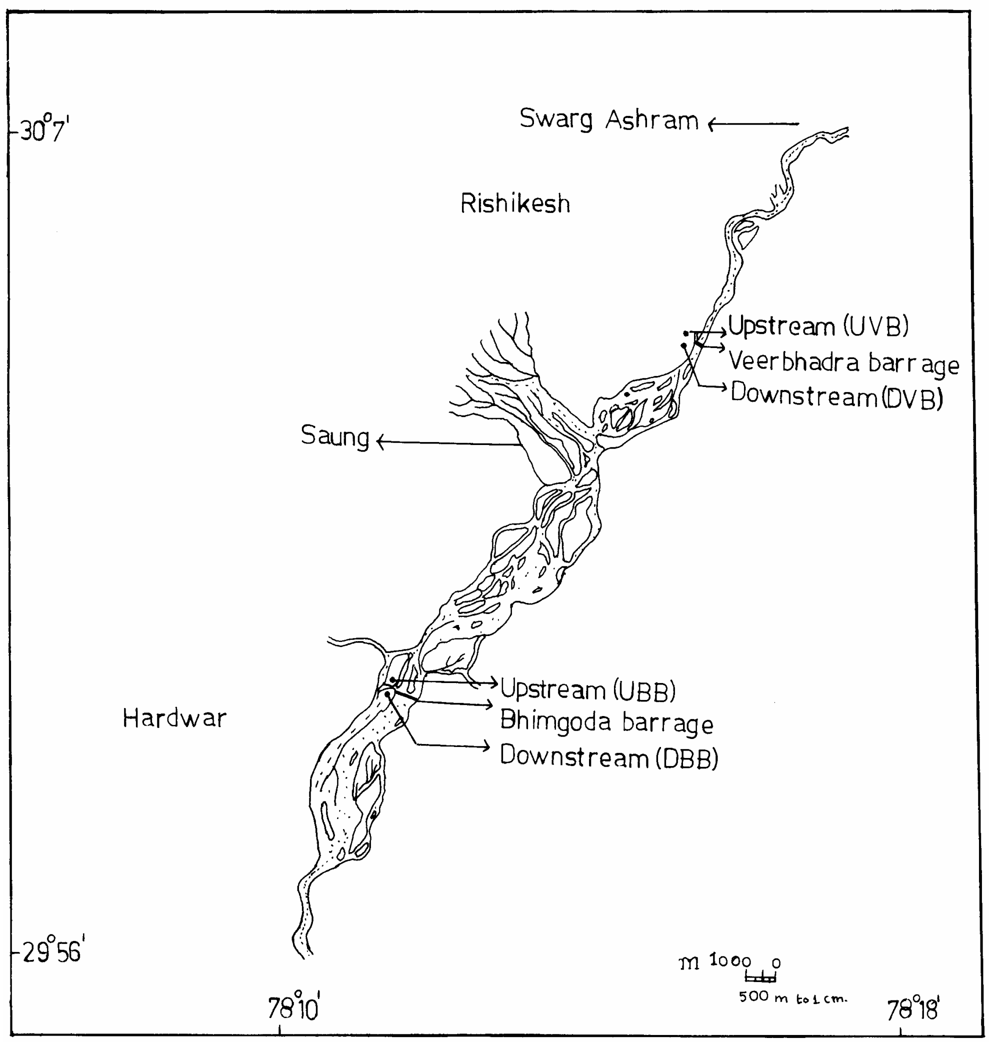

Fig. 1. Sampling stations in the impounded zones of the Ganga river system in the Garhwal region.

and *Zizyhus xylophora* along the left bank. The forest along the right bank included *Shorea robusta, D. sissoo, Mallotus phillinensis* and *Cassia fistula* while *Casurina opositifolia, Pogosteman benghalensis, Callicopa-macrophylla, Murraya koenigii* and *Lantana camara* constituted the ground vegetation (Badoni 1996).

Two barrages have been constructed across the main channel of the Ganga (Fig. 1). These are located on the outskirts of Rishikesh and Hardwar towns, respectively. The Veerbhdra barrage at Rishikesh, diverts the river water for hydroelectric generation. The Bhimgoda barrage on the other hand regulates the flow of Ganga waters at the Har-Ki Pairi or the western upper Ganga canal. This is achieved through the use of one spillover canal and two regulated canals located laterally (along left bank). While the latter two canals are just adjacent to the barrage, the former is a little upstream.

Prior to impoundment the river can be seen in its pristine condition and the flow is fast. However, the riffle zones are short while the pool zones are considerably larger. At Hardwar, the stream regulation alters the flow patterns and only inundated area exists prior to barrage. A long stretch between the two barrages carries nominal discharge. The Chila canal returns the major discharge to the river channel a few kms. upstream of the Bhimgoda barrage near Hardwar. River bed is mainly interspersed with silt, sand, pebbles, cobbles and boulders of varying size.

The sampling sites were selected in the vicinity of each barrage, both in the up and downstream sections. In text the sampling sites have been designated in the following manner: UVB and DVB,

Table 1. Physical and chemical characteristics of upstream and downstream sections of Veerbhadra and Bhimgoda barrage throughout the year.

Sites	J	F	M	A	M	J	J	A	S	O	N	D
Upstream Veerbhadra Barrage (UVB)												
AT (°C)	22	27	33	29	36	33	36	26	24	23	14	21
WT (°C)	13	16	20	19	21	21	21	20	17	17	14.5	11
Velocity (ms^{-1})	0.05	0.02	0.02	0.02	0.01	02	0.45	0.25	0.06	0.03	0.02	0.01
Turbidity (NTU)	1.5	5.0	5.0	44	725	159	190	296	8.0	00	00	00
DO (mg l^{-1})	12.8	11	9.5	10	7.2	10.3	9.5	7.2	10.6	9.2	11.7	12.6
Downstream Veerbhadra Barrage (DVB)												
AT (°C)	20	26	25	21	30	28	36	21	23	27	18	21
WT (°C)	18	20	21	20	22.3	22	21.1	19.5	19	19	19.5	19
Velocity (ms^{-1})	0.42	0.37	0.51	0.46	1.9	0.8	0.9	1.6	1.0	0.03	0.40	0.40
Turbidity (NTU)	1.0	0	4.5	3.0	7	900	157	100	216	15	1	1.0
DO (mg l^{-1})	11.5	9.2	8.5	9.1	8.1	7.8	9.4	7.8	10.2	9.0	9.3	11
Upstream Bhimgoda Barrage (UBB)												
AT (°C)	15	30	26	37	25	34	35	29	23	24	26	19
WT (°C)	14	18	21	20.5	20	24	24	21	20.3	18	17	12
Velocity (ms^{-1})	0.02	0.02	0.01	0.02	0.01	0.05	0.5	3	0.03	0.04	0.02	0.02
Turbidity (NTU)	0	0	4	3	45	1200	150	273	148	1.5	1.0	0
DO (mg l^{-1})	12.0	11.7	8.9	9.2	7.2	10.2	9.8	10.3	10.0	9	11.5	11
Downstream Bhimgoda Barrage (DBB)												
AT (°C)	14	22	30	37	21	32	34	26	23	24	23	20
WT (°C)	16	21	22	20.8	21.8	22	24	21	21	18.5	17	14.5
Velocity (ms^{-1})	0.28	0.3	0.37	0.5	0.2	1.2	2.5	3.0	0.38	0.37	0.23	0.02
Turbidity (NTU)	1.0	2	5	0	8	87.5	0	260	148	6.0	4.0	3.0
DO (mg l^{-1})	10	8.7	8.7	9	9.3	8.7	9.5	10.4	10.3	9.0	9.5	9.8

up and downstream Veerbhadra barrage; UBB and DBB, up and downstream Bhimgoda barrage. High-artificial slanting embankments, as compared with the natural river bed and moderately high embankments, characterized the up and downstream sections, respectively. While the Rajaji National Park forest prevails along the left bank, the human settlements (offices and residences of the staff looking after the barrage) exist along the right bank near both barrages.

At the sampling sites upstream of the barrage (UVB, UBB) the discharge begins to increase with the onset of summer which is usually from March. However, the increased discharge is retained by the barrage for maintaining adequate level of water needed for hydropower generation. The downstream section, especially at Veerbhadra remain dry (summer being the dry period). In case of the Bhimgoda barrage, however, there is more flow in the downstream section because of overflows from the Western Ganga canal. The water flow starts to increase in the downstream sections from May onwards. This is indicated by the high velocity recorded from June to August. The flow begins to decline from September to April (Table 1).

The study was conducted from January to December 1994. Sample of benthic macroinvertebrates were obtained at regular monthly intervals with the help of a square foot Surber's sampler. The substrate, mainly stones large sized cobbles and pebbles were disturbed and immediately transferred to the bucket under water and later rinsed thoroughly to dislodge all the attached macroinvertebrates. The organisms trapped in the Surber's sampler while transferring substrate into the bucket were also transferred into the bucket. The material was sieved through 100 μm sieve. The organisms were then counted after identifying them up to order/family/genus level and recorded as indiv. m^2. The diversity and similarity indices were computed as follows:

Diversity Index $\overline{H} = -\Sigma pi \log_e \Sigma pi$
(Shannon & Weaver 1963)

Similarity Index = 2 C/A+B (Sorensen 1948)

Results

The water temperature ranged from 11-21 (UBV), 17.5-23 (DVB), 12-21 (UBB) and 14.5-22°C (DBB). During the lean season (winter) the current velocity varied from 0.01-0.02 in the upstream section (UVB, UBB) while 0.1-0.42 in the downstream section (DVB, DBB). During summer the flow in the upstream section was low (0.01-0.06 UVB 0.01-3.0 UBB) as compared with the downstream section (0.16-0.9, DVB; 0.2-1.2, DBB). During monsoon it varied from 0.06-0.45 (UVB) and 0.01-3.0 (UBB) in the upstream section, while 0.9-1.6 (DVB) and 0.38-3.0 (DBB) in the downstream section. The turbidity varied from 0-725, 0-900, 0-1200 and 0-260 NTU at respective stations. The dissolved oxygen levels also varied slightly (Table 1).

The density of benthic macroinvertebrates was found to range from 0-792 indiv. m^{-2} in the upstream and 0-715 indiv. m^{-2} downstream section of the Veerbhadra barrage. In UVB only Ephemeroptera (0-100%) occurred in all the seasons whereas Diptera (0-18%), Trichoptera (0-52%) and Mollusca (0-4%) were found only during winter. The benthic forms in the downstream section included Ephemeroptera (0-88%), Diptera (0-60%), Trichoptera (0-11%), Mollusca (0-28%), Coleoptera (0-15%) and some Miscellaneous (0-6%) forms (Figs. 2a-b).

In the Bhimgoda barrage the density of benthic macroinvertebrates was found to range from 0-616 indiv. m^{-2} in the upstream and 0-396 indiv. m^{-2} in the downstream section. The t-values computed to compare the density were found to be 0.7205 (UVB-DVB), 0.704 (UBB-DBB), 0.356 (UVB-UBB) and 0.0157 (DVB-DBB).

In upstream (UBB) and downstream (DBB) sections of the Bhimgoda barrage only Ephemeroptera (0-100%) occurred for most of the months. The other benthic forms in the upstream section included Mollusca (0-95%), Diptera (0-50%), Trichoptera (0-33.3%), Plecoptera (0-6%) and some Miscellaneous (0-33.3%). In DBB Diptera (0-71.4%), Trichoptera (0-50%), Coleoptera (0-14.28%), Plecoptera (0-1.78%) and some Miscellaneous forms (0-4%) were also recorded. (Figs. 2c-d).

As in the ustream section of Veerbhadra barrage with the exception of Plecoptera, four major taxa (Ephemeroptera, Diptera, Trichoptera, Mollusca) were found in the upstream section of the Bhimgoda barrage. Ephemeroptera was the only group occurring in all the seasons. Others exhibited fragmented occurrence. The downstream section (DBB) also harboured taxa similar to the downstream section of Veerbhadra barrage (Ephemeroptera, Diptera, Coleoptera, Trichoptera, Mollusca). Plecoptera not found in downstream

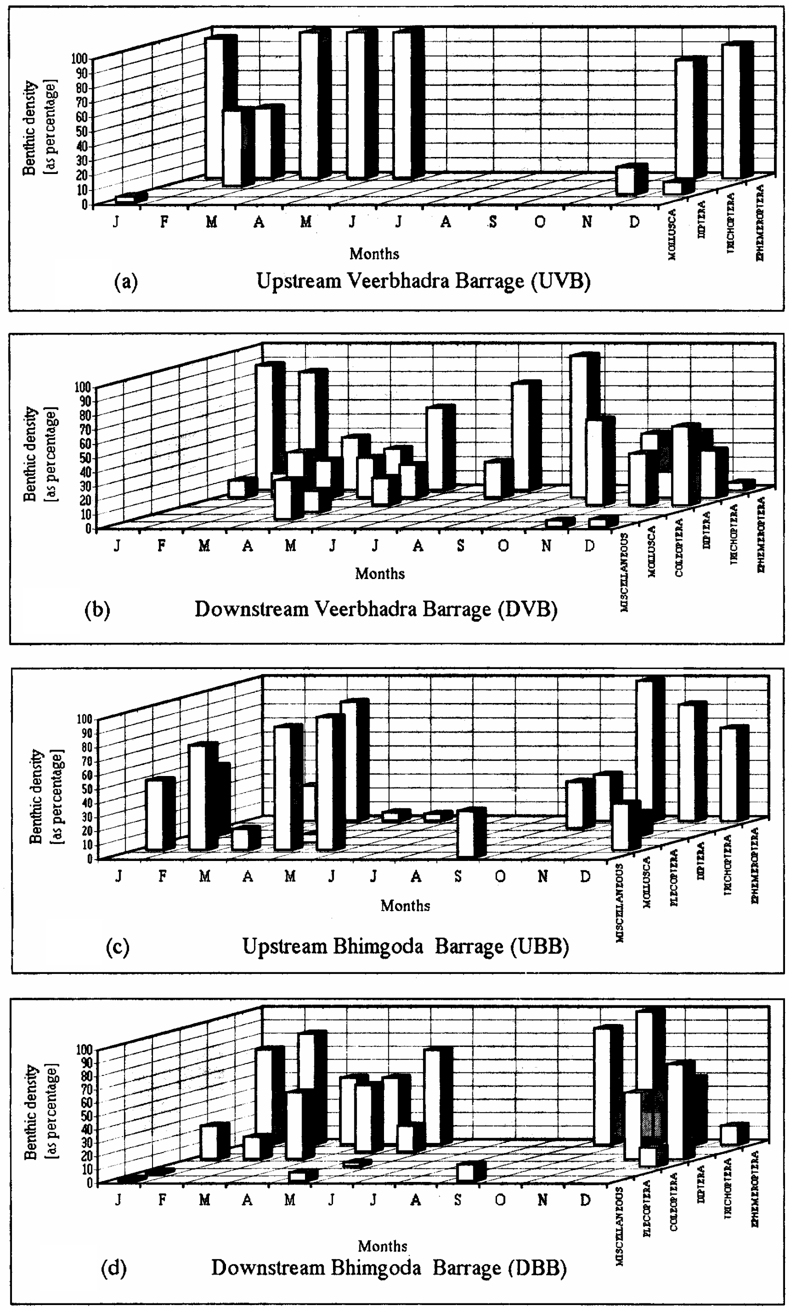

Fig. 2a-d. Monthly variations in percentage composition of major benthic components at impounded locations (UVB, DVB, UBB & DBB).

section of Veerbhadra barrage (DVB) was recorded in downstream section of Bhimgoda barrage (Table 2).

The most predominant taxa was found to be *Heptagenia* for a major part of the year in upstream and downstream sections of both the barrages especially in Bhimgoda barrage. The taxa which may be ranked second, in terms of dominance, however, differed at each location during different months; Simuliidae and Siphlonuridae in

Table 2. Occurrence (annual) of macroinvertibrate taxa in up and downstream locations of impounded sections (UVB, DVB, UBB and DBB) of Veerbhadra and Bhimgoda barrage.

Taxa	Veerbhadra barrage		Bhimgoda barrage	
	UVB	DVB	UBB	DBB
Heptagenia	+	+	+	+
Rithrogena	–	+	–	+
Baetidae	–	+	+	+
Baetis	+	+	–	–
Caenis	–	+	+	–
Siphlonuridae	+	–	–	–
Other Ephemeroptera	–	+	+	+
Hydroposyche	+	+	+	+
Cyrnellus	–	+	–	+
Other Trichoptera	+	+	–	+
Chironomidae	–	+	+	–
Simuliidae	+	–	–	–
Other Diptera	–	+	+	+
Coleoptera	–	+	–	+
Plecoptera	–	–	+	+
Mollusca *Gyraullus convexiculus*	–	–	+	–
Lymnea accuminata	–	+	+	–
Miscellaneous	–	+	+	+

UVB; Chironomidae, Baetidae and *Hydropsyche* in the downstream section (Veerbhadra barrage); Baetidae in upstream and other unidentified taxa in downstream section (Bhimgoda barrage).

The diversity index was found to fluctuate in the upstream (0.1348-1.1319, UVB and 0.4499-1.0875, UBB) and downstream (0.7115-1.6151, DVB and 0.6392-1.5187, DBB) locations respectively in the Veerbhadra and Bhimgoda barrage. The t-values computed for comparing diversity at UVB-DBB, UVB-UBB and DVB-DBB were 0.0017, 0.0409, 0.02002 and 0.5274, respectively. The statistical analysis (T-test) indicated insignificant differences in the density and diversity of benthic macroinvertebrates in upstream and downstream sections in the both barrages.

The similarity index values among the upstream locations (0.8421, UVB-UBB) as compared with the downstream section (0.6522 in DVB-DBB) were found to differ. Among the barrages UVB and DVB were relatively more similar (0.6956) as compared with UBB and DBB (0.5238).

Discussion

Numerous studies have been conducted on the impact of the stream regulation on the various biotic communities (Briggs 1948; Hoffman & Kilambi 1970; Hynes 1970; Lehmkuhl 1972; Pearson *et al.* 1968; Pftizer 1954; Pinter & Backhaus; Kawecka & Szczesny; Whitton & Crisp, quoted from Whitton 1984; Ruttner 1926; Spence & Hynes 1971; Sugunan & Das 1983; Trotosky & Gregory 1974). Some investigation were carried out on the distribution and long term changes of benthic macroinvertebrate community in relation to flow characteristics (Armitage & Pardo 1995; Bickerton 1995; Fjellhein 1996). However, little is known about the influence of stream regulation on the biota of the major Indian river systems. Much of the information pertains to biota of the reservoirs with respect to fisheries (Sugunan & Pathak 1986).

The present investigations revealed that no significant ($P<0.05$) difference occurred in the density of benthic macroinvertebrate community in the up and downstream sections of the impounded areas. The density nevertheless tended to decline in case of the Bhimgoda barrage. Similar observations were made with regards to the density of phytobenthic diatoms in these barrage sections (Nautiyal *et al.* 1997). The density of planktonic (drift) diatoms was much higher in the upstream inundated sections (Bhatt *et al.* 1997). However, the regulated portion of the Ganga exhibited a tremendous decline in the density of benthic macroinvertbrate community (0-792 indiv. m^{-2}) if compared with the upstream pristine part of the river at Rishikesh (60-2560 indiv. m^{-2}) studied earlier by Singh & Nautiyal (1990).

Earlier, Nautiyal *et al.* (1988) had evaluated changes in the water quality in the immediate vicinity of the Maneri Dam on the river Bhagirathi (1277 masl) and found that the density of benthic macroinvertebrate community (345 ± 322 indiv. m^{-2}) declined when compared with the river site 32 km upstream of the dam (646 ± 525 indiv. m^{-2}). In the regulated lotic system the abundance of macroinvertebrates may be elevated or depressed depending on the modified flow pattern. Severe flow fluctuations may deplete the fauna directly or indirectly by effects on substrate and food base and by reducing habitat diversity e.g. by eliminating accumulations of sedimentary detritus (Ward 1976). However, Trotosky & Gregory (1974) have reported that the density declines below the hydroelectric dams while Hoffman & Kilambi (1970) have observed enhanced densities. Extremely high densities have been recorded below surface release reservoirs where flow constancy prevailed (Ward & Short 1978). Thus, the nature of the flow is very important for the benthic macroinvertebrate communities of the regulated stretches. In case of the Veerbhadra and Bhimgoda barrage the decline in the total density may be attributed to the reduced flow for long periods (October-May) in the downstream sections, when compared with the natural riverine course.

A more diverse assemblage comprising Plecoptera (1.6%), Coleoptera (1.4%), Odonata (0-2%), Trichoptera (11.7%), Diptera (35%) and Ephemeroptera (47%) was recorded earlier by Singh & Nautiyal (1990) in the upstream pristine stretch of the Ganga in the foothills (Rishikesh). The upstream (UBB) and downstream (DBB) section of Bhimgoda barrage presented an almost similar picture. Contrary to this, Ephemeroptera, Trichoptera, Diptera and Mollusca only constituted the benthic macroinvertebrate community in the inundated upstream section of the impounded area (Veerbhadra barrage). In addition, the abundance pattern was also changed. While Ephemeroptera remained (0-100%), Trichoptera increased (0-52%) and the Diptera declined (0-18%). Mollusca (0-4%) which were not found in the pristine stretch appear for the first time in the river Ganga. In the downstream stretch, the river exhibits resilience capacity as Diptera tends to regain its abundance (0-60%). Trichoptera (0-11%) was relegated to third abundant group. Ephemeroptera was the most abundant group (0-88%). Coleoptera (0-15%) reappeared and Mollusca (0-28%) were recorded in lower percentage. The upstream and downstream sections of the Bhimgoda barrage also exhibited a similar trend.

The absence of Plecoptera at UVB, DVB and its reappearance at UBB and DBB was a notable feature of the present study. The dominance of Ephemeroptera especially Heptageniids at all the locations was also notable. The prevalance of Heptageniidae in the regulated sections also, indicates their ability to adopt the fluctuating flow regime aided by dorsoventrally flattened body contours and mechanism for anchoring. Functionally, the regulated waters of the Ganga were characterized by the abundance of the scrapers. The scrapers include Heptageniids, Blephericeridae, Psychodidae, Helodidae, Hydraenidae, Dryopidae, Elminthidae, Sericostomatidae, Odontoceridae and Limnephilidae (larvae with inorganic case) which were abundant in the autotrophic (rich in periphyton) stretch (Cotta-Ramusino *et al.* 1995).

According to Radford & Hartland-Rowe (1971), mayflies, depending on the taxa, may either be favoured or reduced below dams. Heptageniids and other species with holdfast organs may be predominant species in streams with rapid current velocity. Ward & Stanford (1990), also reported increased abundance of Ephemeroptera nymphs below headwater dams. This abundance decreased below lower reach dams of the river Gunnison. Scrapers and collector-gatherers comprised the majority of the mayfly fauna in the headwaters of this river as in the present case. The filter-feeders were abundant in the lower stretch.

Earlier, Whitton & Crisp (quoted from Whitton 1984) reported that as a consequence of impoundment the faunal composition altered which included both losses mainly Plecoptera, and gains (Mollusca). According to them impoundment results in the increased abundance of *Gammarus*, Chironomids and Mollusca in the river Tees, while Ecdyonuridae nymphs decreased thus emphasizing the importance of changes in the relative abundance of the groups. According to Kawecka & Szczesny (in Whitton 1984) Chironomids were the most abundant group while Ephemeroptera, Plecoptera and Trichoptera were found in lower percentage in unregulated stretch.

A number of authors have reported that in the regulated stretch loss of Plecoptera was observed while Ephemeroptera, Trichoptera, and even Diptera were more seriously affected (Hoffman & Kilambi 1970; Lehmkuhl 1972; Spence & Hynes 1971; Trotosky & Gregory 1974; Ward 1974; Weber 1959). According to Ward & Short (1978) an enhanced community of filter-feeders characterizes stream below surface release impoundments and natural lakes. Trichoptera and Diptera (Simuliidae) may cover virtually the entire suitable substrate at certain seasons. Other filter-feeders such as bryozoans and sponges may attain high populations under certain conditions. The lack of uniformity in relative abundance of benthic macroinvertebrates in upstream and downstream sections of each barrage can be attributed to the flow conditions in the regulated sections.

The diversity index validates the above findings that upstream locations (UVB, UBB) loose their diversity as compared with downstream sections (DVB and DBB). However, UVB was found to be least diverse of the two upstream locations. Moverover, the diversity which increased in DVB again tended to decline in UBB. Statistically, UBB and DBB did not differ much in terms of diversity.

Earlier, no observations have been made on the species diversity of this community in the pristine stretch of the Ganga in the foothills or upstram of it. Hence, the present results are not comparable. However, Singh & Nautiyal (1990), reported 17 taxa while 15 taxa (including families/orders) including some genera were recorded during the present studies. The species diversity ranged from 0.1348 to 1.6151 in the regulated stretch seems to be low. Ward (1976), maintains that diversity was invariably reduced due to regulation. Ward & Stanford (1990) reported that the species richness was greatly reduced immediately downstream of the dam.

The similarity index indicated greater similarity (0.8421) among the upstream locations (UVB, UBB) as compared with the downstream sections (0.6522 in DVB-DBB). Among the barrages UVB and DVB were relatively more similar (0.6956) as compared with UBB and DBB (0.5238). These index values also indicated that the similarity between the up and downstream sections was relatively very low. This can be attributed to differences in the nature of substrate available in these sections. The dykes on both sides of the impounded area provides little substrate (natural) for colonisation by benthos. A lack of diverse substrate seems to disallow the growth of a diverse benthic community. The downstream stretch with wide variety of substrate but meagre flow provides very little opportunities for their colonisation.

Conclusions

Stream regulation thus effects the loss of habitat due to impoundment in the stream section, and due to negligible flow in the downstream section. The rivers thus tend to loose its diversity in the process. Similarly, the variations in the abundance of benthic macroinvertebrates could also be attributed to differences in the nature of substrate and available discharge. In the upstream sections with semilacustrine conditions and less substrate only Ephemeroptera, Diptera, Trichoptera and Mollusca were observed. The downstream sections with meagre flow does not submerge a wide variety of substratum thus restricting the composition of benthos.

The relatively higher abundance of Ephemeroptera and their constant presence in the regulated sections as compared with fragmented occurrence of Diptera and Trichoptera also supports the above observation. The prevalence of Heptageniidae in the regulated sections also indicates fluctuations in flow regime to which probably they have adapted with dorsoventrally flattened body contours and mechanism for anchoring in varying flow conditions. Moreover, in the pristine upstream sections the relative abundance was well graded and occurrence unfragmented indicating stability in the system. Other groups seem to flourish only during conducive conditions. All these facts pinpoint towards the fragmented state of the habitat in question i.e. the impounded and regulated sections of the river Ganga.

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