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Factors governing longitudinal variation in benthic macroinvertebrate fauna of a small Vindhyan river in Central Highlands ecoregion (central India)

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Abstract: Variation in the taxonomic composition of benthic macroinvertebrate fauna was examined in the Paisuni river at four stations (P1 to P4) located longitudinally along the river, with P1 being nearest the source of origin. The fauna was dominated by insects at all the stations. Total density increased from P1 to P3, decreased at P4 and differed significantly among the stations. Increase in the relative abundance from P1 to P4 was observed for Baetidae, Chironomidae and Gomphidae, and a decrease for Leptophlebiidae, Heptageniidae, Neoephemeridae, Rhyacophilidae and Thiaridae. Ordination analysis indicated that Rhyacophilidae was the characteristic taxon at P1, Thiaridae at P2 and Chironomidae at stations P3 and P4. Ordination also revealed that current velocity, substratum and landuse were the major environmental factors influencing the relative composition of macro-invertebrates. The longitudinal variation in taxonomic composition and assemblages showed a change of trophic status due to direct human interference at P2. Collectors were abundant at all stations but predominated the assemblages from P3 to P4. The balance between collectors, scrapers and predators shifted to predominance by collectors indicating heterotrophic conditions at P3 and P4 in contrast to autotrophic conditions at P1 and P2. Hence, two ecological zones are evident in the Paisuni river.

Resumen: Se examinó la variación en la composición taxonómica de la fauna de macroinvertebrados bentónicos en el río Paisuni en cuatro estaciones (P1 a P4), localizadas longitudinalmente a lo largo del río, siendo P1 la más cercana a la fuente de origen. La fauna estuvo dominada por insectos en todas las estaciones. La densidad total se incrementó de P1 a P3, decreció en P4 y difirió significativamente entre todas las estaciones. Se observó un incremento en la abundancia relativa de P1 a P4 para Baetidae, Chironomidae y Gomphidae, y un decremento para Leptophlebiidae, Heptageniidae, Neoephemeridae, Rhyacophilidae y Thiaridae. Un análisis de ordenación indicó que Rhyacophilidae fue el taxón característico en P1, Thiaridae en P2 y Chironomidae en las estaciones P3 y P4. La ordenación también mostró que la velocidad de la corriente, el sustrato y el uso de la tierra fueron los principales factores ambientales que influyen sobre la composición relativa de los macroinvertebrados. La variación longitudinal en la composición taxonómica y los ensambles de especies mostró un cambio de estatus trófico debido a la interferencia humana directa en P2. Los recolectores fueron abundantes en todas las estaciones pero predominaron en los ensambles P3 y P4. El balance entre recolectores, raspadores y depredadores se modificó hacia una prevalencia de los recolectores, lo que indica que hay condiciones heterotróficas en P3 y P4, en contraste con las condiciones autotróficas en P1 y P2. Por lo tanto, es evidente que en el río Paisuni hay dos zonas ecológicas.

Resumo: A variação na composição taxonómica de macro invertebrados bentónicos no rio

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Paisunifoi examinadaem quatro estações (P1 a P4), localizadas longitudinalmente ao longo do rio, sendo P1 a mais próximada nascente. Em todas as estações afauna era dominada por insectos. A densidade total aumentou de P1 para P3, diminuiu em P4 e diferiu significativamente entre as estações. Observou-se o aumento na abundância relativa de P1 a P4 para os Baetidae, Chironomidae e Gomphidae, e uma diminuição de Leptophlebiidae, Heptageniidae, Neoephemeridae, Rhyacophilidae e Thiaridae. A análise de ordenação indicou que a Rhyacophilidae foi o taxa característico na P1, a Thiaridae na P2 e a Chironomidae nas estações P3 e P4. A ordenação também revelou que a velocidade do caudal, o substrato e o uso do solo foram os principais factores ambientais que influenciaram a composição relativa dos macro-invertebrados. A variação longitudinal na composição taxonómica e agrupamentosmostrou uma mudança do estado trófico devido àinterferência humana directa em P2. Os colectores foram abundantes em todas as estações, mas predominaram os agrupamentosem P3 a P4. O balanço entre colectores, raspadores e predadores ultrapassou a predominância dos colectores indicando as condições heterotróficas características em P3 e P4, em contraste com as condições autotróficas em P1 e P2. No rio Paisuni são assim evidentes duas zonas ecológicas.

Key words: Benthic macroinvertebrates, chironomidae, current velocity, India, longitudinal variation, Paisuni river, river continuum.

Introduction

The water resources of India are under severe stress to meet the domestic, agricultural, and hydropower demands of the ever increasing population. Impoundment for irrigation and hydropower modifies water flow and fragments the river ecosystem. In addition, river linking projects are planned for the rivers of Indian Peninsula and Himalaya (NWDA 2006). Reduction in spatial heterogeneity constrains the species represented at any particular site (Pan *et al.* 2000). The spatial distribution of benthic invertebrates provides a sensitive indicator of the effect of landuse (Hawkins *et al.* 1982). Compared to intensive investigations from other parts of the world (Guinand *et al.* 1996; Murphy & Davy-Bowker 2005; Nerbonne & Vondracek 2001; Usseglio-Polatera & Beisel 2002), knowledge regarding the spatial distribution of benthic macroinvertebrates in Indian rivers in general, and in the rivers of the Central Highlands ecoregion in particular, remains scarce and preliminary. The Ganga and Yamuna are the only rivers near the Central Highlands in which the spatial patterns of macroinvertebrates have been examined. Works from the Ganga include Bilgrami & Dutta Munshi (1985), Singh & Nautiyal (1990), Singh *et al.* (1994), the Yamuna (Anon. 2003) and the Cauvery (Sivaramkrishnan *et al.* 1995) and the Neyyar (Nair *et al.* 1989).

India has varied terrain and climatic conditions. Each ecoregion has numerous streams and rivers of different orders, many of which have been used for irrigation, domestic supply and power generation to narrow the demand-supply gap. In the Ganga as well as other river systems of India, industries and civic bodies discharge waste causing point and non-point pollution. With a view to contributing to general knowledge regarding spatial distribution of benthic macroinvertebrates and to providing baseline information on the current effects of landuse, the present study was performed in a low order Central Highlands river, the Paisuni. Longitudinal changes in the benthic macroinvertebrate fauna and factors governing their distribution were examined, and river zonation and functional status of the river were also determined.

Materials and methods

Study area

The Paisuni River is located in the Central Highlands ecoregion of India along the southern fringe of the Gangetic Plains drained by the river Yamuna (Fig. 1, Table 1). It arises at 275 m above sea level (m asl) in the Kaimur hills of Vindhyan range and flows ca. 100 km north across the Bundelkhand Plateau to meet the Yamuna at 80 m asl. Four stations, approximately 10 to 25 km apart (except P3 and P4, 58 km apart), were sampled.

Table 1. The geographical co-ordinates, physical characteristics, landuse and substrate combinations found at each sampling location in the Paisuni river. The combination of substrate indicated heterogeneity at each station. The dominant substrate type are written first in the substrate combination (Abbreviations: B- Boulder; C- Cobble; Cl-Clay; G-Gravel; P- Pebble; S-Sand; R-Rock; Si-Silt).

Station	P1	P2	P3	P4
Distance from source (km)	10	26	42	100
Latitude (°N)	25° 04'25"	25° 10'25"	25° 13'01"	25°° 25'25"
Longitude (°E)	80° 52'05"	80° 52'12"	80° 54'09"	81° 08'52"
Altitude (m asl)	180	135	131	80
Landuse type	Forest	Agriculture, Temple	Agriculture	Agriculture
Substrate combination	R; B; C; P	Cl; Si; B; P-G	Si; C; C-P; B; S; P-G; Cl	Si; C-P; Cl; S; P-G
Water temperature (°C)	21.0 - 22.5	16.5 - 21.5	15.5 - 17.0	28.5 - 33.0
Current velocity (cm s^{-1})	6.2- 23.2	0 - 30.9	2.81-30.2	10.3- 20.6
Discharge (Litre s^{-1})	2.53	1.1	1.22	11.8
pH	7	7.36	7.6	7.6

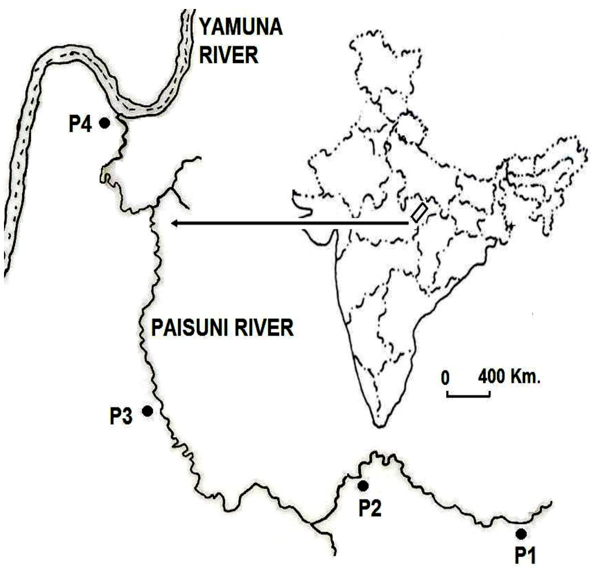

Fig. 1. Location of the Paisuni river in India and sampling stations (P1 to P4) selected for the study.

The maximum depth was 60 cm at all stations except P4 (56 cm); width was 42, 95, 22 and 50 m at P1, P2, P3 and P4, respectively. Stony substrate occurred from P1 to P3; silt-clay-sand, at P4. Except for natural forest in the headwaters, agriculture was the major landuse along the sampled stretch. Mass bathing during pilgrimage and religious occasions is a regular source of direct interference, while offerings such as flowers, fruits, grains, etc. cause organic pollution at station P2.

Sampling

The focus of the study is to generate information on the spatial distribution of macroinvertebrates along the length of the river Paisuni, particularly during the dry season. One-time intensive sampling (20 quadrats per station) in the dry-period was considered appropriate for such studies (Corkum 1989, 1991). The dry-period extends from October to June but sampling was restricted to only a part of this period i.e. December to March because long stretches of the river tend to dry up during the summer season (March to June), forming pools of various sizes and thus the continuum is disrupted. We focus on the dry period also because it accounts for a major part of the year (9 months) compared to the wet period (3 months) due to monsoon from July to September (Unni 1996; Vombatkere 2005). The composition of macroinvertebrate fauna remains relatively stable in the dry period than in floods (Ormerod *et al.* 1994; Jüttner *et al.* 2003). The floods replenish nutrients and particulate organic matter in the river, which sustain the food chains and thus these communities.

Sampling procedures at each station involved lifting stones (boulder, cobble, pebble, gravel) and sieving clay and silt from 0.09 m^2 area in different flows (turbulent, swift, slow, placid). The substrate was washed to dislodge the fauna, which was preserved in 5 % formalin for further analysis. As broad taxonomic classifications are acceptable

Table 2. Total mean density, median density and actual minimum and maximum densities of benthic macroinvertebrate fauna. Mean densities (indiv. m-2) of the class, orders and families in the Paisuni river are significantly different (H: Kruskal - Wallis test statistics, df = degree of freedom) among sites. (Abbreviation: obs. = observed).

Phylum/Class/Order/Family	P1	P2	P3	P4	H obs.
Arthropoda- (Insecta)	180.9 ± 31.9	345.9 ± 33.6	1277.6 ± 169.2	594.6 ± 102.4	43.7*
Ephemeroptera (mayfly nymphs)	106.7 ± 23.9	157.8 ± 31.2	739.2 ± 118.4	314.6 ± 71.1	14.2*
Leptophlebiidae	48.4 ± 14.7	25.3 ± 16.4	325.0 ± 74.	118.2 ± 39.3	11.7*
Neoephemeridae	20.9 ± 5.6	26.9 ± 11.87	9.9 ± 5.2	16.5 ± 7.6	3.3
Baetidae	9.3 ± 3.1	60.5 ± 14.1	256.8 ± 46.6	114.4 ± 31.0	26.7*
Heptageniidae	17.6 ± 7.2	6.0 ± 3.4	34.6 ± 10.7	14.8 ± 6.7	6.9
Trichoptera (mayfly nymphs)	61.6 ± 10.8	26.9 ± 8.1	148.5 ± 30.9	46.2 ± 11.5	12.8*
Rhyacophilidae	59.4 ± 10.9	3.8 ± 2.7	29.7 ± 6.8	13.7 ± 4.7	24. 4*
Hydropsychidae	0.5 ± 0.5	6.0 ± 3.0	33 ± 8.5	14.8 ± 5.4	12.9*
Diptera (two winged flies)	6.0 ± 2.1	100.6 ± 25.3	371.8 ± 198.4	204.05 ± 91.4	15.4*
Chironomidae	5.5 ± 2.0	79.7 ± 22.9	360.8 ± 196.6	193.0 ± 89.1	6.6
Odonata	2.7 ± 1.3	44 ± 12.1	11.5 ± 5.9	26.9 ± 9.7	8.3*
Gomphidae	2.7 ± 1.3	42.9 ± 12.2	11.5 ± 5.9	26.9 ± 9.7	8.2*
Mollusca - (Gastropoda, Pelecypoda)	12.6 ± 5.1	77.5 ± 13.8	20.9 ± 7.4	41.2 ± 10.1	17.2*
Gastropoda/Mesogastropoda / Thiaridae	12.1 ± 4.8	72.6 ± 13.2	10.4 ± 5.8	23.1 ± 8.3	11.3*
Pelecypoda / Heterodonta / Corbiculidae	0.5 ± 0.5	4.9 ± 2.1	10.4 ± 4.2	18.1 ± 6.0	6.0
Annelida - (Oligochaeta, Hirudinea)	0	24.2 ± 9.62	4.9 ± 2.5	4.9 ± 2.5	3.1
Oligochaeta / Neooligochaeta / Glossocolecidae	0	16.5 ± 7.3	3.3 ± 2.4	3.3 ± 2.4	2.9
Hirudinea /Arhynchobdellida /Salifidae	0	7.7 ± 4.3	1.6 ± 1.2	1.6 ± 1.2	0.7
Total Mean Density ± SE	193.6 ± 32.6	447.7 ± 33.2	1306.8 ± 167.1	640.75 ± 101.8	48.9*
Median Density	165	434.5	1204.5	577.5	-
Minimum - Maximum	44-660	198-693	418-3718	110-1826	-

*Significant at 5 % H at 3 df = 7.81

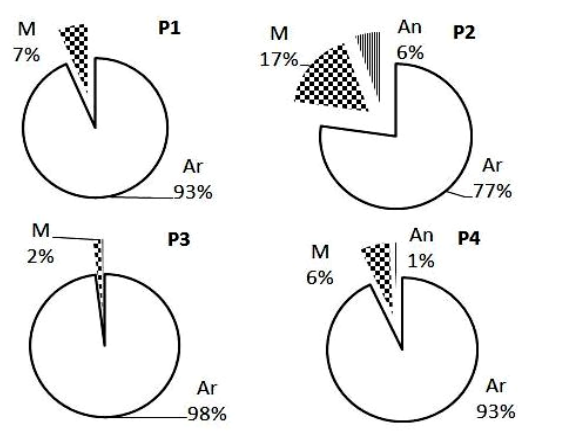

Fig. 2. Percentage composition of higher taxonomic groups (Ar = Arthropoda; An = Annelida; M = Mollusca) at stations P1 to P4, in the river Paisuni.

when the empirical relationships involving benthic invertebrates are to be developed in a large study area (Corkum 1989), the fauna was identified to family level (Edmondson 1959; Edington & Hildrew 1995; Nesemann *et al.* 2004; http://animal diversity.ummz.umich.edu). The families were grouped to understand relationship at higher taxonomic level (Order and Class).

Counts were made to obtain total density (indiv. m-2), relative abundance (as %), the taxonomic composition at each location and the longitudinal variation between them. The mean, standard error and median densities were computed for each station from total density obtained for each of 20 quadrats sampled at each station. The functional groups were determined according to Cotta Ramusino *et al.* (1995) and Dudgeon (1984). The Kruskal-Wallis test (Henderson 2003) was used to deter-

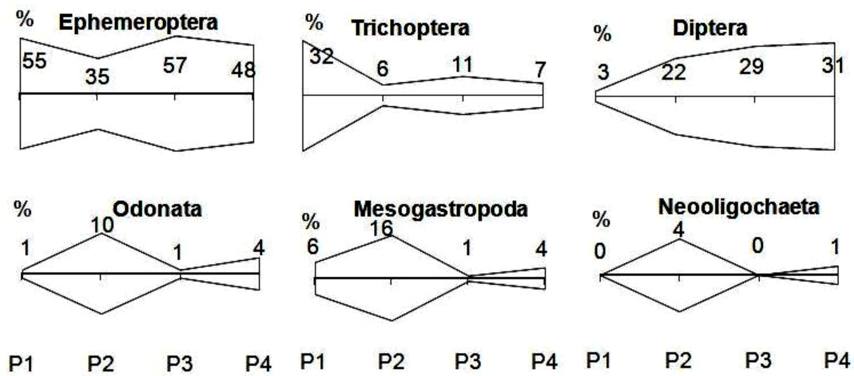

Fig. 3. Longitudinal variation in taxonomic composition of higher taxon groups (Orders) of benthic macroinvertebrates showing continuous and substantial presence at most of the stations from P1 to P4, in the river Paisuni.

mine significant differences between stations in total density of the community and higher taxa (order, families). Principal Component Analysis (PCA) was used to determine the characteristic taxa at each station, and the Canonical Correspondence Analysis (CCA; ter Braak & Smilauer 2002) helped to identify the environmental variable(s) causing longitudinal variation in the taxonomic composition of the benthic macroinvertebrate fauna. The multivariate analysis (CCA and PCA) were based on the raw data, i.e. counts of invertebrate fauna from each quadrat.

Results

The physiographic conditions of the river, the altitude, gradient, water current velocity and the combination of substrate differed slightly at each sampling station (Table 1). The water temperature shows a general trend of increase from P1 to P4, as the river flows from high to low elevation in the alluvial Gangetic Plains. However, the water temperature was lower at P2 and P3, due to winter rains on the days of sampling, and was considerably high at station P4, since station P4 was sampled last, during mid February. The ambient temperatures increase in February compared to December and January. The winter rains thus led to a disparity in the observed thermal profile. The fauna, their densities and composition, is not affected by short spell of winter rains as the annelids, insects and molluscs have an annual life-cycle pattern.

The density of benthic macroinvertebrate fauna increased considerably from P1 to P3 and decreased at P4. As standard error (SE) was high, the median was a better estimator than the mean (Table 2). The benthic fauna comprised three major taxonomic groups (phyla): arthropods, molluscs and annelids. The arthropods are represented only by Class Insecta, the molluscs by Class Gastropoda and Pelecypoda, while the annelids by Class Oligochaeta and Hirudinea. Increase and decrease in their share corresponded with that of the total density (Table 2). The insects dominated at all stations ranging from a low of 77 % at P2 to a high of 93 % at P3 (Fig. 2), others accounting for the remaining share at each station (Fig. 2). Compared to other stations, the share of insects was low at P2. The density of some higher taxon (Orders and Families) differed significantly from P1 to P4 (Table 2).

Longitudinally, among the insects, the Order Ephemeroptera (may-fly) was a major component of the benthic macroinvertebrate fauna from P1 to P4 (Fig. 3), Trichoptera (caddis-fly) exhibited a decline from P1 to P4 (Fig. 3), while Diptera (two-winged fly) increased from P1 to P4. Among the molluscs, the Order Mesogastropoda decreased from P1 to P4, but abruptly increased at P2. Among the annelids, the Order Neooligochaeta, represented only by family Glossoscolecidae, were present only at P2 and P4, and Arhynchobdellida represented by Salifidae at P2 only, with a low but equal share.

The water temperature showed an overall generally increasing trend with a temporary decline at P3 caused by heavy rainfall on the day of sampling, which due to its temporary nature does not affect the densities and composition of benthic macroinvertebrate fauna. The mayflies - Baetidae show negative relationship with water temperature and Neoephemeridae show positive

Table 3. Percentage composition of the Functional Feeding Groups (FFG) of benthic macroinvertebrate fauna at different stations of Paisuni river. Families have been grouped on the basis of their functional role in the ecosystem into FFG viz. scraper, gathering collectors, filtering collectors, predators. Each family is expressed as % of number of individuals in the total count from 20 quadrats at each location.

Functional Feeding Family/groups	FFG (as %)			
	P1	P2	P3	P4
Scraper				
Caenidae	5	3	-	1
Neoephemeridae	11	6	1	3
Heptageniidae	9	1	3	2
Thiaridae	6	16	1	3
Total	31	26	5	9
Gathering Collectors				
Leptophlebiidae	25	6	25	18
Baetidae	5	14	20	18
Ephemerillidae		1	1	-
Brachycentridae	-	3	2	2
Glossosomatidae	1	-	4	-
Hydropsychidae	-	1	3	2
Hydroptilidae	-	1	-	-
Chironomidae	3	18	28	30
Tabanidae	-	2	-	1
Heleidae	-	3	1	1
Total	34	49	84	72
Filtering Collectors				
Oligochaeta (Glossoscolecidae)	-	4	-	1
Pelecypoda (Corbiculidae)	-	1	1	2
Total	-	5	1	3
Total Collectors (Gathering + Filtering)	34	54	85	75
Predators				
Rhyacophilidae	31	1	2	2
Perlidae	1	1	-	-
Gomphidae	1	10	1	4
Hirudinea (Salifidae)	-	2	-	-
Total	33	14	3	6
Miscellaneous Groups	1	6	7	10

relationship with water temperature from P1 to P4, while Leptophlebiidae show an apparently positive relationship with current velocity. Giant insect nymphs, Gomphidae (dragon fly) increased at P2 while temperature decreased, and when temperature increased dramatically at P4, Gomphidea only increased little from P1 to P4. Baetidae and Chironomidae increased from P1 to P4 along with increase in pH.

The benthic macroinvertebrate assemblages varied longitudinally: Rhyacophilidae - Leptophlebiidae - Neoephemeridae dominated at P1; Chironomidae - Thiaridae - Baetidae - Gomphidae, at P2; and Chironomidae - Leptophlebiidae - Baetidae, at P3 and P4 (Table 3). These observations conform to inferences obtained from Principal Component Analysis, as Rhyacophilidae was characteristic at P1, Thiaridae - Agrionidae at P2, Chironomidae - Leptophlebiidae - Glossosomatidae - Heptageniidae at P3 and Chironomidae - Brachycentridae - Dytiscidae - Ephemerellidae at P4 (Fig. 4). Functionally, the macroinvertebrate fauna contained equal share of collector (gathering and filtering), predator and scraper (31 to 34 %) at P1 compared to the dominance of collectors (54 %) followed by scraper (26 %) at P2. This is in contrast to the

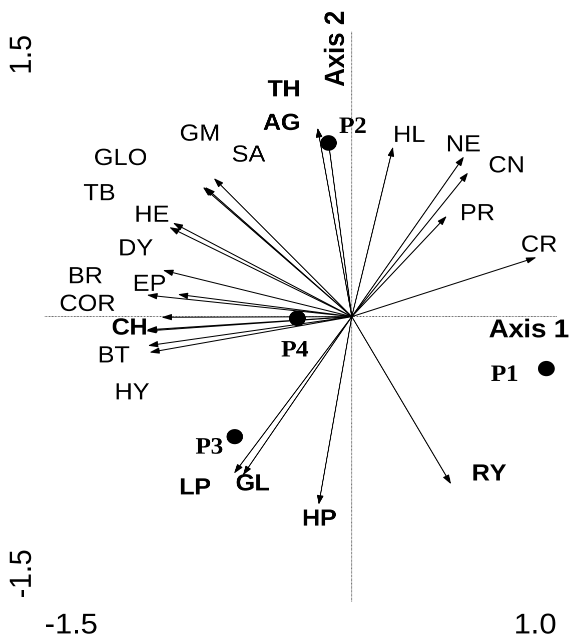

Fig. 4. Principal Component Analysis (PCA). The ordination indicates the characteristic taxa through graphical presentation between the taxon (arrows) and station (circles) at each station in the river Paisuni. The taxa close to the station are characteristic of that station and represented in bold letters (AG - Agrionidae, BT - Baetidae, BR - Brachycentridae, CH - Chironomidae, CN - Caenidae, COR - Corbiculidae, CR - Crustacea, DY - Dysticidae, EP - Ephemerellidae, GM - Gomphidae, GL - Glossosomatidae, GLO - Glossocolecidae, HE - Heleidae, HP - Heptageniidae, HL - Hydroptilidae, HY - Hydropsychidae, LP - Leptophlebiidae, NE - Neoephemeridae, PR - Perlidae, RY - Rhyacophilidae, SA - Salifidae, TB - Tabanidae, TH - Thiaridae).

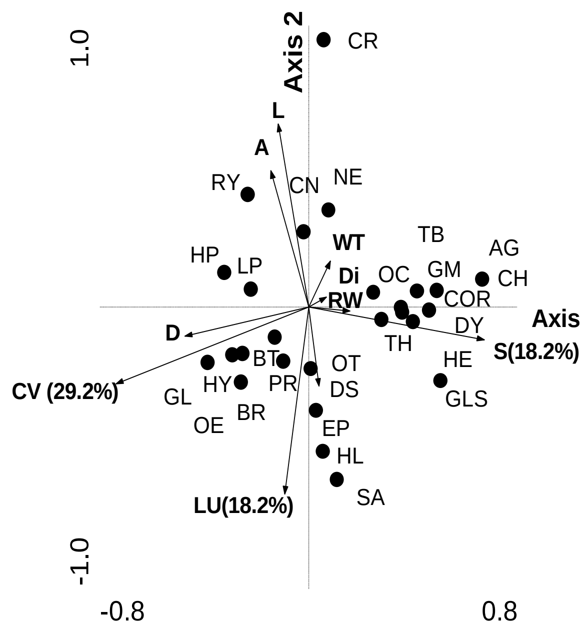

Fig. 5. Canonical Correspondence Analysis (CCA). The multivariate analysis indicates the relationship between benthic macroinvertebrate taxa and environmental variables in the river Paisuni. Taxon and stations are indicated by arrows and circles, respectively. Current velocity is the most important variable causing 29.26 % longitudinal variation in taxonomic composition from P1 to P4, followed by substratum (18.29 %) and landuse (18.29 %). The effective environmental variables are indicated in bold letters. (Abbreviations - A-Altitude, CV- Current velocity, D-Depth, Di- Discharge, DS - Distance from source, L - Latitude, LU- Landuse, RW-River width, S- Substratum, WT- Water temperature, OT - Other Trichoptera, OC - Other Coleoptera. For the rest of the acronyms see Fig. 4.

predominance of collectors at P3 and P4 (Table 3). The assemblages and trophic status point to the existence of two ecological zones in the Paisuni river.

Factors governing longitudinal variation in assemblages in the Paisuni were explored through CCA. The cumulative percentage variance of taxon - environmental variation for CCA axes 1 and 2 was 44.4 % and 21.6 %, respectively; the eigen values were 0.364 and 0.177 (Canonical eigen value 2.404). Current velocity and substrate on axis 1 and landuse on axis 2 explained 29.2 %, 18.2 % and 18.2 % variation in taxonomic composition, respectively, in the river. Different taxa were associated with these variables (Fig. 5). The characteristic taxa varied among the stations.

Discussion

The total density of benthic macroinvertebrate fauna exhibited a generally increasing trend from P1 to P3 (Table 2); however, it varied significantly from P1 to P4. The increased faunal density can be explained by the increase in the surface area caused by the gradual reduction in the particle size leading to substrate heterogeneity; from predominantly rock at P1, cobble at P2 to cobble-pebble at P3. Similarly, decreased density at P4 can be explained by the presence of more homogeneous substrate in the form of silt - clay. Longitudinal increase in the density of benthic macroinvertebrate fauna has also been reported in other small order rivers such as the European River Wye (Edwards & Brooker 1984), Credit and Little Bow Rivers (Corkum 1991). Higher densities at P3 compared to other stations also suggest greater food presence at P3 in the form of Particulate Organic Matter (POM) generated from agriculture landuse in the basin. As chironomid feed on Fine Particulate Organic Matter (FPOM) and function as collectors, their abundance of at P3 supports the conclusion that greater food presence played a role in enhancing the densities.

Longitudinal trends of gradual increase and decrease in the abundance of major groups from P1 to P4 were observed only in Diptera and Trichoptera (Fig. 3), respectively. On the other hand, the larger shares of Leptophlebiidae and Baetidae kept Ephemeroptera almost constant across the stations. Ephemeroptera and Trichoptera dominated at P1 but declined at P2, which was associated with increased abundance of Mesogastropoda. While the abundance of Trichoptera continued to decline, Ephemeroptera regained abundance at P3 and declined marginally at P4. The decline at P2 suggests longitudinal disruption of their ecological roles (reflected by the Functional Feeding Groups - FFG) despite the presence of the preferred cobble-pebble substrate and other abiotic regimes. The decline of Trichoptera and Ephemeroptera and increase in abundance of Diptera, Mesogastropoda and Neooligochaeta from P1 to P2 is attributable to anthropogenically caused variation in the trophic status of the river at P2. In particular, intense religious activities (mass bathing, offerings such as flowers, fruits, grains, etc.) related to pilgrimage combined with the presence of a larger human settlement compared with other stations causes increased organic matter input at this station.

Longitudinal variation occurred in the taxonomic composition; and we attribute this primarily to variation in the substrate type (Table 1), decrease in current velocity, and synergistic action of landuse practices which altered the type of organic inputs in the vicinity of the sampling stations. As a result, while the caddis-fly Rhyacophilidae and the mayfly Neoephemeridae decreased, Chironomidae (midges) increased in abundance from P1 to P4, and Baetidae from P1 to P3 (Table 3). These patterns reflect respective preferences for substrate, current velocity and landuse type. Rhyacophilidae and Neoephemeridae are known to prefer rocky substratum, Heptageniidae and Baetidae the boulders and cobble, and Chironomidae the silt-clay (Aagaard *et al.* 2004; Death 2003; Knight & Gaufin 1966). As observed in other studies (Kerans *et al.* 2005), the above factors and the abundance of macrophytes (due to organic inputs from pilgrimage activity which serve as food as well as shelter) were responsible for increased abundance of Thiaridae (mesogastropod) and Gomphidae at P2. The macrophytes (*Eichhornia* sp. etc.) are preferred substrate for the highly abundant Thiaridae and Gomphidae. The macrophyte growth due to landuse practice at P2 masks the naturally occurring substrate (boulder, cobbles, pebbles, etc.) and the macroinvertebrate fauna (such as Rhyacophilidae, Leptophlebiidae, etc.) occurring on it, thus disrupting the continuum from P1 to P4 predicted by the River Continuum Concept (Vannote *et al.* 1980).

These observations conform to results from Principal Component Analysis: Rhyacophilidae was characteristic at P1, Thiaridae at P2 and Chironomidae at P3 and P4. Consequently, the assemblages reflected longitudinal change in the trophic status of the river, especially from P1 (Rhyacophilidae - Leptophlebiidae) to P2 (Chironomidae-Thiaridae) as compared to P3 and P4 (Chironomidae - Leptophlebiidae). Despite different substrate type, similar landuse (agriculture) at P3 and P4 accounted for similar assemblages at these stations (Table 1). Since, all abiotic factors change proportionately along the length of the river in remaining part of the dry-period and landuse patterns remain constant, the relationships of the faunal elements with the abiotic factors as reported in this study can be extrapolated for the entire year, except for the breeding period.

Vannote *et al.* (1980) state that gradients of physical and chemical characteristics from headwater to mouth result in different community and functional feeding groups (FFG). In the Paisuni, landuse influenced the proportion of FFG from P1 to P4. The FFG collector, scraper and predator in the form of Ephemeroptera and Trichoptera contributed equally at P1, reflecting a balanced ecosystem. As the collectors that feed on FPOM increased and scrapers decreased downriver, the continuum of function was disturbed. We attribute this to agriculture landuse. Vannote *et al.* (1980) opined that agricultural landuse and tributaries add organic particulate matter to the river channel. Notably, Leptophlebiidae was the main component of collectors with similar abundance at P1 and P3; however, it decreased abruptly at P2 and slightly at P4. We suggest that its decline, despite the presence of preferred substrate at P2, was due to intense pilgrimage activity which generated detritus making the cobble substrate unsuitable for colonization by Leptophlebiidae. The lower stretch receives considerable amount of detritus from agricultural landuse rendering it heterotrophic in contrast to P1 and P2. Relatively high abundance of scrapers at P1 and P2 and collectors at P3 and P4 suggests more autotrophic activity in the upper stretch than in the lower part (P3, P4). This reflects the existence of two ecological zones in the Paisuni river, stations P1 and P2 constitute the upper autotrophic zone, while stations P3 and P4 constitute the lower heterotrophic zone.

Ordination (CCA) showed that current velocity and substratum, followed by landuse, explained most of the longitudinal variation in the taxonomic composition from P1 to P4. The current velocity was associated with the abundance of Glossosomatidae, Hydropsychidae, Brachycentridae and Baetidae. Substrate was associated with dipterans, mesogastropods and pelecypods. Geographical coordinates and other physical gradients had relatively little impact compared with current velocity (Fig. 5). In the Plateau Rivers, water current velocity, substrate size, conductivity and abundance of aquatic plants are known to govern the distribution of the benthic macroinvertebrate fauna (Miserendino 2001).

Conclusions

The benthic macroinvertebrate density increased longitudinally with gradual reduction in substrate particle size causing substrate heterogeneity and increase in surface area. The increase in density was related to increased substrate heterogeneity. The longitudinal changes in composition showed disruption of the river continuum, due to anthropogenic stress and agricultural practices, leading to a shift from autotrophic to heterotrophic status downstream of the headwater. Two ecological zones were evident in the river Paisuni. Current velocity, substratum and landuse caused taxonomic variation in the river. The study indicated that multiple factors (current velocity, substratum and landuse) affect density and composition of benthic macroinvertebrate fauna red. The observations of dry period can be extrapolated to cover the entire year except monsoon.

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