International Journal of Environmental Sciences

(A peer reviewed International Journal)

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International Journal of Environmental Sciences, Vol. 1 No. 3. pp. 150-158. 2277-1948. 2012

ISSN *2277 – 1948*

Article type *Full Length Research Article*

Submission date *20 April 2012*

Acceptance date *30 June 2012*

Publication date *15 July 2012*

Article URL *http://www.crdeep.org/category/ijes*

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International Journal of Environmental Sciences Vol. 1 No. 3. 2012. Pp. 150-158

Full Length Research Paper

Longitudinal Distribution of Benthic Macroinvertebrate Fauna in a Vindhyan River, India

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Abstract
The present study examines longitudinal distribution of benthic macroinvertebrate fauna in the Ken R. (Central India). The river originates in Kaimur (Vindhyan) hill-ranges and drains the Bundelkhand Plateau. The total mean density decreases from S1 to S4 and differs significantly among all the stations. The insect fauna predominates at stations S1, S2 and S3, compared with S4. The relative abundance increases from S1 to S4 for Diptera, Odonata and Heterodonta, but decreases for Ephemeroptera. The abundant taxa vary at each station; Neoephemeridae, Caenidae, Leptophlebiidae and Thiaridae at S1, S2, S3 and S4, respectively. PCA ordination also indicates the variation in characteristic taxa at each station. CCA indicates that substratum (hard and macrophyte) is an important factor for the distribution of benthic macroinvertebrate fauna at each station in the Ken river. Scrapers (autotrophs) dominate the fauna from S1 to S2 and collectors (heterotrophs) from S3 to S4, representing autotrophic and heterotrophic functional zones, respectively, in contrast to the continuum concept.

Keywords: *Bundelkhand Plateau, Panna National Park, Functional zones, Ordination, Thiaridae*

Introduction

Consistent patterns of benthic macroinvertebrate community structure and function occur along the length of a river (Illies & Botosaneanu 1963; Hawkins & Sedell 1981; Dudgeon 1984; Whitton 1984; Gibon & Statzner 1985; Singh & Nautiyal 1990). Most of the knowledge generated from these studies help to explain the distribution of macroinvertebrates in the temperate streams, as very little is known from the tropical regions including the Indian subcontinent (Miserendiro 2001; Milesi et al. 2009; Mesa 2010; Ezekiel et al. 2011; Mishra & Nautiyal 2011). India has a vast and highly variable terrain, the Plains, Plateaus and Mountains. Within each geographical region there is considerable variability; especially in the Himalaya followed by Plateau in the zones comprising hills and mountain chains such as the Central Highlands and Western Ghats. In the Deccan Plateau variability occurs with change in the climate across the length and width of the Peninsula. The northern Central Highlands present a unique terrain as the rivers find source in the mountain chains (Vindhya, Aravalli) and flow across the Plateau into the Gangetic Plains. Scarce information exists on

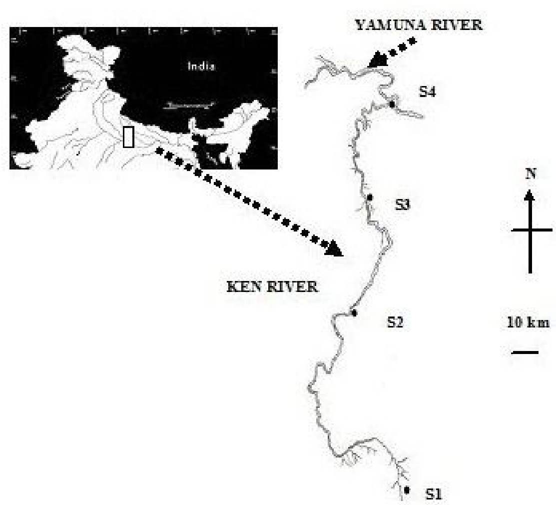

Figure 1 Location of the Ken river in Central India and sampling stations (S1 to S4) selected for the study.

longitudinal changes in the benthic macroinvertebrate fauna and community structure for the rivers that flow through different geographical regions e. g. Western Ghats and Deccan Plateau (Sivaramakrishnan et al. 1995). The present investigation on the longitudinal changes in benthic macroinvertebrate fauna and their functional role pertains to the Ken in the northern Central Highlands (Central India).

Materials and Methods

Study Area

The Chambal, Betwa, Ken, Paisuni, Tons and Sone are the major rivers in the northern part of Central Highlands that lie between the Yamuna-Ganga in the north to Narmada in the south, close to the Tropic of Cancer. The Ken arises from the north-west slopes of the Kaimur hills close to Shahnagar (Madhya Pradesh) and flows north across the Bundelkhand Plateau to meet the Yamuna at 86 m asl. Only four sampling locations had easy approach by train or national/state highway. These locations were considered suitable for recording longitudinal changes, as each station is 75 to 100 Km apart representing the headwater, middle, lower and mouth zones of the river. Besides, the substrate particle size also differs substantially at each station (Fig. 1, Table 1). Station I is a 1st order stream location (topo sheet 63D) and rest are 4th order locations. One-time intensive sampling is considered suitable for determining spatial variations (Corkum 1989, 1992). Hence, each location was sampled once between November to February in the 9- month long dry-period extending from October to June, when the community is relatively stable compared to the floods (Ormerod et al.1994).

The benthic macroinvertebrate fauna was collected by lifting all available substrate (Table 1) from 20 quadrant (area of each 0.09 m^2) per station at 30-60 cm depth in various microhabitats created by different combinations of flow (turbulent, swift etc) and substrate (boulder, cobble etc) conditions. Each sample was sieved, washed to dislodge the fauna and preserved in 5% formalin for identification and counting in the laboratory. The counts were made for each sample of a station to obtain density (indiv m^{-2}) for each quadrant. On this basis the mean total density and other descriptive statistics were computed for each. Differences in the density among the stations were tested by Kruskal-Wallis test (Henderson 2003). To determine the community composition (as %) each individual was taxonomically resolved to family level based on standard literature (Edmondson 1959; Edington & Hildrew 1995; Nesemann et al. 2004). Functional feeding groups were assinned according to Dudgeon (1984) and Cotta Romisuno et al. (1995).

Data Analysis

The changes in the macroinvertebrate fauna are considered to be longitudinal if the community composition at first station changes in terms of either components or abundance increases or decreases at subsequent downstream stations. Multivariate analyses (CANOCO, ter Braak and Smilauer 2002) were used to determine the characteristic taxa for each station

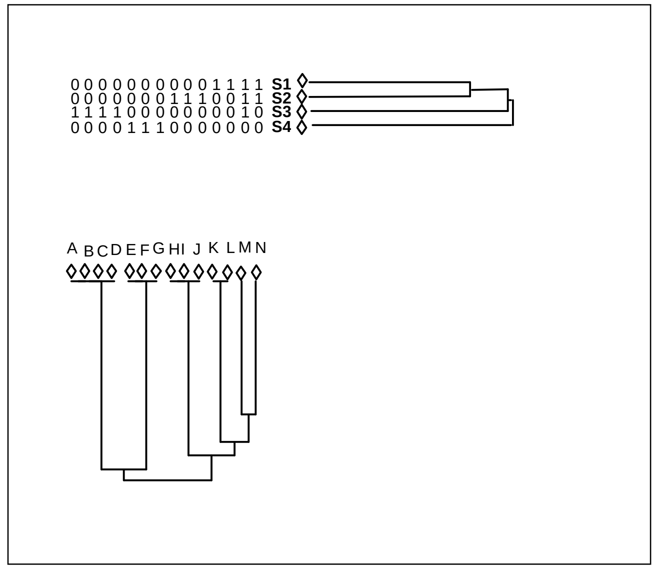

Figure 2 Cluster analysis based on 2-way constrained method indicates four broad categories of substrate in the Ken, corresponding to stations from S1 to S4. First category consists of large hard particle size (boulder-cobble), second category of hard moderate particle size (cobble to gravel), third of small hard and soft particles (pebble to sand) and fourth of small soft sediments (silt-clay), predominant from S1 to S4. The grouping is based on the counts of the organisms. Substrate type- B-Boulder; C-Cobble; P- Pebble; G- Gravel; S-Sand; ST- Silt; CL-Clay. Acronyms used in figure: A- PSG; B-SGST; C-GS; D-S; E-CLST; F-CL; G-STCL; H-CP; I-PGS; J-P; K-CLS; L-PC; M-B; N-C)

and explain the precise longitudinal change in the taxon/taxa and factors responsible for it. The analyses were based on the count data for each taxon in all 20 quadrants, with the premise that the characteristic taxa will differ with downward flow of the river. The environmental variables (Table 1) contributing to the longitudinal change were assessed with the help of Canonical Correspondence Analysis (CCA). However, it is to be noted that the benthic macroinvertebrate sampling is based on the variety of substrate present at each station. Therefore, the influence of substrate on the taxonomic composition is quite obvious. Another reason for its greater influence is that the substrate type differs at each station as the particle size reduces from headwater to mouth zone.

In view of these and the observations on the high abundance of Caenidae and Neoephemeridae (Table 2) in boulder, cobble, pebble substrate individually or in combination not only at S1 but also at S2, two broad categories of substrate were recognized; hard and soft sediments. Hard sediments consisted of three sub-groups; large-hard, moderate-hard and small-hard (Figure 2). These four categories were used for CCA in contrast to numerous substrate types mentioned in Table 1. The CCA was performed with and without substrate and landuse as an environmental variable to know their role, and that of other factors. The landuse was excluded from the analysis because it is not a natural environmental variable, and we desired to know the influence of natural factors on the longitudinal changes.

Results

The geographical (latitude, altitude), physical (substrate combinations, depth, width, water temperature, current velocity) and chemical characteristics (pH, conductivity) gradually change from Stations 1 to 4. However, the current velocity increases from S1 to S2 but decreases at S3 and S4.

Qualitatively, the arthropod (Class Insecta, Crustacea), mollusc (Class Gastropoda, Pelecypoda) and annelid (Class Oligochaeta, Polychaeta) elements consisting of 22 taxa constitute the benthic macroinvertebrate fauna of the Ken. The taxonomic richness increases from S1 to S3 but decreases at S4 (Table 1). Qualitatively, the insects occur in high numbers at all stations, but are highest at S3 and least at S4. The mollusc and annelid account for the remaining share at each station (Figure 3). The mayfly (Class Insecta, Order Ephemeroptera) occur in very high numbers in the river Ken. The mean and median density of benthic macroinvertebrate fauna decreases and differs significantly from S1 to S4.

Table 1 The geographical co-ordinates, physical characteristics, landuse, substrate combinations, richness and total density ± standard error for each sampling location in the Ken river. The combination of substrate indicated heterogeneity at each station. The dominant substrate types are written first in the substrate combination. (Acronyms: Ag-Agriculture; V-Village; F-Forest; C-City; B- Boulder; C-Cobble; Cl-Clay; G-Gravel; P- Pebble; S-Sand; R-Rock; Si-Silt).

Station	**S1**	**S2**	**S3**	**S4**	**H observed**
Distance from source (Km.)	10	142.5	267.5	340	
Latitude (°N)	23°59'28"	24°44'17"	25°28'38"	25°46'15"	-
Longitude (°E)	80°18'01"	80° 0'41"	80°18'51"	80°31'36"	-
Altitude m (asl)	365	200	95	86	-
Slope (m km^{-1})	3.5	1.24	0.84	0.12	-
Landuse type	Ag-V	F	Ag-C	Ag	-
Substrate combination	B:C :R:P	C: P: B:R:G	P:G:B: C: S	Cl: Si	-
Water temperature (°C)	15.0-21.5	16.5-22	17.0-24.5	20.5-27	-
Current velocity (cm s^{-1})	1.0	10-60	2.0-12	1.0	-
pH	7.2-7.5	7.0-7.2	7.2-7.5	7.2-7.5	-
Taxonomic Richness	10	15	15	11	
Total mean density ±SE	**319±23.34**	**284±29.01**	**158.4±22.48**	**248.6±27.51**	**17.1***

Significant at 5%H at 3 df=7.81

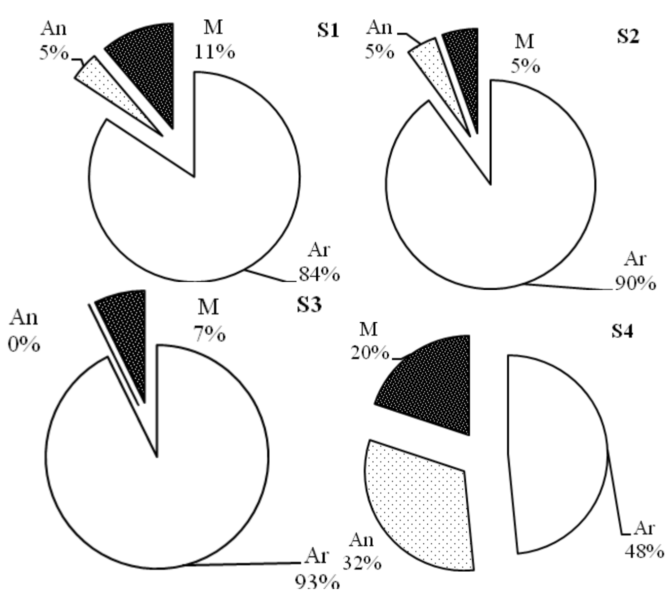

Figure 3 Percentage composition of higher taxonomic groups (Ar - Arthropoda; An - Annelida; M- Mollusca) at each station (S1 to S4), in the river Ken. Insect predominance is evident from S1 to S3. The higher taxa occur more proportionately at S4.

The share of mayfly decreases and that of the dragon and damsel fly (Odonata) and mollusc (Heterodonta) increases from S1 to S4, while the caddis-fly (Trichoptera) exhibits increase from S1 to S3 and an abrupt decline at S4 (Table 2). Diptera shows no trend. Mesogastropoda and Polychaeta (Nephthydae) decrease gradually from S1 to S3 but increase abruptly at S4. The share of Order Neooligochaeta (Glossoscolecidae) is similar at S1and S2. It is absent at S3 and increases at S4. The Ken is a characteristically mayfly dominated river for a large part of its length (ca. 268 Km) due to high abundance of Caenidae and Neoephemeridae at S1, S2 and moderate abundance of Leptophlebiidae and Baetidae at S3. The caddis-fly is meagerly present in this stretch. The mouth zone (S4) is devoid of both may- and caddis-fly. An assortment of Diptera, Odonata, Coleoptera, Mollusca and Annelida occurs at S4.

Examination of the data shows gradual longitudinal changes in the macroinvertebrate faunal components and their composition from S1 to S4. In respect of occurrence, only Chironomidae, Thiaridae, Nephthydae, Glossoscolecidae and Corbiculidae consistently occur from S1 to S4 (except S3). The number of taxa increases from 10 at S1 to 15 at S2, because in addition to nine taxa found at both locations, other five taxa are added to the fauna of S2. The components change at downstream location S3, because some elements from S1 and S2 do not occur at S3 and three other taxa make first appearance here. For similar reasons the faunal components at S4 differ from all upstream locations. The similarity of faunal components declines downstream of S2; of the 9 taxa common to S1 and S2 only 6 occur at S3 and 5 at S4. However, the river is qualitatively more similar from S1 to S3 and a greater resemblance exists between S2 and S3, where 11 taxa are similar compared with only 7 taxa among S3 and S4.

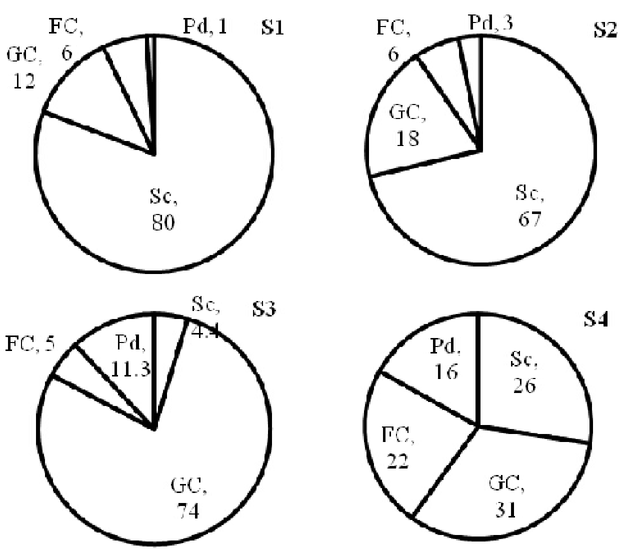

Figure 4 Percentage compositions of different functional feeding groups (FFG) at each station (S1 to S4) in the Ken river. The scrapers and collectors constitute the bulk of the FFG (Acronyms: SC-Scrapers; GC- Gathering collectors; FC-Filtering collectors; Pd- Predators).

Gradual changes occur in the community composition also; Neoephemeridae, Chironomidae and Thiaridae decline in abundance while Caenidae increase. These four taxa together account for 91% at S1 compared with 70% at S2. Since Neoephemeridae, Caenidae and Thiaridae function as scraper their predominance (Figure 4) points to autotrophic conditions (grazing chain) in the stretch of the river from S1 (80%) to S2 (67%). The other taxa occur in very low abundance (<5%) at S1 and S2. The abundance of Neoephemeridae and Caenidae declines at S3 compared to Chironomidae and Thiaridae. Instead, Leptophlebiidae, Hydropsychidae, Baetidae and Gomphidae become abundant in the community at S3. Thus, the community composition changes radically at S3. The abundance pattern of taxa at S4 partly resembles S1 and S3, and therefore is not as entirely different as S3; at S4 Chironomidae and Thiaridae occur in slightly higher abundance than S1 and Gomphidae has similar abundance level at S3 and S4. Nephthydae and Heleidae are the only other taxa occurring in notable abundance, which makes the station somewhat different from all upstream river locations. Further, all abundant taxa at S3 and S4 (except Thiaridae) are functionally collectors (Figure 4). They indicate prevalence of heterotrophic state (detritus food-chain) from S3

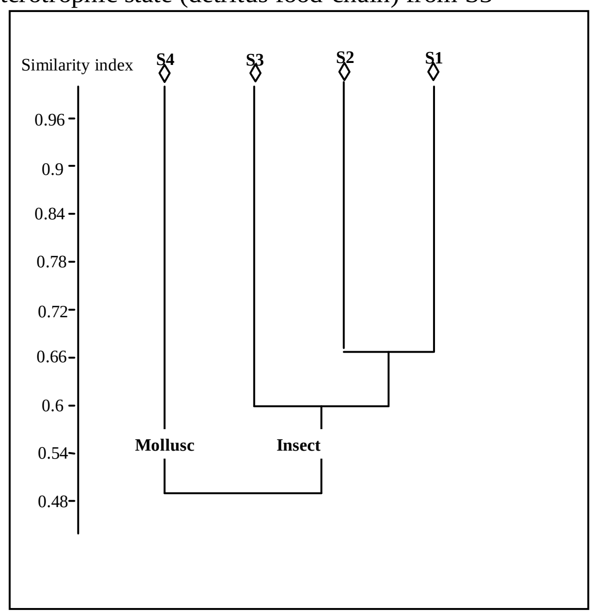

Figure 5 Cluster analysis demonstrating ecological zonation in the river based on counts of benthic macroinvertebrate fauna from all quadrants at each station. The mollusc zone is an outlier and hence quite distinct. The insect zone extends from S1 to S3 of which S1 and S2 are essentially similar.

to S4, especially at S3 because the scrapers decline substantially compared with S4 where the grazing food-chain is also present. Thus, longitudinal changes occur in the functional feeding groups also; scrapers decline, the gathering collector (GC) increase; though marginally from S1 to S2 (exceptional at S3) compared with S4, filtering collector (FC) have low share from S1 to S3 and moderately increase at S4, while the predators increase gradually, especially from S3 to S4 (Figure 4). Based on abundant taxa two ecological zones exist in the Ken; insect zone from S1-S3 and mollusc zone at S4 (Figure 5).

The most abundant taxon at each station varies longitudinally from S1 to S4; Neoephemeridae at S1, Caenidae at S2, Leptophlebiidae at S3 while Thiaridae at S4 (Table2).

Table 2 The longitudinal variation of benthic macroinvertebrate fauna at different stations of the Ken river. The orders are represented in bold and family in normal font. Higher abundance is also represented in bold.

Orders/Family	**S1**	**S2**	**S3**	**S4**
Ephemeroptera				
Caenidae	**29**	**37**	0.4	-
Neoephemeridae	**41**	**27**	1	-
Leptophlebiidae	-	3	**30**	-
Baetidae	-	4	**13**	-
Trichoptera				
Rhyacophilidae	1	1	-	-
Brachycentridae	1	3	7	-
Hydropsychidae	-	-	**14**	-
Hydroptilidae	-	-	1	-
Diptera				
Chironomidae	11	3	8	**16**
Thiaridae	10	3	3	**26**
Tabanidae	-	1	-	5
Heleidae	-	4	1	10
Dytiscidae	-	-	0.3	4
Gomphidae	-	2	11	10
Agrionidae	-	-	-	2
Oligochaeta (Glossoscolecidae)	2	2	-	4
Polychaeta (Nephthydae)	3	2	-	**16**
Pelecypoda (Corbiculidae)	1	2	5	6
Miscellaneous groups	1	3	2	1

Table 3. CCA ordination indicates substratum as most important variable for taxonomic variation in benthic macroinvertebrate fauna in the river Ken.

Variables	**λ -value**	**% variance**	**F-value**	**P -value**
Substratum	0.46	38.33	11.72	0.002
Latitude (^{o}N)	0.32	26.67	8.99	0.002
Land use	0.14	11.67	4.21	0.002
Depth (m)	0.08	6.67	2.42	0.004
pH	0.07	5.83	2.05	0.006
River width (m)	0.05	4.17	1.68	0.034
Water temperature (^{o}C)	0.05	4.17	1.38	0.14
Current velocity (ms^{-1})	0.03	2.5	1.16	0.298

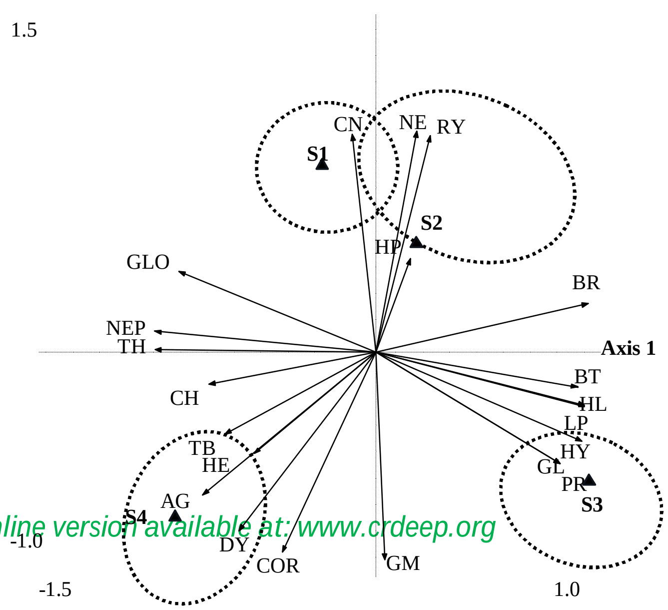

Figure 6 Principal Component Analysis (PCA). The ordination indicates the characteristic taxa through graphical presentation between the taxon (arrows) and station (triangles) at each station from S1 to S4. The taxa close to the station are characteristic of that station and encircled. Acronyms: AG - Agrionida; BT - Baetidae; BR - Brachycentridae; CH - Chironomidae; CN - Caenidae; COR - Corbiculidae; DY - Dytiscidae; GM - Gomphidae; GL - Glossosomatidae; GLO - Glossocolecidae; HE – Heleidae; HP –Heptageniidae; HL – Hydroptilidae; HY – Hydropsychidae; LP – Leptophlebiidae; NE – Neoephemeridae; NEP- Nepthydae; PR – Perlidae; RY - Rhyacophilidae; TB - Tabanidae; TH -Thiaridae.

In PCA ordination, first (46.9%) and second (43%) axis account for major variation (89.9%) in the faunal composition of river. Stations 1 and 2 lie close to 2nd axis, and station 3 is under the negative influence of axis 1. Ordination indicates that Caenidae is characteristic at S1, while Neoephemeridae, Caenidae and Rhyacophilidae are characteristic at S2; Glossosomatidae and Hydropsychidae at S3, and Agrionidae, Helidae and Tabanidae at S4 (Figure 6). With respect to the role of environmental variables in longitudinal variation, CCA ordination shows that axis 1 and 2 cause 45.1% and 33.6% variations, respectively in taxon and environmental variable. Substrate on 1st axis

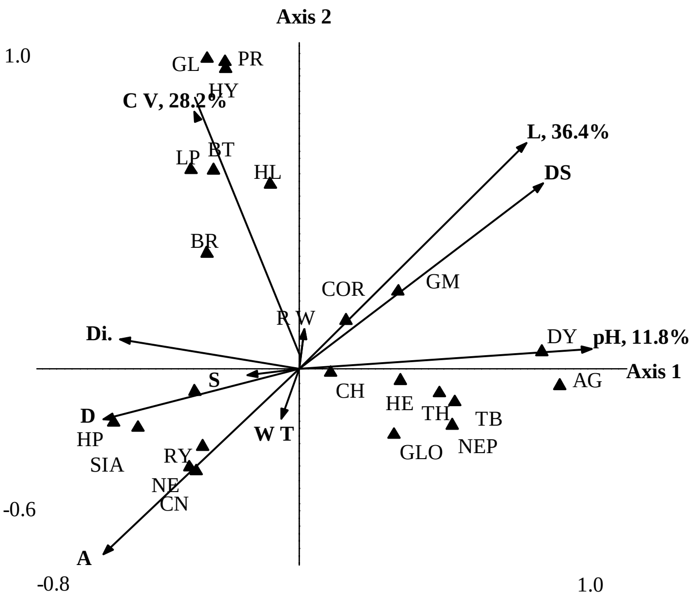

Figure 7 Canonical Correspondence Analysis (CCA) indicates the relationship between benthic macroinvertebrate taxa and environmental variables in the river Ken. Taxon and stations are indicated by arrows and triangles, respectively. After exclusion of the substrate and landuse from the analysis, latitude becomes most important variable causing 38.4 % variation in the taxonomic composition followed by current velocity (28.2%) and pH (11.8%). The effective environmental variables are indicated in bold letters. Acronyms: A-Altitude, CV- Current velocity, D-Depth, Di-Discharge, DS - Distance from source, L - Latitude, RW-River width, WT- Water temperature, EP – Ephemerillidae, , SIA – Salifidae). For the rest of the acronyms see Figure 6.

causes highest variation, followed by latitude, landuse, depth (Table 3). On exclusion of substrate and landuse from the analysis, latitude lying near 2nd axis causes highest variation (Figure 7).

Discussion

The distribution of benthic macroinvertebrates is largely related to environmental factors (Richards et al. 1993; Benbow et al. 2003) and their structure is known to vary spatially (Townsend and Hildrew 1994) and longitudinally (Hawkins & Sedell 1981; Vannote et al. 1980). Longitudinal environmental changes are among the most important factors with respect to the distribution of benthic invertebrates in high-gradient mountain streams (Singh et al. 1994; Burgherr & Ward 2001; Helson et al. 2006). The present study examines how far this is true in case of a Plateau river, the gradient of which is low; S1-S4 0.85 m km^{-1} (Table 1).

The median and mean density decreases along the length of the river from S1 to S4 and differs significantly. The decrease can be related to gradual reduction in particle size from boulder to silt-clay from S1 to S4. Though the substrate is more heterogeneous at S2 and S3, the density declines, noticeably at station S3, attributed to anthropogenic stress caused by cattle bathing, disposal of municipal waste and abstraction of water for irrigation and domestic use. In contrast the taxonomic richness increases from S1 to S3 but declines at S4. This coincides with increasing substrate heterogeneity vis-à-vis increase in the variety of hard substrate (boulder, cobble, pebble, gravel, sand), from S1 to S3 and less heterogeneous substrate (sand-silt-clay) at S4 (Fig. 2), as observed earlier also (Singh et al. 1994, Paul & Meyer 2001). In the nearby Plateau river Paisuni a general trend of downstream increase has been recorded (13, 21, 16, 19 taxa; unpublished).

Many faunal components of the Ken (23-25°N) except Dytiscidae, Agrionidae and Nephthydae occur in the Paisuni (25°N). The fauna of rivers further south (12°N) in the Deccan Plateau, become more different and only 10 taxa of the Ken are present in the Kaveri river system consisting 43 taxa. Caenidae is the only taxon that attains high abundance in both rivers and is widely abundant (C, D and E group sites) from 1 to 1100 m asl (Sivaramakrishnan et al. 1995). The macroinvertebrate fauna of the Ken differs substantially from the Plateau rivers of Africa (14 taxa, Sombreiro R, Nigeria, 6°N; Ezekiel et al. 2011), and South America (58 taxa, Brazilian streams, 27°S; 25 taxa, Lules River basin, Argentina 26°S; 650 to 1300 m asl; Mesa 2010), as only 2, 15 and 8 taxa respectively are similar to the Ken. The Jaccard similarity index is significant and high for the Ken - Paisuni (0.63) while insignificant for Ken-Kaveri (0.18), Ken- Sombreiro R. (0.05), Ken-Brazilian streams (0.23) and Ken-Lules River basin (0.17). Among the taxa that are abundant; Nephthydae is common to the Ken and Sombreiro river (Nigeria), Chironomidae to the Brazilian streams, while Baetidae and Caenidae to the Lules river (Mesa 2010).

It augurs that in the Plateau rivers of same and adjacent ecoregions, the faunal components have considerable similarity but are not precisely identical and differ considerably in respect of the community dominant. They have faint similarity with distantly located rivers across the continents and this demonstrates that the macroinvertebrate fauna is more affected by local scale factors compared to large-scale or geographical factors (Frissel et al. 1986).

The present study on longitudinal changes shows that few taxa occur continuously from S1 to S4, very few taxa appear or disappear at downstream stations in the Ken. The longitudinal distribution in the Ken River is accompanied by a relatively predictable spatial arrangement of taxa in respect of highest abundance exhibiting distinct relationship with substrate conditions; Neoephemeridae at S1 and Caenidae at S2 to the prevalence of boulder-rock and cobble substrate, Leptophlebiidae at S3 to dominance of pebble-gravel while Thiaridae at S4 to that of silt - clay. Similar, substrate preferences have been recorded for these taxa in the past (Mishra & Nautiyal 2011; Tolkmap 1980; Death 2003).

Despite high faunal similarity, the longitudinal changes in the Ken are different from the Paisuni, especially the community composition. Thus, in contrast to the abundance of mayfly taxa in the Ken, the caddisfly dominates headwaters and Chironomidae in downstream sections of the Paisuni (Mishra & Nautiyal 2011), despite similar substrate conditions in the upper half of the Ken and Paisuni. In the Paisuni, the mayfly taxa though present are not abundant. The food availability seems to account for this difference, because the Ken headwaters (1st order; 365 m asl) are 'open' type favouring scrapers in agreement with Vannote et al. (1980), compared with 'canopy' cover in the Paisuni suiting the collectors. Neoephemeridae is known to prefer mid elevations (Habera et al. 2000). Therefore, altitude along with food availability may be responsible for its abundance.

Though the longitudinal variation in benthic macroinvertebrate community differs in the Ken and Paisuni there is some similarity regarding the altitudinal distribution of some faunal components. In the Ken mayfly Caenidae is abundant from 365 to 200 m asl but does not occur below 100 m asl i.e. mouth zone. Chironomidae and Thiaridae extend from 365 m asl to 86 m asl but are most abundant at 86 m asl. Leptophlebiidae occurs from 200 -100 m, but is most abundant at 100 m. In the Paisuni, Leptophlebiidae occurs from 180 to 80 m but highest abundance occurs from 180-130 m, Chironomidae abundance extends from 135 to 80 m, Thiaridae is most abundant at 135 m only (Mishra & Nautiyal 2011). This may be attributed to same ecoregion vis-à-vis climatic conditions. The Ken and Paisuni are not similar functionally also, which suggests that the environmental factors responsible for longitudinal change differ even in nearby river basins of Central Highlands.

PCA ordination also reveals that characteristic taxa vary along the length of the river from headwater to river mouth. This also supports the River Continuum Concept hypothesis that the community varies longitudinally. CCA shows that substratum is an important factor causing highest (38%) variation in longitudinal trend of fauna as well as abundant taxon, because of natural reduction in substrate particle size from large-hard stony substrate to soft silt-clay substrate from S1 to S4. On excluding substrate, latitude (36%) accounts for longitudinal variation in fauna. In case of Plateau rivers, current velocity, substrate size, conductivity, abundance of aquatic plants (Miserendino & Pizzolon 2003), pH and hardness (Ormerod & Edwards 1987) are known to govern the distribution of the benthic macroinvertebrate fauna. Geomorphology of the stream bed (Wallace & Webster 1996) and substrate type (Buss et al. 2004) also govern the distributional pattern of aquatic organisms. In the Paisuni, current velocity acts as an important factor for abundance of Glossosomatidae, Hydropsychidae, Brachycentridae and Baetidae. However, in the Indian Himalayan river, the Alaknanda, substratum is an important factor (Negi & Singh 1990). The mean and near bed hydraulic conditions, conductivity as well as substrate roughness, represent major factors along which benthic invertebrates are distributed in the Lules River basin (Mesa 2010).

The study is in agreement with the River Continuum Concept (RCC; Vannote *et* al.1980), as the functional feeding group change from grazers in 1st order streams with restricted riparian vegetation to predominantly collectors-grazers in 4th order streams, with change in geomorphology (substrate type) downstream of the origin. Thus, two functional zones occur in the river, the upper half (S1-S2) of the river dominated by scrapers is autotrophic and the lower half (S3-S4) by collectors is heterotrophic. The abundance pattern of fauna points to two differ ecological zones in the Ken; hard (stony) substrate zone from S1 to S3 and soft (clay) substrate zone at S4, corresponding to insect and mollusc zones, respectively.

Acknowledgements

The authors acknowledge the academic support granted by Prof. H.R. Singh, Former-Vice Chancellor, University of Allahabad and Prof. J. P. Bhatt, Head, Department of Zoology, H. N. B. Garhwal University, Srinagar. First author (ASM) is thankful to U.G.C. New Delhi, for providing research fellowship during D.Phil. degree programme from the University of Allahabad, Allahabad, Uttar Pradesh.

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