Applied Biological Research 24(4): 503-513; (2022)
DOI: 10.5958/0974-4517.2022.00063.5

DISTRIBUTIONAL PATTERNS OF BENTHIC MACROINVERTEBRATE FAUNA IN RIVER BHILANGANA, GARHWAL HIMALAYA, INDIA

Vijay Prakash Semwal[1] and Asheesh Shivam Mishra[2]

[1]*Department of Zoology, Government PG College, New Tehri – 249 001, Uttarakhand (India)*
[2]*Department of Zoology, Nehru Gram Bharati (Deemed to be University), Prayagraj – 221 505, Uttar Pradesh (India)*
*e-mail: *vpsemwal75@gmail.com, ashivam18@gmail.com*

(Received 26 July, 2022; accepted 21 November, 2022)

ABSTRACT

A study was designed to evaluate the spatial distribution of benthic macro-invertebrate communities in river Bhilangana, Uttarakhand (India). The samples were collected during March 2018 to February 2019 at five stations (S1 to S5) from headwater to mouth. The total mean density of benthic macro-invertebrate community varied significantly among the stations. Taxonomic composition revealed that Diptera as the most abundant taxa at S1 (3.6%), S2 (44.1%) and S5 (36.2%), and Trichoptera at S3 (30.5%) and S4 (34%). However, at family level, Simulidae was most abundant at S1 (11.2%) and S3 (11.2%), and Chironomidae at S2 (21.2%) and S5 (12.8%). Similarly, Limnephilidae (21.8%) was the most abundant taxa at S4. The assemblage patterns varied longitudinally from S1 (Simulidae - Limnephilidae - Philopotamidae - Chironomidae) to S2 (Chironomidae - Simulidae), S3 (Simulidae - Philopotamidae), S4 (Limnephilidae - Simulidae) and S5 (Chironomidae - Simulidae). Ordination technique PCA identified characteristic taxa at S1 (Belostomatidae and Vellidae), S2 (Chironomidae, Tabanidae and Psephenidae), S3 (Glossosomatidae, Hydropsychidae, Psychomyiidae, Agrionidae, Blepharoceridae and Leptidae), S4 (Caenidae, Haliplidae, Dryopidae and Dixidae) and S5 (Tipulidae and Corydalidae). The variation in the characteristic taxa at these stations was primarily attributed to substrate heterogeneity and forest type patterns; conifer-oak rhododendron, oak-rhododendron, pine-oak, etc.

Keywords: Bhilangana river, Chironomidae, forest type, PCA, Simulidae, spatial distribution, taxonomic composition

INTRODUCTION

The benthic macroinvertebrates are worldwide used for biological monitoring of freshwater ecosystems because of their presence in most of the habitats and easy collection. There is a diversity of forms that ensures a wide range of sensitivities to changes in water quality (Varnosfaderany *et al*., 2010; Gurang *et al*., 2021; Kumar *et al*., 2022). The distribution of benthic macroinvertebrates is largely related to the environmental factors (Benbow *et al.*, 2003; Mishra and Nautiyal, 2011; Mishra *et al*., 2020). Changes in the benthic community structure are often assessed by examining the taxonomic compositions along the stream continuum (Mishra and Pandey, 2019; Pandey and Mishra, 2021). Spatial variations are mostly attributed to the habitat characteristics (Boyero, 2003), sediment grain size (Teske and Wooldridge, 2003; Singh *et al*., 2010; Mishra and Nautiyal, 2016) and vegetation (Rios and Bailey, 2006; Shilla and Shilla, 2012).

In India, scanty information is available on the distribution of benthic macroinvertebrate fauna in river ecosystems and the information is highly fragmentary in different biogeographical regions including the Himalaya (Habib and Yousuf, 2014; Rana *et al.*, 2017; Kumar and Nautiyal, 2020; Masresha *et al*., 2022), in Central Indian region (Kulshrestha, 2009; Mishra and Nautiyal, 2013; Pandey and Mishra, 2021) and Western ghat (Subramanian *et al.*, 2005; Dinakaran and Anbalagan, 2007; Cimpean *et al*., 2022). In Uttarakhand, many anthropogenic activities like road cutting, dam constructions, etc. are continuing, which cause flow disturbances in the river ecosystem and disturb the biotic communities of river (Singh *et al.*, 2019; Kumar and Nautiyal, 2020).

The river Bhilangana is a major tributary of river Bhagirathi in Garhwal Himalaya. It originates from Khatling glacier, approximately 50 km south of the ice cave at Gaumukh at elevation of 3717 m masl. The snow-fed river flows distance of 95 km from its origin to join river Bhagirathi at old Tehri. Since river Bhilangna faces anthropogenic threats due to various hydroelectric projects, its riverine habitat has shrunk to 70 km length because of impoundment for Tehri Dam reservoir and 25 km river length has inundated to lacustrine habitat. Presently, a small Bhilangana hydropower project of 22.5 MW is operational near Ghansali town, district Tehri (Garhwal), while a few small hydropower projects are proposed on Bhilangana basin. These projects have disrupted the continuum of river and disturbed the natural distributional patterns of benthic macroinvertebrate fauna. As a result, these disturbances may lead to the extinction of many benthic invertebrate species from the river as well as from the biogeographical region. The disruption of natural course and flow regime of river system affects alteration in water temperatures and biological community (Born *et al.*, 1998; Bunn and Arthington, 2002). Similarly, stream regulations like dam, barrage, etc. impact the composition and density of benthic communities (Singh *et al.* 2019). The present study was aimed to determine the assemblages and distributional patterns of benthic macroinvertebrate fauna in the Bhilangna river.

MATERIALS AND METHODS

Physiography of the sampling stations

The river Bhilangana was sampled at five stations (Fig. 1) which varied in substrate type and land-use patterns. Forest was the major land-use patterns at all stations along the river length. The sampling was conducted bi-monthly from March 2018 to February 2019.

Station 1 (Gangi): The **s**tation is located at an elevation of 2525 m masl, 30˚37'05" ˚N latitude and 78º50'47" ˚E longitude. Boulder-rock-cobble-pebble was the dominant substrate type and the land-use was mainly temperate forest with dominance of conifer oak rhododendron.

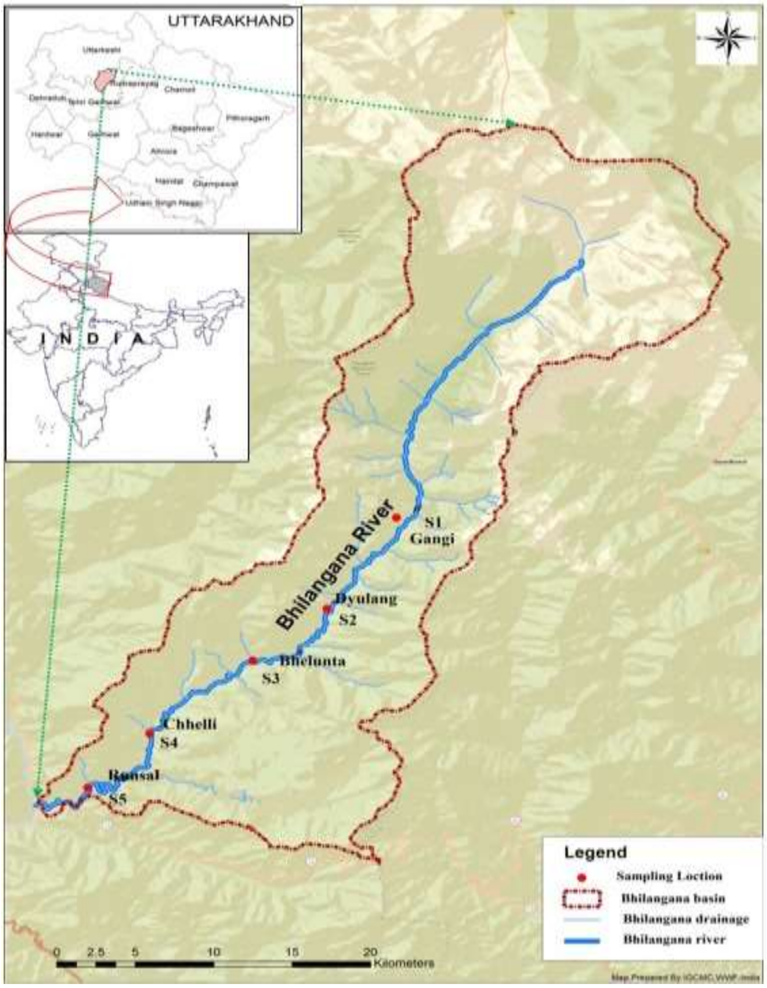
Station 2 (Dyulang): It is situated at an altitude of 1761 m masl along with 30˚33'28" ˚N latitude and 78˚48'29" ˚E longitude. The substrate type composed of boulder-cobble-pebble-gravel with oak-rhododendron forest as dominant land-use.

Station 3 (Bhelunta): It is located at an elevation of 1461 m masl, 30˚31'25" ˚N latitude and 78˚45'51" ˚E longitude. Coble-pebble-gravel-sand was the dominant substrate type with oak-rhododendron forest as dominant land-use.

Station 4 (Chhelli): This station is located at an elevation of 1130 m masl, 30˚28'35" ˚N latitude and 78˚41'44" ˚E longitude. The substrate type composed of Coble-boulder-pebble-gravel-sand with pine-oak forest as dominant land-use.

Station 5 (Runsal): This station is located at an elevation of 912 m masl, 30˚26'19" ˚N latitude and 78˚40'14" ˚E longitude. The substratum is mainly composed of gravel-sand-coble-pebble with pine

Fig. 1: Location of Uttarakhand in India and Bhilangana river in Uttarakhand. The sampling stations (S1 to S5) are indicated in the map as red filled circle



and mixed forest as major land-use pattern.

Physicochemical analysis

The air- and water-temperature were determined by a digital thermometer (Mextech multi-meter). The turbidity (nephelo-meter), water current velocity (ENCON current meter), pH (model HI 96107) and conductivity (Labtronics model-LT23) were analyzed. Winkler's method (APHA, 1998) was used to determine dissolved oxygen at each station. Free CO_2 (APHA, 1998) and discharge (mean depth x mean velocity x width of river) were calculated at all the stations. At each sampling stations, the predominance of substrate type was determined visually i.e. when cobble (C) substrate covers river- bed followed by boulders (B) and gravels (G), then the substrate type was recorded as C: B: G. Wentworth (1922) classification was used to categorize the substrate names and size.

Sampling and data analysis

The benthic macroinvertebrate fauna was collected by lifting the stones from the earmarked area which were then washed in a bucket full of water by dipping many times to dislodge the attached fauna. The fauna that remained attached to the substrate surface were removed with the help of a brush. The bucket water was filtered through 0.5 mm sieve to retain benthic macroinvertebrate (Mishra and Nautiyal, 2011). The collected samples were preserved in 5% formalin for further analysis. Various benthic taxa were identified up to family level with the help of different keys (Macan, 1979; Edington and Hildrew, 1995). Family level counts were made to calculate the percent abundance. Significant difference in density between stations was determined by using the Mann-Whitney (U) test, and among the stations using the Kruskal-Wallis (H) test (PAST software *http://nhm2.uio.no/norlex/past*). Principal component analysis (PCA) was used to determine the characteristic taxa at each station (Canoco ver 4.5; ter Braak and Smilauer, 2002).

RESULTS AND DISCUSSION

In river Bhilangana, the physical and chemical parameters varied from station to station (Table 1 & 2). The water temperature increased from 1.0 to 10.2°C at S1 and from 1.5 to 16.5°C at S5. The

Table 1: Geographical co-ordinate of the sampling stations along with different forest types, substratum and total mean density (± SE) of benthic macroinvertebrate fauna in the Bhilangana river

Stations	S1	S2	S3	S4	S5
Latitude (^{O}N)	30º37'05"	30º33'28"	30º31'25"	30º28'35"	30º26'19"
Longitude (^{O}E)	78º50'47"	78º48'29"	78º45'51"	78º41'44"	78º40'14"
Altitude (m masl)	2525	1761	1461	1130	912
Substratum	B>R>C>P	B>C>P>G	C>P>G>S	C>B>P>G>S	G>S>C>P
Land use (Forest type)	CORF	ORF	ORF	POF	P+MF
Total mean density (indiv.m^{-2})	664.7 ± 38.3	711.8 ± 50.3	680.0 ± 37.6	684.2 ± 43.6	642.6 ± 39.1
Final p value of U- test	S1-S2: 0.9315	S2-S3: 0.378	S3-S4: 0.4751	S4-S5: 0.5065	S5-S1:0.3799
Final p value of H-test among station			0.667		

The non-parametric test like Mann-Whitney tests (between every two stations) and Kruskal-Wallis test (among all stations) determines significant difference in total densities (individual m^{-2}): S1 - Gangi, S2 - Dyulang, S3 - Bhelunta, S4 - Chhelli and S5 - Runsal; B - Boulder, C - Cobble-, P - Pebbles, G - Gravel and S - Sand, CORF – Conifer-oak-rhododendron forest, ORF - Oak-rhododendron, POF – Pine-oak forest, P + MF- Pine-mixed forest

Table 2: Range value of various abiotic environmental factors recorded at different sampling stations in Bhilangana river

Stations	S1	S2	S3	S4	S5
Air temperature ºC)	2.5 - 23.2	2.0 - 24.0	2.5 - 24.2	2.5 - 25.3	2.5 - 34.5
Water temperature (ºC)	1.0 - 10.2	1.0 - 12.0	1.0 - 13.2	1.0 - 14.3	1.5 - 16.5
Current velocity (ms^{-1})	0.18–0.82	0.18–0.77	0.17–0.98	0.18–0.75	0.19–0.89
Width (m)	0.85–3.50	0.73–2.65	0.82–3.56	0.78–3.68	0.93–2.67
Depth (m)	0.55 –1.48	0.25 –1.28	0.23 –1.25	0.16 –1.48	0.25 –2.34
Discharge (m^{3}s^{-1})	0.07 -2.33	0.09 -2.32	0.08-2.21	0.07 - 2.12	0.09 - 2.15
Turbidity (NTU)	1.2 - 5.4	1.5 - 7.0	1.5 - 4.5	1.0 - 4.5	1.0 - 3.5
Dissolved oxygen (mg L^{-1})	8.5 - 10.5	8.5 - 10.5	8.0 - 9.5	7.5 - 9.5	7.5- 9.5
pH	6.5 - 8.4	6.3 - 8.5	6.5 - 7.4	7.0 - 7.4	7.3 -7.5
Free CO_2 (mg L^{-1})	0.54 -1.2	0.24 -1.21	0.49 -1.27	0.43 -1.76	0.14 -1.72
Conductivity (µS^{-1})	69.5 -127.5	69.25-167.5	95.5-182.5	94.5-167.5	89.5- 197.2

current velocity showed slight increasing trend downstream the river, while the river width decreased and depth increased from S1 to S5. The maximum range of width (0.78-3.68 m) and depth (0.25-2.34 m) was observed at S4 and S5, respectively. The discharge was highest at S1 (0.07-2.33 ms^{-3}) and lowest at S4 (0.07-2.12 ms^{-3}). The station S2 was highly turbid as compared to the other stations. The dissolved oxygen ranged from 8.5 to 10.5 mg L^{-1} at stations S1 and S2, but range value declined at S3 (8.0-9.5 mg L^{-1}) and at S4 and S5 (7.5-9.5 mg L^{-1}). The pH value was slightly high at S1 (6.5 - 8.4) and S2 (6.3 - 8.5). The highest values of free CO_2 (0.43 - 1.76 mg L^{-1}) and conductivity (89.5- 197.2 µS^{-1}) was noted at S4 and S5, respectively.

The total mean density (individuals m^{-2}) of benthic macroinvertebrates fauna increased from S1 (664.76 ± 38.31) to S2 (711.82 ± 50.35) but declined at S5 (642.64 ± 39.11). The mean density significantly varied among the stations (p = 0.667, H χ^2 = 2.372, $H_{(c)}$ = 2.376) and between each two stations. The increase in density at S2 could be attributed to the dominance of boulder substratum, because as the substrate particle size increased, the availability of hard surface area became more, which provided periphytonic growth and increased invertebrate density. The reduction in substrate particle size is responsible for the decline in mean density from S3 to S5. The decline may be attributed to anthropogenic activities like water extraction for agriculture (Mishra and Nautiyal, 2013; Singh *et al*., 2019). However, Semwal and Mishra (2019) recorded high density at the mouth section of some spring fed Himalayan streams. Mishra and Nautiyal (2013) observed decrease in mean density at mouth section in a central Indian river, Tons.

Taxonomic composition of benthic macroinvertebrate fauna

Arthropoda contributed >90% share in invertebrate composition at each station, followed by Mollusca and Annelida (Fig. 2). Among the Arthropoda, Insecta was the only group observed in present study. Among the Insecta, Diptera was the most abundant taxa at S1 (30.6%), S2 (44.1%) and S5 (36.2%), while Trichoptera was the most abundant taxa at S3 (30.5%) and S4 (34%). Ephemeroptera was the recorded 2^{nd} (S2 - 16.9%, S5 - 20.3%) as well as 3^{rd} (S1-1.8%, S3 - 19.6%, S4 - 18.6%) abundant taxa (Table 3). Coleoptera significantly contributed to the benthic invertebrate community at all the stations. Diptera did not show any changing pattern in percent composition from S1 to S5, but Trichoptera showed increasing trend in middle and lower section of the river (from S2 to S4). However, Ephemeroptera showed declining pattern from S1 to S5. Similarly, the percentage composition of other taxa like Plecoptera, Coleoptera, Megaloptera and Mollusca showed increasing trend, while Hemiptera, Odonata, Lepidoptera and Annelida depicted declining trend from S1 to S5. In spring-fed Himalayan streams, Ephemeroptera was dominant taxon in Khanda Gad (Rawat and Nautiyal, 2005). Nautiyal *et al.* (2015) reported the abundance of Trichopterans in spring fed mountain streams of the Uttarakhand, India.

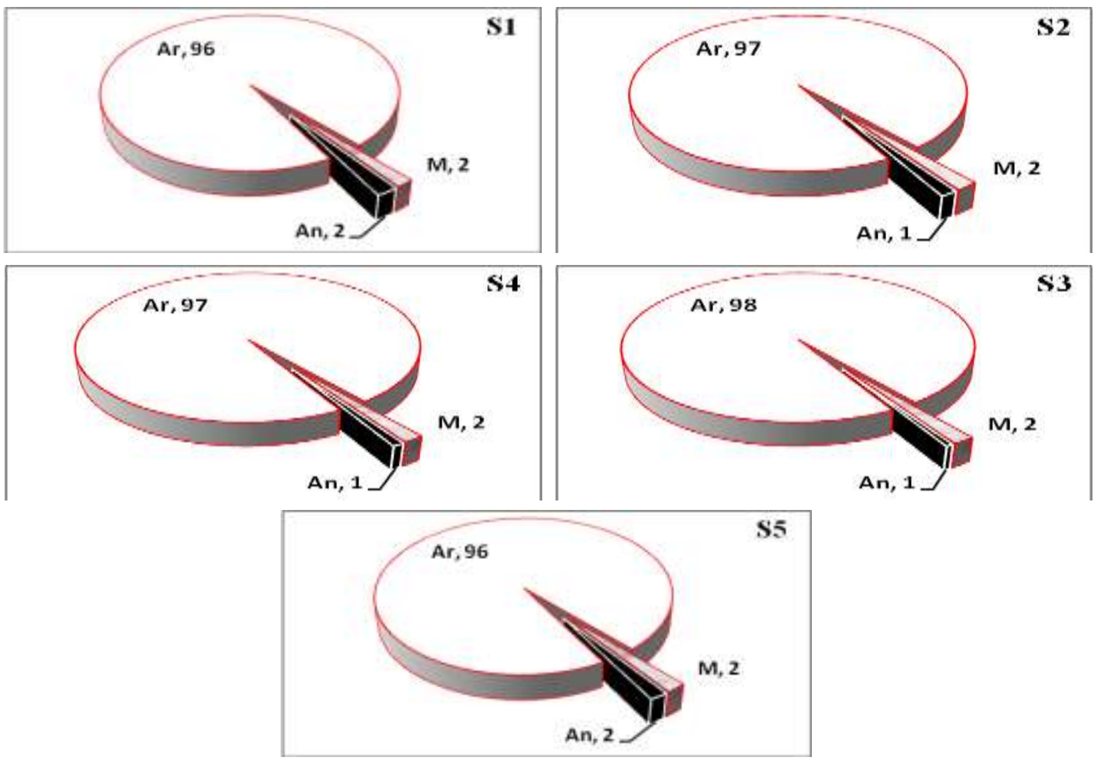


Fig. 2: Percentage composition of higher taxonomic group at stations in Bhilangana river: Ar - Arthropoda, An - Annelida, M - Mollusca

At family level, the most abundant benthic macroinvertebrate taxa (>5%) varied at each station. Simulidae was most abundant taxa (11.2%) at S1 and S3, while Chironomidae was abundant at S2 (21.2%) and S4 (12.8%). Limnephilidae (21.2%) was most abundant taxa at S4 (Fig. 3). The faunal assemblages indicated variation at S1 (Simulidae - Limnephilidae - Philopotamidae - Chironomidae), S2 (Chironomidae - Simulidae), S3 (Simulidae - Philopotamidae), S4 (Limnephilidae - Simulidae) and S5 (Chironomidae - Simulidae). The dominance of Simulidae at S1 and S3 was attributed to the abundance of boulders and cobbles, while Chironomidae was dominant at S2 and S4. The dominance of Hydropsychidae, Heptageniidae and Chironomidae at S3, S4 and S5, respectively, revealed the impact of substratum, as evident in central Highlands river (Mishra and Nautiyal, 2016).

Table 3: Taxonomic composition of benthic macroinvertebrate taxa (order/ family) at various stations in river Bhilangana. Phylum, Class and Order are indicated in bold while family is in normal font.

Taxa	S1	S2	S3	S4	S5
Phylum Arthropoda	96.2	96.6	97.7	97.3	96.6
Order Ephemeroptera	21.8	16.9	19.6	18.6	20.3
Heptageniidae	3.8	2.6	2.6	2.4	3.4
Baetidae	2.6	2.1	2.2	2.9	2.9
Ephemerellidae	2.5	2.2	3.2	3.0	2.5
Ephemeridae	2.2	2.1	2.2	1.8	2.1
Leptophlebiidae	3.2	2.2	2.5	2.4	3.1
Caenidae	3.4	2.0	2.3	2.1	2.3
Siphlonuridae	2.7	2.3	3.1	2.6	2.4
Ecdyonuridae	1.4	1.3	1.4	1.3	1.5
Order Trichoptera	23.5	16.8	30.5	34.0	18.8
Hydropsychidae	3.0	2.3	3.7	2.7	3.2
Limnephilidae	8.9	4.8	6.7	21.2	3.9
Glossosomatidae	1.5	1.3	3.9	1.3	1.4
Leptoceridae	1.2	1.1	2.4	1.2	2.2
Philopotamidae	5.0	4.7	10.4	4.4	4.9
Brachycentridae	1.7	0.6	0.8	0.9	0.6
Psychomyiidae	1.2	1.2	1.6	1.1	1.2
Rhyacophilidae	1.1	0.9	1.0	1.2	1.4
Order Diptera	30.6	44.1	29.9	26.9	36.2
Simulidae	11.2	8.2	11.2	10.7	6.9
Blepharoceridae	1.7	0.9	2.2	0.7	1.0
Order Tendipedidae	1.7	3.8	1.6	1.5	3.9
Chironomidae	5.0	21.2	4.2	4.1	12.8
Psychodidae	1.0	0.9	0.9	0.9	1.0
Leptidae	0.4	0.4	1.0	0.4	0.5
Tipulidae	0.7	0.6	0.6	0.6	1.2
Dixidae	0.7	0.7	0.7	0.8	0.8
Athericidae	1.7	1.5	1.6	1.6	1.6
Culicidae	4.3	3.8	3.9	3.6	4.1
Tabanidae	0.9	1.1	0.9	0.9	1.3
Limoniinae	0.5	0.4	0.4	0.4	0.5
Rhagionidae	0.6	0.6	0.6	0.7	0.7
Order Plecoptera	3.0	3.1	2.9	3.1	3.4
Perlodidae	0.9	0.9	0.9	1.0	1.0
Perlidae	0.6	0.9	0.6	0.7	1.0
Chloroperlidae	0.8	0.8	0.8	0.8	0.9
Nemouridae	0.6	0.6	0.6	0.6	0.7
Order Coleoptera	7.9	7.7	6.1	6.3	8.7
Dryopidae	0.6	0.6	0.6	0.9	0.7
Hydrophilidae	0.5	0.4	0.4	0.4	0.5
Elmidae	1.8	1.7	1.8	1.7	1.8
Haliplidae	0.6	0.5	0.6	0.6	0.6
Psephenidae	4.1	4.1	2.3	2.3	4.8
Dytiscidae	0.4	0.3	0.4	0.4	0.4
Order Neuroptera	1.0	0.9	0.9	0.9	1.0
Sialidae	0.5	0.4	0.4	0.5	0.5
Corydalidae	0.5	0.4	0.4	0.5	0.5
Order Hemiptera	4.2	3.7	3.9	3.9	4.0
Corixidae	0.5	0.4	0.4	0.4	0.5
Naucoridae	0.6	0.5	0.6	0.6	0.6

Gerridae	0.1	0.1	0.1	0.1	0.2
ZVeliidae	0.6	0.4	0.4	0.5	0.5
Nepidae	0.6	0.6	0.6	0.6	0.7
Notonectidae	1.2	1.1	1.2	1.1	1.1
Belostomatidae	0.6	0.5	0.5	0.5	0.6
Order Odonata	2.5	2.0	2.2	2.2	2.3
Agrionidae	0.5	0.4	0.5	0.5	0.5
Gomphidae	0.4	0.3	0.3	0.4	0.4
Coenagrionidae	0.6	0.4	0.5	0.6	0.5
Chlorocyphidae	0.6	0.5	0.5	0.5	0.5
Agridae	0.4	0.4	0.4	0.3	0.4
Order Megaloptera	0.5	0.4	0.6	0.4	0.6
Corydalidae	0.5	0.4	0.6	0.4	0.6
Order Lipidoptera	1.2	1.0	1.1	1.0	1.1
Pyralidae	1.2	1.0	1.1	1.0	1.1
Phylum Mollusca	1.7	1.9	1.8	1.7	1.9
Planorbidae	1.2	1.1	1.4	1.1	1.0
Lymnaeidae	0.5	0.8	0.3	0.6	0.9
Phylum Annelidae	2.1	1.5	0.5	1.0	1.7
Class Hirudinaria	2.1	1.5	0.5	1.0	1.7

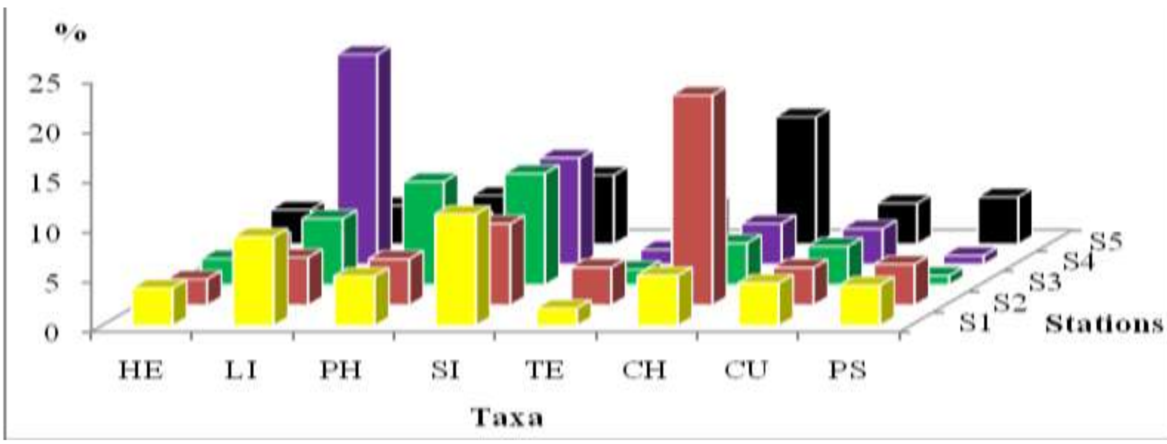


Fig. 3: Taxonomic composition of dominant (>5%) benthic macroinvetyebrate fauna in the river Bhilangana; HE - Heptageniidae, LI - Limnephilidae, PH - Philopotamidae, SI - Simulidae, TE - Tendipedidae, CH - Chironomidae, CU - Culicidae, and PS - Psychomyiidae

The abundance of dipterans (Simulidae and Chironomidae) revealed the dominance of fine particulate organic matter in most of the river sections, except S4 where Limnephilidae was abundant, due to the maximum reduction of substrate particle size. Simulidae was dominant in conifer-oak and oak forest at S1 and S3, respectively; while Limnephilidae was dominant in pine-oak forest at S2. Semwal and Mishra (2019) reported similar findings in a spring-fed stream of lesser Himalaya. Nautiyal *et al.* (2015) observed similar pattern in the streams/rivers of Uttarakhand Himalaya. Similarly, the impact of landuse pattern on distribution of benthic macroinvertebrate fauna was recorded in a central Indian river, Ken (Mishra and Nautiyal, 2013). Subramanian *et al.* (2005) reported the impact of forest type on assemblage pattern.

Characteristic taxa: Principal component analysis (PCA)

The eigen values for PCA axis 1 ($\lambda 1 = 0.606$) and 2 ($\lambda 2 = 0.251$) explained 60.6 and 25.1% cumulative variance in taxonomic composition, respectively, in river Bhilangana. The characteristic benthic macroinvertebrate taxa differed among the stations. Belostomatidae and Vellidae were the characteristic taxa at S1; Chironomidae, Tabanidae and Psephenidae at S2; Glossosomatidae,

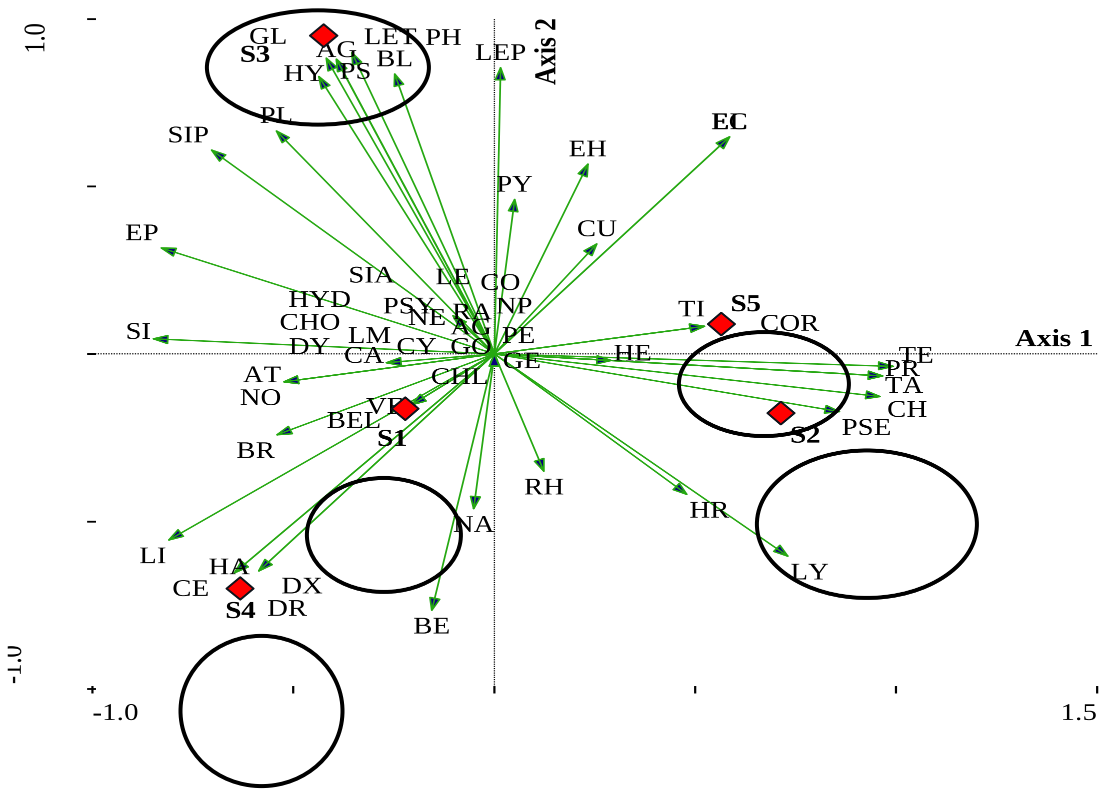


Fig. 4: Principal component analysis (PCA) of benthic macroinvertebrate fauna indicates the characteristic taxa (in circle) through graphical presentation between the taxon (arrows) and station (filled square) in the Bhilangana river. The taxa close to the station are characteristic of that station and encircled. BE - Baetidae, EP - Ephemerellidae, EH - Ephemeridae, LE - Leptophlebiidae, CA - Caenidae, SIP - Siphlonuridae, EC - Ecdyonuridae, HY - Hydropsychidae, GL - Glossosomatidae, LEP - Leptoceridae, BR - Brachycentridae, RH - Rhyacophilidae, BL - Blepharoceridae, PSY - Psychodidae, LET - Leptidae, TI - Tipulidae, DX - Dixidae, AT - Athericidae, TA - Tabanidae, LM - Limoniinae, RA - Rhagionidae, PE - Perlodidae, PR - Perlidae, CHL - Chloroperlidae, NE - Nemouridae, DR - Dryopidae, HYD - Hydrophilidae, EL - Elmidae, HA - Halipliidae, PSE - Psephenidae, DY - Dytiscidae, SIA - Sialidae, CY - Corydalidae, CO - Corixidae, NA - Naucoridae, GE - Gerridae, VE - Veliidae, NP - Nepidae, NO - Notonectidae, BEL - Belostomatidae, AG - Agrionidae, GO - Gomphidae, CE - Coenagrionidae, CHO - Chlorocyphidae, AG - Agridae, COR - Corydalidae, PY - Pyralidae, LY - Lymnaeidae, HR -Hirudinaria. Rest of acronyms in caption of Fig. 3.

Hydropsychidae, Psychomyiidae, Agrionidae, Blepharoceridae and Leptidae at S3; Caenidae, Halipliidae, Dryopidae and Dixidae at S4, and Tipulidae and Corydalidae at S5 (Fig. 4). The variation in the characteristic taxa at different stations may be attributed to the difference in substrate heterogeneity (Table 1) and forest type (S1 – conifer - oak rhododendron forest, S2, S3 – oak -rhododendron forest, S4 – pine - oak forest, S5 – pine - mixed forest). Nautiyal and Mishra (2012) and Mishra and Nautiyal (2016) found land use and substratum as important factors for taxonomic variation in the central Indian rivers. Similarly, Nautiyal *et al.* (2015) and Semwal and Mishra (2019) reported the impact of anthropogenic activities in Himalayan streams. Vannote *et al.* (1980) suggested longitudinal or continuum models which predicted that invertebrate assemblages will change along the length of rivers as evident in the present study.

Conclusion: The mean density of benthic macroinvertebrates decreased along the river length (except S2); and differed significantly between and among the stations. Also, taxonomic composition and assemblages of benthic macroinvertebrates varied along the river length. These variations were attributed to substrate heterogeneity, forest type, conifer oak rhododendron forest, oak rhododendron forest, pine oak forest, pine mixed forest and land-use type.

Acknowledgements: The authors (VPS) acknowledge the financial support granted by WWF-India, New Delhi. Academic support granted by Dr. Renu Negi Principal Government P.G. College New Tehri, Tehri Garhwal and Prof. O.P. Guasin, Department of Zoology, H.N.B. Garhwal University Srinagar Garhwal and Dr. D.N. Jha, Regional Head, ICAR-CIFRI, Prayagraj, Uttar Pradesh for providing library facility. I am thankful to Dr. Arnnendran Gopala (WWF) for preparing the study area map.

REFERENCES

APHA. 1998. Standard methods for examination of water and wastewater. pp. 1-135. **In**: *American Public Health Association* (eds. A.E. Greenberg, L.S. Clesceri and A.E. Eaton) (Part 4000) and 10000, APHA Press, New York, USA.

Benbow, M.E., Burky, A.J. and Way, C.M. 2003. Life cycle of a torrenticolous Hawaiian chironomid (Telmatogeton torrenticola): Stream flow and microhabitat effects. *Annales de Limnologie - International Journal of Limnology*, **39**: 103-114.

Born, S.M., Genskow, K.D., Filbert, T.L., Hernandez-Mora, N., Keefer, M.L. and White, K.A. 1998. Socioeconomic and institutional dimensions of dam removals: The Wisconsin experience. *Environmental Management*, **22:** 359-370.

Boyero, L. 2003. The effect of substrate texture on colonization by stream macroinvertebrates. *Annales de Limnologie - International Journal of Limnology*, **39**: 211-219.

Bunn, S.E. and Arthington, A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, **30:** 492-507.

Cîmpean, M.S., Uteu, A.M., Berindean, A. and Battes, K.P. 2022. Diversity of spring invertebrates and their habitats: a story of preferences. *Diversity*, **14**: 1-17.

Dinakaran, S. and Anbalagan, S. 2007. Anthropogenic impacts on aquatic insects in six streams of South Western Ghats. *Journal of Insect Science*, **7:** 37. [*www.insectscience.org/7.37*].

Edington, J.M. and Hildrew, A.G. 1995. Caseless caddis larvae of the British Isles. *Freshwater Biological Association Scientific Publication,* **53**: 1-133.

Gurung, S., Singh, R., Wagle, B., Jha, B. R., Khatri, K. and Jacobsen, D. 2021. Macroinvertebrate assemblages in mountain tributaries of glacial-fed and rain-fed rivers in eastern Nepal. *Nepal Journal of Environmental Science*, **9**(2): 45-55.

Habib, S. and Yousuf, A.R. 2014. Benthic macroinvertebrate community of a fourth order stream, in Kashmir Himalaya, India. *African Journal of Environmental Science and Technology*, **8**(4): 234-238.

Kulshrestha, S.K. 2009. Biodiversity of some aquatic environments in Central India. pp. 1-28. **In**: *Biodiversity and Ecology of Aquatic Environments* (eds. H.R. Singh and P. Nautiyal), Narendra Publishing House, Delhi.

Kumar, S. and Nautiyal, P. 2020. Community features of benthic macroinvertebrates and bio-assessment of the stretch of Bhagirathi river impacted by Maneri Bhali stage I Hydroelectric Project. *International Journal of Ecology and Environmental Sciences*, **45**(3): 311-315.

Kumar, K., Smriti, G., Jha, B.R. and Khadka, U.R. 2022. Benthic macroinvertebrates assemblages of glacial-fed (Bheri) and rain-fed (Babai) rivers in western Nepal in the wake of proposed inter-basin water transfer. *Biodiversity Data Journal*, **10**: e79275. [*https://doi:10.3897/BDJ. 10.e79275*].

Macan, T.T. 1979. *A Key to Nymphs of the British Species of Ephemeroptera with Notes on their Ecology (3rd edn.)*. Freshwater Biology Association, Scientific Publication no. 20, Ambleside, Cumbria, U.K.

Masresha, B.F., Simon, A., Clement, K.K. and Minwyelet, M. 2022. Impacts of anthropogenic activities on the benthic macroinvertebrate assemblages during the wet season in Kipsinende river, Kenya. *Turkish Journal of Fisheries & Aquatic Science*, **22**(6): *TRJFAS18410*http://doi.org/10.4194/ *TRJFAS18410*

Mishra, A.S. and Nautiyal P. 2011. Factors governing longitudinal variation in benthic macroinvertebrate fauna of a small Vindhyan river in central highlands eco-region (central India). *Tropical Ecology*, **52**(1): 103-112.

Mishra, A.S. and Nautiyal P. 2016. Substratum as determining factor for the distribution of benthic macroinvertebrate fauna in a river ecosystem. *Proceedings of the National Academy of Sciences (Biological Sciences)*, **86**(3): 735-742.

Mishra, A.S. and Nautiyal, P. 2013. Longitudinal distribution of benthic macroinvertebrate assemblages in a central highlands river, the Tons (Central India). *Proceedings of the National Academy of Sciences (Biological Sciences)*, **83**(1): 47–51.

Mishra, A.S. and Pandey, C.K. 2019. Structural and functional status of benthic macroinvertebrate fauna in the rivers of central highlands ecoregion, India. *Bioved*, **30**(2): 195-201.

Mishra, A.S., Nautiyal, P. and Singh, K.R. 2020. Factors governing distribution of benthic macroinvertebrate fauna in the spring fed headwaters of Doon valley, India. *Journal of Mountain Research*, **15:** 159-167.

Nautiyal, P. and Mishra, A.S. 2012. Longitudinal distribution of benthic macroinvertebrate fauna in Vindhyan river, India. *International Journal of Environmental Sciences*, **1**(3): 150-158.

Nautiyal, P., Mishra, A.S. and Semwal, V.P. 2015. Spatial distribution of benthic macroinvertebrate fauna in mountain streams of Uttarakhand, India. pp. 31-51. **In**: *Aquatic Ecosystem: Biodiversity, Ecology and Conservation* (eds. M. Rawat *et al.*) Springer. htps://doi.org/10.1007/978-81-322-2178- 4_4.

Pandey, C.K. and Mishra, A.S. 2021. Longitudinal patterns of benthic macroinvertebrate fauna in river Dhasan, Central India. *Applied Biological Research*¸ **23 (4)**:331-340.

Rana, J.S., Semalty, B., Singh, P., Swami, N., Dewan, S., Singh, J., Gusain, M.P. and Gusain, O.P. 2017. Checklist of benthic macroinvertebrate taxa along different riparian land use types in Alaknanda river catchment of the Central Himalaya, Uttarakhand (India). *Proceedings of the Zoological Society*, **72**: 130-153.

Rawat, G. and Nautiyal, P. 2005. Diversity of Ephemeroptera assemblage in lesser Himalayan streams and rivers (Garhwal region). pp. 213-223. **In**: *Biological diversity in freshwater environments* (eds. P. Nautiyal *et al*.) Transmedia Srinagar, Uttarranchal, India.

Rios, S.L. and Bailey, R.C. 2006. Relationship between riparian vegetation and stream benthic communities at three spatial scales. *Hydrobiologia*, **553:** 153-160.

Semwal, V.P. and Mishra, A.S. 2019. The distributional pattern of benthic macroinvertebrates in a spring-fed foothill tributary of the Ganga river, Western Himalaya. *Journal of Threatened Taxa*, **11**(12): 14511-14517.

Shilla, D.J. and Shilla, D.A. 2012. Effects of riparian vegetation and bottom substrate on macroinvertebrate communities at selected sites in the Otara Creek, New Zealand. *Journal of Integrative Environmental Sciences*, **9(3):** 131-150,

Singh, P., Sharma, K., Swami, N., Rana, J.S., Gusain, M.P. and Gusain, O.P. 2019. Assemblages of benthic macroinvertebrate communities downstream of a dam on river Alaknanda in Garhwal Himalaya, Uttarakhand, India. *International Journal of Ecology and Environmental Sciences*, **45**(4): 403-412.

Singh, J., Gusain, O.P. and Gusain, M.P. 2010. Benthic–insect substratum relationship along an altitudinal gradients ina Himalayan stream India. *International Journal of Ecology and Environmental Sciences*, **36(4):** 215–231

Subramanian, K.A., Sivaramakrishnan, K.G. and Gadgil, M. 2005. Impact of riparian land use on stream insects of Kudremukh National Park, Karnataka state, India. *Journal of Insect Science*, **5**:49, available online: insectscience.org/5.49

ter Braak, C.J.F. and Smilauer, P. 2002. CANOCO Reference Manual and Canodraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power (Ithaca, NY, USA).

Teske, P.R. and Wooldridge, T.H. 2003. What limits the distribution of sub-tidal macrobenthos in permanently open and temporarily open/closed South African estuaries? Salinity vs. sediment particle size. *Estuarine, Coastal and Shelf Science*, **57**(1-2): 225-238.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E. 1980. The river continuum concept. *Canadian Journal of Fisheries & Aquatic Sciences*, **37:** 130-137.

Varnosfaderany, M.N., Ebrahimi, E., Mirghaffary, N. and Safyanian, A. 2010. Biological assessment of the Zayandeh Rud river, Iran, using benthic macroinvertebrates. *Limnologica*, **40:** 226-232.

Wentworth, C.K. 1922. A scale of grade and class terms for classic sediments. *Journal of Geology*, **30:** 377-392