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DISTRIBUTION OF BENTHIC MACROINVERTEBRATES ALONG SEDIMENT GRADIENTS IN A MOUNTAIN LAKE OF KUMAUN HIMALAYAS, INDIA

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Abstract

Distribution of benthic macroinvertebrates with sediment characteristics was determined in Lake Sattal of Kumaun Himalayas, India. Sampling was undertaken monthly for two consecutive years at four sites using Ekman dredge bottom sampler. A total of 31 benthic macroinvertebrates species belonging to 10 groups viz, Diptera (5), Trichoptera (5), Gastropoda (4), Ephemeroptera (3), Hirudinea (3), Odonata (3), Coleoptera (2), Decapoda (2), Oligochaeta (2), and Platyhelminthes (2) were collected. Temporal and spatial variations of sediment grain sizes, total organic matters, dissolved oxygen (DO) at the near-bottom layer (NBL) were estimated. Our study reveals that the diversity of macroinvertebrates was higher at the stable medium-sized particles and reduces in coarser-grained sediment bed. Although organic matter regulates the abundance of both sensitive insect larvae and pollution tolerant chironomids, the two groups have different habitat preferences and functional feedings. Increased detrital inputs and periodical anoxia at near bottom layer (NBL) augmented the domination of deposit-feeders. Changes in the land-use pattern in the catchment alter the habitat structures and enhance basal resources segregation in the upland lake. Therefore, determination of habitat-specificity of benthic macroinvertebrates could develop priority efforts to protect the mountain ecosystem.

*Key words:*habitat, Himalayan Lake, macroinvertebrates, organic matter, particle-size

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1. Introduction

Sediment is considered a critical resource for ecosystem functioning in an aquatic environment (Larson and Sundbäck, 2012). The upper organic-rich sediment substrate has been widely used to determine insight of early diagenetic changes. Topographic variation influences geo-morphology and landform of underlying benthic topology. Lakes of mountain regions are generally sensitive and rapid flushing rates (Steingruber et al., 2013; Stoica et al., 2014; Vreca and Muri, 2006). They are characterized by coarser substrate, good intake of particulate organic terrestrial matter. The degradation processes of terrestrial inputs from its origin to burial sites are normally low because of the steep slope and shorter sinking period. Due to poor mobility and sedentary existence, benthic biota of the mountain lakes is highly responsive to environmental change (Lampitt, 1985; Rakocinski et al., 1997; Snelgrove and Butman, 1994).

Slope stability, surface erosion, and sedimentation rates have fundamental linkages with the community structure of the benthic invertebrates (Christensen et al., 1996; Gamulin-Brida, 1967). This is due to variation of habitat characteristics *viz,* substrate types, organic matters, periphyton, and lake depth, etc. (Peeterset al., 2004; Stoffelset al., 2005; White and Irvine, 2003). Lakes of Kumaun Himalayas have great variabilities in the benthic substratum and hydro-ecology owing to the altitudinal variation regulating the vegetation, climate, and lithology (Panigrahy et al., 2012). Hence, sedimentary features

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might affect the benthic macroinvertebrates populating in it. Thus, it is imperative to evaluate niche separation of macroinvertebrates to identify early signals of ecological alteration before rapid changes in trophic levels occur in the mountain environment.

While enormous information on the distribution pattern of macroinvertebrates is available in the marine environment, studies in freshwater lakes of the upland region are less known. We studied the temporal variation of macroinvertebrates diversity, density, and biomass in a mountain lake. This study aimed to establish the relationship between sediment characteristics and benthic macroinvertebrates in a subtropical lake of the Kumaun Himalayas, India. We determined seasonal variation of sediment textures, dissolved oxygen (DO) of the near-bottom layer (NBL), and total organic matter (TOM) with the distribution of macroinvertebrates. The study will provide useful information on the habitat-specificity of benthic invertebrates and the cascading impact of resource segregation on ecosystem functioning in the mountain lake.

2. Materials and method

2.1. Study site

The study was conducted in Lake Sattal, a mesotrophic lake (Inaotombi et al., 2016) of the Kumaun Himalayas between 29°20′52″N latitude and 79°31′55″E longitude, India (Fig. 1(a), (b)).

The lake is situated about 1286 m above sea level and has a maximum depth of 20 meters. The Lake has two basins namely Eastern and Western basins which form a V-shaped structure. The major sources of water in the lake are springs, streams, and rainfall. Geomorpholocially, the lake is characterized by lacustrine deposits and drainage patterns are of treillage type and structurally governed by fractures and faults (Das et al., 1994). The rocks in the catchment area of Sattal include Jantwaliagaon limestone along with the Bhimtal volcanic, Bhowali Quartzite, and Schists (Valdiya, 1988).

2.2. Samples collection

Four sampling sites, two in each basin were selected (Fig. 1c). Sampling was carried out at a monthly interval of time for two years. Triplicate sediment samples were collected using Ekman dredge bottom sampler (25 × 25 cm) for determining the sediment characteristics and macroinvertebrates indices. Samples were packed into airtight polyethylene bags and transported to the laboratory within two hours. For benthic macroinvertebrates analysis, samples were rinsed using a sieve having a pore size equal to 0.5 mm. The animals captured by sieve were transferred into white enamel trays and preserved in 10% formaldehyde. Benthic macroinvertebrates species were identified and counted in Petri dishes.

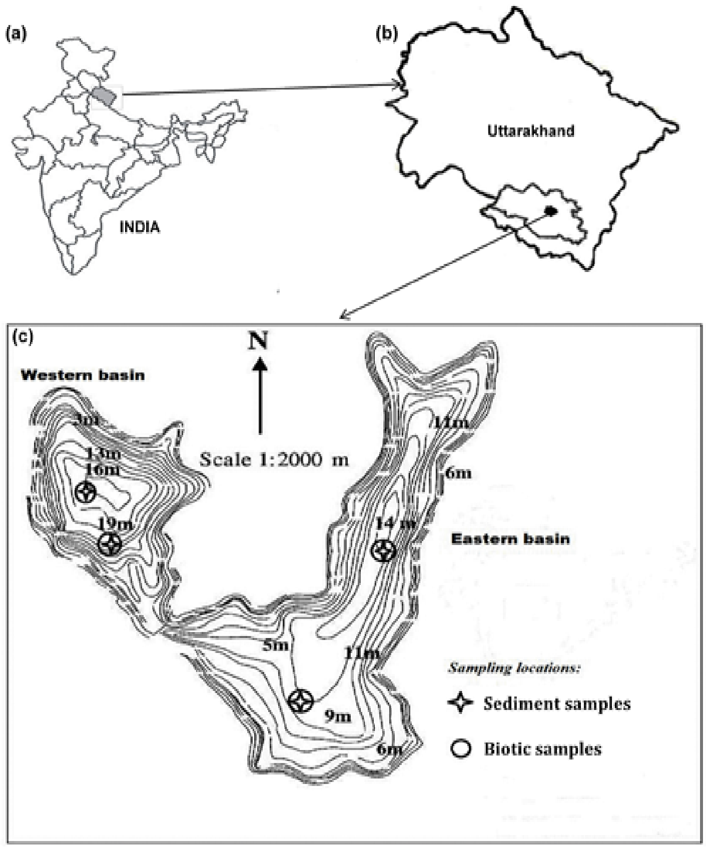

Fig. 1. (a) Map of India indicating location of Uttarakhand state (b) map of Uttarakhand indicating location of Lake Sattal, (c) Bathymetric Map of Lake Sattal indicating four sampling stations

Data obtained were converted to number per square meter. As computed by Gupta and Pant (1983), wet biomass of the benthic macroinvertebrates was determined by drying on an absorbent paper for a few minutes and weighing them in a Mettler Analytic Balance with three decimals accuracy. The wet weights were then converted to dry weight by assuming dry wt. 15 % of wet wt. For analysis of sediment characteristics, samples were dried in air and marked with site and date of collection, then stored in the cold dark area to decrease bacterial decay and reduce the volatiles losses. The particle sizes of the sediment bed were separated by the standard sieves of the Geological Survey of India (GSI). The portions passed through each consecutive sieve were measured, and data were converted into percentages by the dry weight of the initial samples. The sediment particles were classified according to their sizes (Udden 1914) as sand (0.06 to 1.0 mm), silt (0.0039 to 0.06 mm), and clay (< 0.0039 mm). The total organic matter (TOM) was estimated by the loss-on-ignition method. The initial weight of oven-dried sediment samples was measured and then ignited at 550 ºC in a ceramic crucible for 2 hours and then cooled in desiccators (Jackson, 1973). Organic matter content was calculated from the difference of initial sample weight to final sample weights. The data were converted as the percentage by dry weight. The concentration of dissolved oxygen (DO) at near bottom layer (NBL) was determined at the site itself using calibrated portable probe YSI-600-XL (Yellow Springs Inc., Ohio, USA).

2.3. Statistical analysis

Triplicates of 96 collected samples for each parameter were statistically analyzed. Shannon species diversity (Shannon and Weaver, 1949), Concentration of dominance (Simpson, 1949) for macroinvertebrates was calculated. Spatial and temporal variation of environmental data and biotic parameters were tested with analysis of variance (ANOVA). Pearson's correlation was applied to account relationship of sediment characteristics and assemblages of benthic macroinvertebrates community. Both the tests were executed using the SPSS software 16.0 version. Log-transformation [log10 (x+1)] was done before statistical tests to reduce heteroscedasticity of data. Canonical Correspondences Analysis (CCAs) was used to determine the factor influencing the distribution pattern of the benthic macroinvertebrates community by developing visualizes matrix using software PAST (version 3.01). Monte-Carlo permutation tests (n = 999) were conducted for evaluating the statistical strength of the eigenvalues. We regressed data of macroinvertebrates diversity with sand and silt grain size composition of the sediment; then biomass against DO at NBL separately. The relationships among the indices were constructed using a complete linkage clustering technique on the Bray–Curtis dissimilarity from the data matrix through time (Bray and Curtis, 1957). Hierarchical clustering was constructed based on Euclidean distance and complete linkage. To visualize the trends in the macroinvertebrates community data, a non-metric multidimensional scaling (nMDS) analysis was used by calculating the minimum spanning tree and Euclidean similarities in 2D plot.

3. Results and discussion

3.1. Abiotic variables

Sediment properties of the Himalayan lakes are mainly control by transport energy, weathering, and pedogenesis in the catchment as well as post-depositional alteration processes. Catchment erosion and lithogenic leaching were the primary sources of the ionic constituent of Lake Sattal. Typically, the lake was developed in the quartzitic country having lacustrine deposits (Choudhary et al., 2009; Das et al., 1994). The mean values of abiotic parameters and their spatial variations Lake Sattal were depicted in Table 1.

Sand, silt, and clay particles in the eastern basin varied from 56% to 93%, 3% to 35%, and 3% to 14%, respectively. Likewise, the portion of the sand, silt, and clay in the western basin were varied from 43% to 96%, 2% to 34%, and 2% to 23%, respectively. (Fig. 2). Although the textural featuresof the two basins were more or less similar, the TOM of the two basins were significantly varied (ANOVA $F2, 96 = 7.04$; $p< 0.01$).

Consistently high sand particles in Sattal may attribute to the transportation of sandy soil from the terrain through stormwater entailed with weathering. DO at the NBL ranged from 0.26 mg/L to 2.3 mg/L in the eastern basin whereas it was 0 mg/L to 2.44 mg/L in the western basin. The availability of DO at the NBL has a positive correlation with sand ($p < 0.05$) and negative with the clay particles ($p < 0.05$).

Table 1. Biannual mean values of sediment variable in the eastern and western basins of Lake Sattal of Kumaun Himalaya

Variable	***Eastern basin***	***Western basin***	***ANOVA (One-way)***	
			F	***Sig.***
DO at NBL (mg/l)	1.18 ± 0.82	1.45 ± 0.82	0.436	0.512
Sand %	56.25 ± 8.41	58.75 ± 11.74	0.719	0.401
Silt %	22.79 ± 6.41	19.96 ± 7.55	1.963	0.168
Clay %	21.67 ± 7.41	21.38 ± 8.33	0.016	0.899
TOM	6.55 ±2.14	4.94 ± 2.06	7.044	p< 0.01

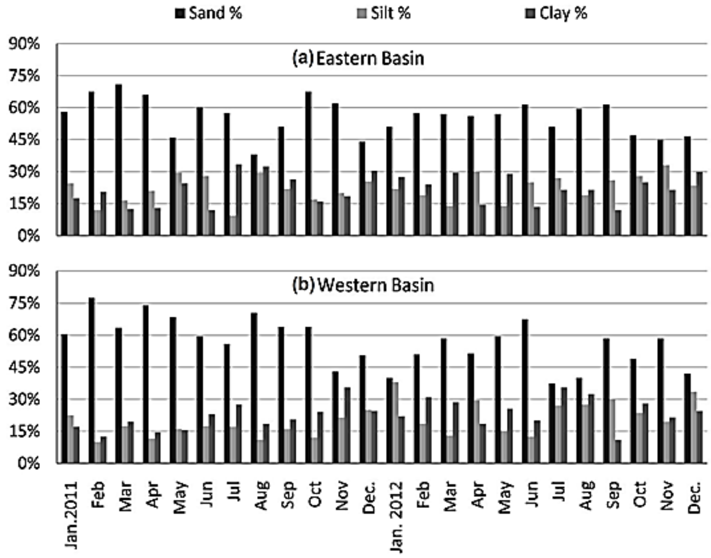

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Fig. 2. Percentage composition of sediment grain sizein the (a) eastern and (b) western basins of the lake

Oxygen availability at the NBL was higher at the sandy sites and drastically reduces at clay dominant sites. This might be due to the low surface area in the sandy region. The mean TOM in the eastern basin was 4.7% while it was 3.7% in the western basin. Significant spatial variations in the percentage of TOM clearly show heterogeneous habitats of the lake.

3.2. Species richness and diversity

A total of 31 species of benthic macroinvertebrates belonging to 10 groups were recorded (Table 2). The maximum number of species belongs to group Trichoptera followed by Diptera. The taxonomic groups in descending order of species number were: Gastropoda>Ephemeroptera = Hirudinea = Odonata>Coleoptera = Decapoda = Oligochaeta = Platyhelminthes.

Macro-invertebrates are considered as a principal component of the lentic ecosystem in a mountain environment (Reice and Wohlenberg, 1993). They are functionally diverse, geographically variable, and distributes at strong patchy in their local. The mean diversity index of the benthic macroinvertebrates in the eastern basin was 2.17 while it was 1.98 in the western basin. The diversity of macroinvertebrates in the eastern basin was significantly higher than the western basin (ANOVA F2, 96 = 4.86; $p< 0.05$). No definite trends of seasonality were observed in the diversity index. Silt particles showed strong positive correlation ($p < 0.05$) and sand particles negatively correlated ($p < 0.05$) with species diversity. The mean concentration of dominance in the eastern basin was 0.17; while it was 0.06 in the western basin. The diversity of macro-invertebrate in Lake Sattal was low towards the coarser grain (sandy) sites. This is probably due to the poor supply of detritus food particles in the well-sorted sands. Nevertheless, higher diversity in silt dominated sites suggested the formation of heterogeneous habitat in the stable medium-sized substrate. Although the diversity of macroinvertebrates is mainly controlled by grain size composition, community abundance of which was highly influenced by available organic matter ($p= 0.043$).

3.3. Population density and biomass

The average abundance of macroinvertebrates community in the eastern basin was 198 ind m^{-2} while it was 184 ind m^{-2} in the western basin. TOM of the sediment showed a strong positive correlation ($p < 0.05$) with the community abundance. Among the group, Diptera was the most dominant group contributes 42 % of the total abundance followed by Oligochaeta, Trichoptera, Gastropoda, Hirudinea, and Odonata which shared 13.0%, 12.5%, 9.0%, 8.0%, and 6.5%, respectively. Temporal variations in population density of important species are depicted in Fig. 3.

C. plumosus was the most dominant macroinvertebrates which contribute 46.28% of the total community abundance in the lake. The species varies from a minimum of 26 ind/m^2 (June) to a maximum of 194 ind/m^2 during April with an average density of 64 ind m^{-2} in eastern and 73 ind m^{-2} in the western basin. The density of *C. plumosus* has positive correlation with TOM ($p = 0.049$) and DO at near-bottom layer ($p = 0.041$) while it was negatively correlated ($p = 0.049$) with clay particle (Table 2). *L. hoffmeisteri* has an average density of 15 ind m^{-2} and showed the peaks density during summer and monsoon seasons. The averages densities of *T. tubifex* were 13 ind m^{-2} and 7 ind m^{-2}, respectively in the eastern and western basin. The density of *T. tubifex* showed strong spatial variation (ANOVA F2, 96 = 9.40; $p< 0.01$).

Triaenodes sp. has the mean density of 8 ind m^{-2} and 10 ind m^{-2}, respectively in the eastern and western basin. It has a significant positive correlation with the TOM of the sediment ($p = 0.028$). *Glossiphonia weberi* has an average density of 11 ind

m^{-2} in the eastern basin and 6 ind m^{-2} in the western basin. Seasonally, a single pronounced peak was observed in monsoon season in the eastern basin while no patterns of seasonality were observed in the western basin. The densities of *Barbronia weberi* were equal (6 ind m^{-2}) in both basins which have negatively correlated with the sand particles ($p = 0.043$).

The relative abundance of macroinvertebrates groups varied extensively with concomitant changes in functional traits and features of the sedimentary food resources in the ecosystem (Heino, 2008; Tomanova et al., 2006). The coarser particulate organic matter consisting of riparian litter has direct correspondences with the abundance of the pollution sensitive macroinvertebrates. The terrestrial subsidies in the food webs of benthic habitats appear to greater control in the biota of upland lakes. In SattalLake, the input of twigs and woody debris from the surrounding terrestrial ecosystem influenced the abundance of pollution sensitive Trichopteran larvae. Inputs of such debris in sediment improved the physical support for case-building caddisfly. In the present study, the shredder herbivores (i.e. *Triaenodes* sp.) mostly collected with plant twigs; and their abundance increased during late spring when death and decays of plant's twigs emerge.

Table 2. List of macroinvertebrate species recorded from Lake Sattal of the Kumaun Himalaya

Group	***Species***
Coleoptera	*Donacia marginata* Hoppe, 1795 (larvae)
	Coptotomus sp.(larvae)
Decapoda	*Palaemonetes argentines* Nobili, 1901
	Cambarus sp.
Diptera	*Chironomus plumosus* Linnaeus, 1758
	Pentaneura sp.
	Procladius culiciformis Linnaeus, 1767
	Aedes albolateralis Theobald, 1908 (larvae)
	Tipula plumose Linnaeus, 1758
Ephemeroptera	*Caenis* sp.
	Leptophlebia marginata Linnaeus, 1767 (nymphs)
	Baetis alpinus Pictet, 1845
Gastropoda	*Gyraulus convexiusculus* Hutton 1849
	Lymnaea auricularia Linnaeus, 1758
	Lymnaea columella Say, 1817
	Promenetus exacuous Say, 1821
Hirudinea	*Glossiphonia weberi* Oka, 1910
	Barbronia weberi Blanchard, 1897
	Helobdella sp.
Odonata	*Epicordulia princeps* Hagen, 1861 (Larvae)
	Argia apicalis Say, 1839
	Anax junius Drury, 1773
Oligochaeta	*Tubifex tubifex* Otto Friedrich Müller, 1774
	Limnodrilus hoffmeisteri Claparède, 1862
Platyhelminthes	*Planaria* sp. (larvae)
	Dugesia dorotocephala Woodworth, 1897 (larvae)
Trichoptera	*Hydroptila augusta* Ross, 1938
	Triaenodes sp.
	Rhyacophila sp.
	Hydropsyche decalda Ross, 1947 (larvae)
	Leptocerus sp.

The species richness was positively correlated with TOM ($p < 0.05$) and silt grain sizes ($p < 0.05$) of the sediment (Tables 3-4). The taxonomic richness of macroinvertebrates was higher at the organic-rich silty sediment. This is because of the greater availability of organic debris supports larger detritivores

Table 3. Pearson's correlation analysis of important macroinvertebrates and sediment variables in Lake Sattal of Kumaun Himalayas

Features	***Silt***	***Clay***	***TOM***	***DO (NBL)***	***Diversity***	***Richness***	***Abundance***	***Biomass***
Sand	-.730**	-.658**	.172	.331*	-.336*	-.176	-.061	-.139
Silt		.018	-.039	-.172	.344*	.300*	.205	.226
Clay			-.219	-.335*	.106	-.094	-.159	.000
TOM				.085	.105	.355*	.455**	.140
DO (NBL)					.031	.201	.219	.344*
Diversity						.857**	.331*	.519**
Richness							.646**	.554**
Abundance								.278
Biomass								1

Table 4. Pearson's correlation analysis of important macroinvertebrates and sediment variables in Lake Sattal of Kumaun Himalaya

Features	***Silt***	***Clay***	***TOM***	***DO (NBL)***	***Chiro-nomus***	***Glossi-phonia***	***Bar-Bronia***	***Tubi-fex***	***Limno-drilus***	***Triae-nodes***
Sand	-.730**	-.658**	.172	.331*	.198	-.213	-.302*	.060	-.125	.151
Silt		.018	-.039	-.172	-.010	.218	.239	-.137	.104	.004
Clay			-.219	-.335*	-.295*	.109	.179	.147	.014	-.250
TOM				.085	.403**	.048	.010	.040	-.086	.373**
DO (NBL)					.204	.046	.177	-.112	-.022	.053
Chiro- nomus						-.187	-.148	-.041	.088	.457**
Glossi-phonia							.356*	.407**	.335*	-.100
Bar - bronia								-.079	.063	-.162
Tubi- fex									.305*	-.048
Limno- drilus										.149

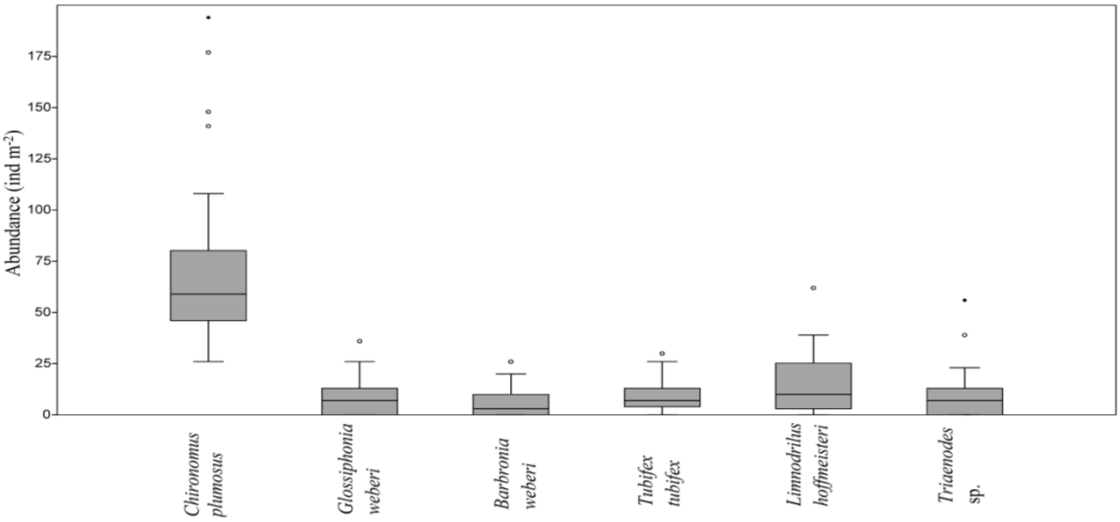

Fig. 3. Spatio-temporal variations in population densities (ind m^{-2}) of important macroinvertebrates in Lake Sattal

Anax junius, *B. weberi*, *C. plumosus*, *Lymnaea auricularia*, and *Lymnaea columella* were the major contributors to community biomass. Overall, *A. junius* contributes to maximum biomass having peak density during winter seasons. The biomass of *B. weberi* rises intermittently, but no definite patterns of seasonality were observed. Maximum biomass of *C. plumosus* was found during summer with average biomass of 0.04 g m^{-2} and 0.05 g m^{-2} respectively, in eastern and western basins. *L. auricularia* and *L. columella* did not show any definite pattern of seasonality in their biomasses. In our studies, available dissolved oxygen along with organic matter regulates the community biomass of macroinvertebrates. The maximum biomass was contributed by shredder odonatan larvae. Thus, coarse particulate detritus in the stable oxygenic microhabitat supports shredder biomasses, while fine particulate organic matter sustains hypoxia-tolerant macroinvertebrates.

3.4. Macroinvertebrates and environment variables

CCAs were performed to evaluate the relationship between assemblages of benthic macroinvertebrates and abiotic variables in the lake environment. Sand, silt, and TOM of the sediment are the major sedimentary factors controlling the distribution of the macroinvertebrates (Fig. 4). As much as 88.11 % of the total variance was explained by combining axes 1 and 2. The eigenvalues for axes 1 and 2 were 0.083 (59.88% of total cumulative variance) and 0.039 (28.23 % of the cumulative variance), respectively. Monte Carlo permutations test demonstrated significant species-sediment relationship along the canonical axis 1 ($p = 0.006$) and canonical axes 2 (p ratio = 0.013). The diversity of macroinvertebrates was greater in silt sediment than that of coarser sandy sediment (Fig. 5).

The community abundance showed a strong positive relationship with the percentage of TOM while the biomass of which has positively influenced by DO at NBL (Fig. 6) in regression analysis. In the minimum spanning tree of nMDS, assortative distribution of *C. plumosus* and *Triaenodes* sp. observed extension at different ends. For biomass, *Lymnaea auricularia* has the closest to the *C. plumosus* in the cluster (Fig. 8). The accumulated larger organic detritus are either shredded by macroinvertebrates or decayed by physical processes. The finer detritus is microbially mineralized and changes to stable flocculated organic detritus that liable to create sub-oxic labile sediment substrate.

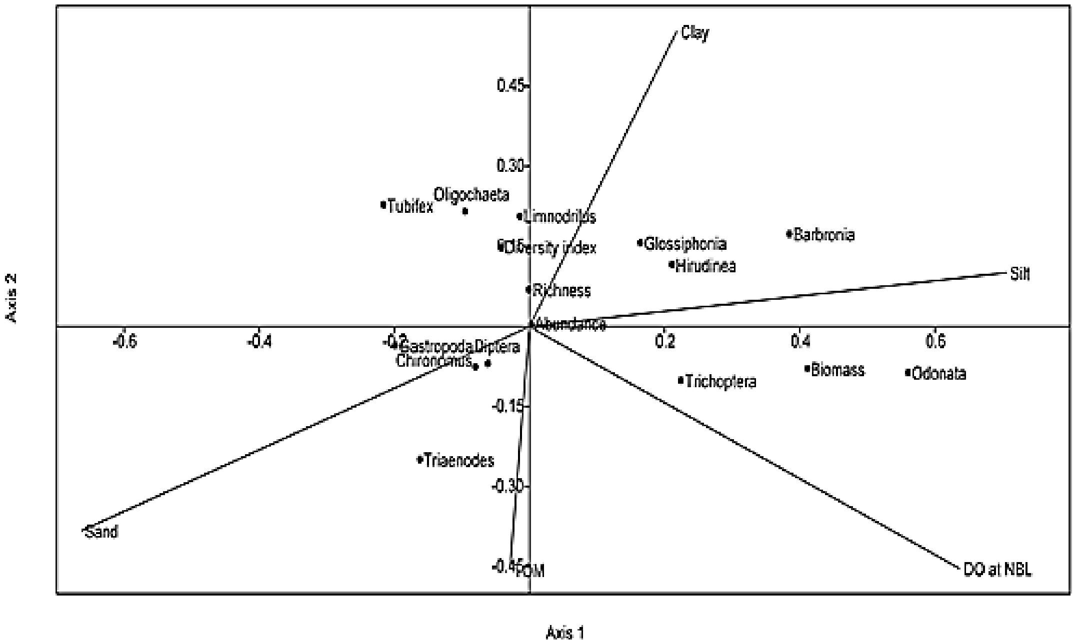

Fig. 4. CCA ordination bi-plot of environment variables and macro-invertebrates assemblages in Lake Sattal

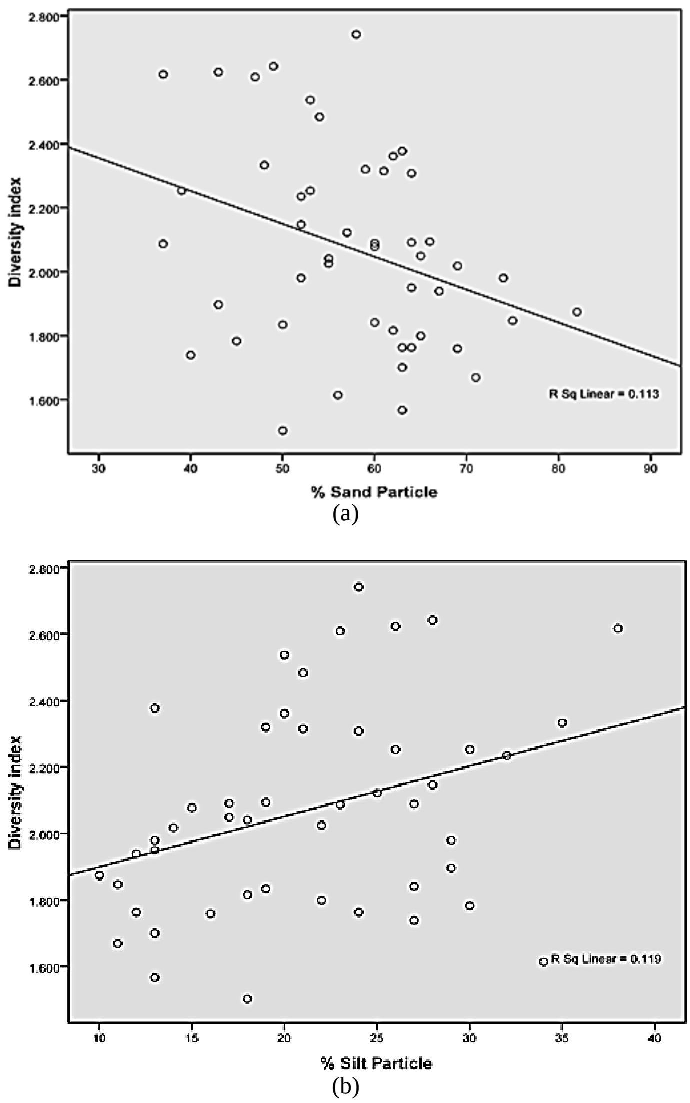

Fig. 5. Regression analysis of macro-invertebrate diversity with (a) sand and (b) silt grain size in Lake Sattal

During the process of mineralization, the deposited oxidizable organic matters control the availability of food particles (Fenchel et al., 1998; Jahnke et al., 1982). *C. plumosus* shared maximum contribution in the community abundance of macroinvertebrates. The simulated secondary organic matter tends to support the abundance of tubificids and associated organisms *viz*, *L. hoffmeisteri*, *T. tubifex*, *Barbonia weberi* and *G. weberi*, etc. Particulate organic matter in a deeper profundal zone of the sediment degraded more rapidly under low oxygen concentration. Nevertheless, non-biting midges larvae, *C. plumosus* and segmented worms, *T. tubifex* were highly dominated in the deeper organic-rich zone. These species are highly tolerant of extreme organic contamination (Mason, 1996; Wilhmand Dorris, 1968). The high density of *C. plumosus*, moderate density of *T. tubifex* and *L. hoffmeisteri* and intermittent appearance of sensitive insect larvae*viz.* stoneflies, mayflies, and caddisflies in Lake Sattal indicates the transition of trophic level. Since trichopterans are pollution sensitive macrofauna, their abundance decreased with increasing organic deposits. The higher abundance of these species onto susceptible NBL indicates onset of eutrophication of the lake. Both *C. plumosus* and *Triaenodes* sp. were populated in high TOM sediment gradients. However, *C. plumosus* exhibit distant pattern in Bray-Curtis matrix while remaining species assemble in a different cluster (Fig. 7).

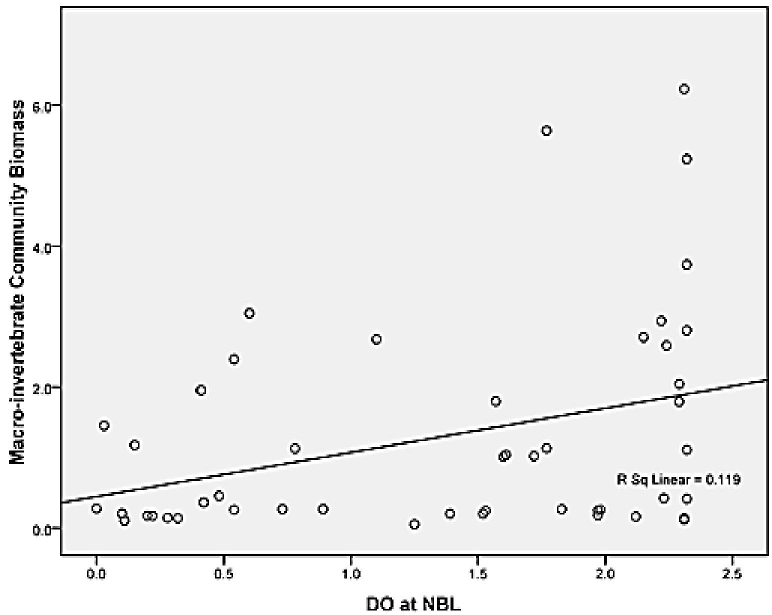

Fig. 6. Regression analysis on the biomass of macro-invertebrate with DO at NBL in Lake Sattal

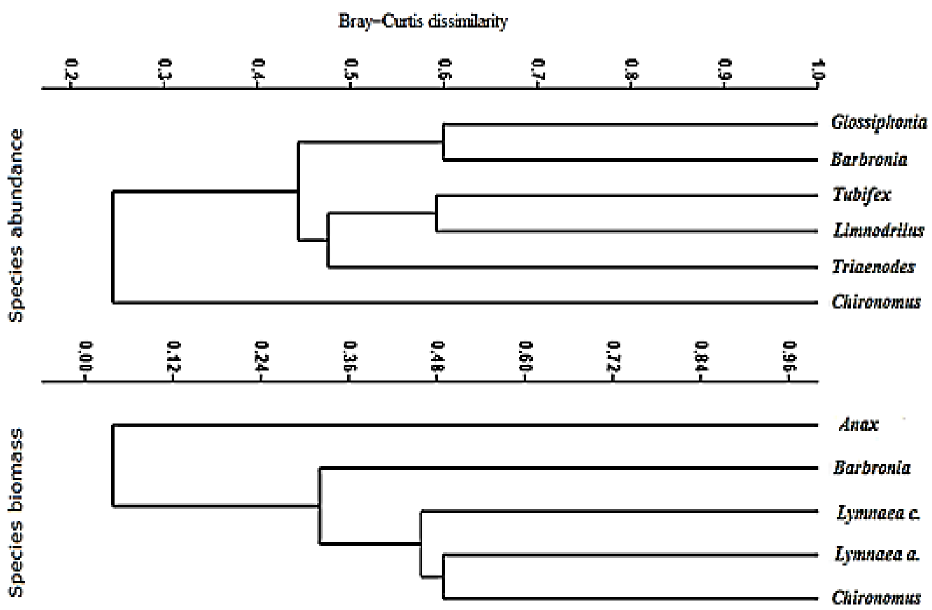

Fig. 7. Cluster analysis of macroinvertebrates community in the lake using a Bray–Curtis similarity matrix

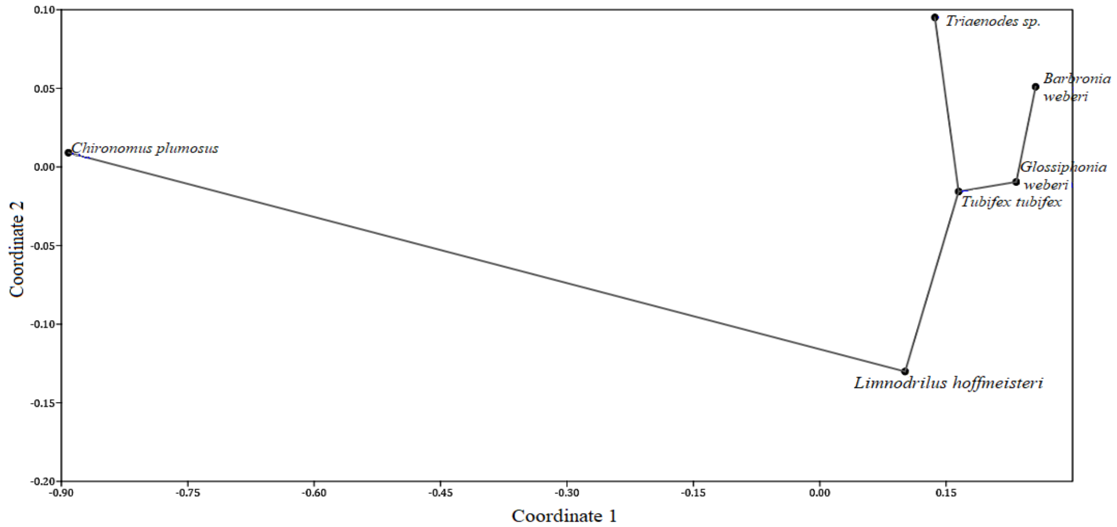

Fig. 8.nMDS analysis with minimum spanning tree of important macroinvertebratesusing Euclidean similarities matrix

The strong separation of *Triaenodes* sp. from *C. plumosus* in nMDS signifies the deterrence of sensitive species from nutrient-bound sediment and wider linkages of the food web. It is clear that although multihabitat interactions are integral to the mountain lake, sediment yields of catchment greatly influenced the diversity and food webs in the benthic habitats. Disturbance of catchment further transforms the sediment textures and disrupts the route that links benthic habitats. As the retention capacity of organic pollution in the mountain lakes generally low, the Kumaun Himalayan lakes are more vulnerable to the ascendancy of dysbiosis condition. It is imperative to evaluate the sensitivity of habitats that could provide an early insight into the occurrence of serious dysbiosis episodes.

4. Conclusions

The grain size arrangement of sediment bed affects the taxonomic richness and diversity of macroinvertebrates in the mountain aquatic ecosystem. Benthic macro-fauna highly diversifiedon stable medium-sized particles assorted with organic matters. Bathymetric macrofaunal diversity declines toward coarser sediment. The organic matter along with dissolved oxygen at NBL supports the production of macroinvertebrates biomass.

Although available food particles derived from organic matter influenced the abundance of both sensitive insects and pollution tolerant chironomids; their functional feeding and habitat preferences were quite different. This is because of the large segregation of habitats and dissociation in their food webs. The aquatic-inputs of catchment origin are crucial to the assemblage of macroinvertebrates under the mountain ecosystem. Changes in the land use pattern due to intensification of tourism in the Kumaun Himalayas could perhaps disrupt habitat structures. This study provides insight into early signals of ecological change before the abrupt shift of trophic level occurs and also identify priority efforts to protect the mountain lake.

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