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Comparing diversity of freshwater macroinvertebrate community along habitat gradients within a riverine system in North Bengal, India

Anwesha Roy and Sumit Homechaudhuri

Abstract
The main aim of the study was to estimate macroinvertebrate species diversity and overall beta-diversity with respect to interrelationship of environmental gradients-substrate types in some river streams of Jalpaiguri and Darjeeling district, West Bengal. Macroinvertebrates were collected by D-shaped net sampling-hand picking method and field measurements were recorded for one year from November 2013 to October 2014. A total of 1,500 individuals belonging to 39 families distributed in nine different study sites. The results indicated the tendency of species densities towards higher habitat substrates, air temperature and water temperature. Site Teesta, which was found to have highest beta diversity at the level of beta-dissimilarity matrix (0.8-0.89) and Whittaker beta-diversity (27.5), which was significantly negatively correlated with species density (r=-0.936), air temperature (r=-0.773) and water temperature (r=-0.878) and significantly positively correlated with sand (r=0.726) from rest of study sites. Thus habitat characteristics control macroinvertebrate species abundance and diversity.

Keywords: Macro invertebrate association, species diversity, habitat substrata, environmental variables, beta diversity, diversity-habitat interrelationship

1. Introduction

The benthic macroinvertebrate association is an important component of stream diversity, because its members are integral link between the different habitat types of streams [4]. As such, study on one of the major components of aquatic trophic structure *viz*. aquatic macro-invertebrate can provide a useful tool for measuring habitat quality.

Any environmental alteration is considered as one of most important factors of aquatic ecosystem in determination of aquatic biodiversity [35, 30]. Various studies have extensively described the significance of substratum type for the construction of stream macroinvertebrate communities [26, 27, 8, 12] and distinctive connection of trophic resources and sheltering against predation or flow disturbance [8].The usual geographical scale of stream habitats, microhabitats, watercourses and its tributary stretches incorporate their divergence at level of biotic and abiotic conditions [19, 17, 1].

Biological diversity in a particular belt is divisible into two segments. The first segment is alpha diversity which constitutes the diversity of species within sites. The second segment, beta diversity, reveals the contrast of communities along gradients or the scale of species change among sites[12]. Beta diversity is a measure of biological dissimilarities among environments. From their previous studies, the two main causes i.e. difference in environmental conditions and geographical distance, are considered as important factors in stream macroinvertebrate assemblages affecting beta diversity [12].

Another well studied effect and its importance for macroinvertebrate community is the modification of the natural flow regime. Constructions of physical barriers interrupting the riverine flow are expected to decrease macroinvertebrate diversity because they deeply vary downstream environment, especially in altitudinal rivers [32, 24]. However, development planning process is not always compatible with the conservation of this diversity. No such clear evidence relating the effects of geographical distance of North Bengal to variation of stream macroinvertebrate assemblages have been done yet. Thus proper restoration of bio resource and bio indicator of ecosystem has become challenge to the ecologists.

Biological diversity is mainly important as the river systems in North Bengal have potential hotspots of important biological resources.

Any habitat alteration would have potential to destabilize the bio resource relationship as happened in the case with many important ecosystems. The main aim of this study was:

1. Determination of taxonomic and species diversity of macro-invertebrates in some river streams in Jalpaiguri and Darjeeling district, West Bengal.
2. Analysis of the interrelationship of macro-invertebrate (aquatic insects) diversity and physico-chemical parameters.
3. Evaluation of spatial dynamics of macro-invertebrate (aquatic insects) population to understand their response to various environmental variables and types of substrata on stream bed.
4. Assessment of overall beta diversity of the aquatic habitats with regard to spatial and temporal heterogeneity for proper evaluation of the freshwater riverine ecosystem health.

The role of various environmental gradients on shaping macroinvertebrate community structure was also investigated. We also figured to find differences in habitat disparity and overall beta-diversity among sites and its relationship with habitat differentiation.

2. Materials and Methods

2.1 Study area and sampling design

Nine study sites, with different physical features (tributaries ranges from high altitude mountain sites through the forest regions) were selected randomly covering about 5200 km^2 keeping in mind the presence of diversity according to different influencing environmental parameters. The study was conducted from November 2013 to October 2014 in Jalpaiguri (26° 32' N, 88° 46' E) and Darjeeling (27° 03' N, 88° 18' E) districtin West Bengal (Figure1). Sampling was carried out from November 2013 to October 2014. At each replicative sampling site fifteen to twenty 4x4 m^2 quadrats were established randomly.

Field measurements (Table 1) were recorded for variables, viz. air temperature, water temperature and total dissolved solids (Multiparameter, HDS1014), pH (Control Dynamics pH meter, pHep HI 98107), dissolved oxygen (Dissolved Oxygen Meter, Lutton, DO-5509). Water velocity was measured at each site using locally built the floatation method at run of at least five meters along the transect. Habitat composition, which included woody debris parts and algal mat cover on the riverbed, were visually estimated by indigenous method [11, 37, 13], while percentage of bank vegetation cover was determined using a locally built densitometer. The percentage cover of different-sized substrata within each site was estimated by visual inspection using the substrate size classes [6] of sand (0.06–2 mm), fine gravel (2–32 mm), coarse gravel (32–64 mm), cobbles (64–256 mm) and boulders (256 mm).

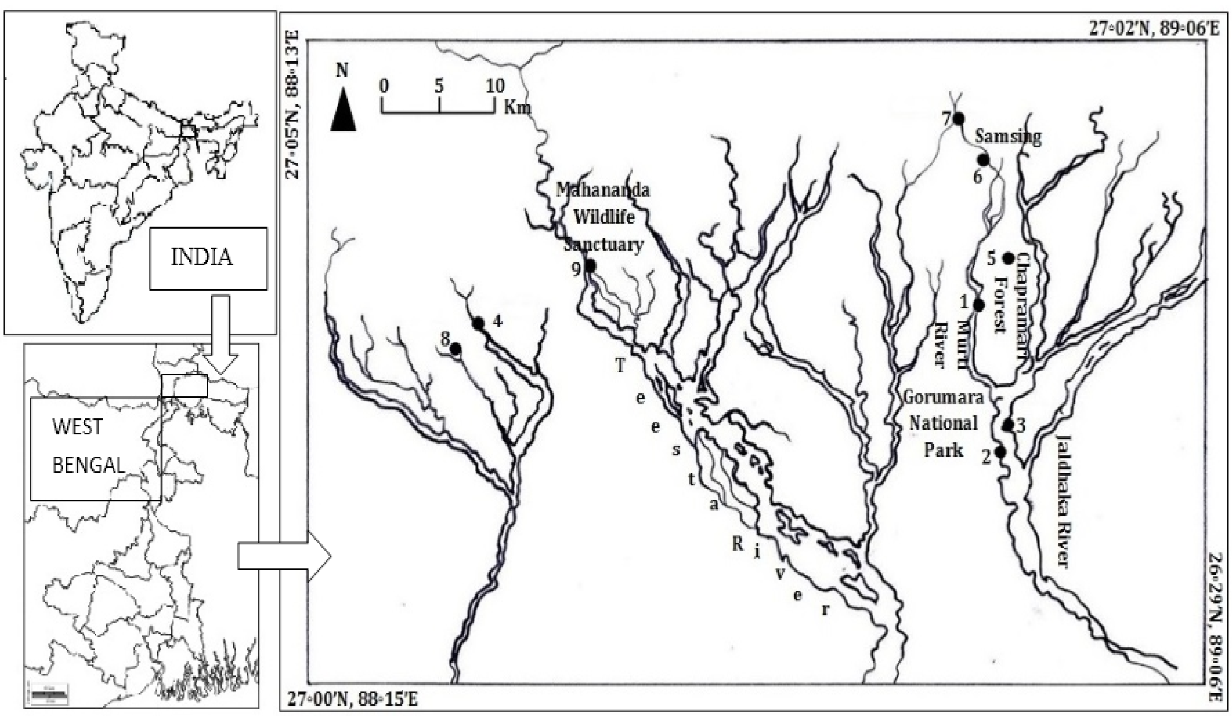

Fig 1: Map of the Darjeeling and Jalpaiguri districtshowing the locations of study sites and sampling stations marked as numbered black dots.
Note: 1=Murti Banani, 2=Murti GNP, 3=Jaldhaka GNP, 4=Mahananda River, 5=Kalikhola River, 6=Murti Samsing, 7=Murti Rocky Island, 8=Panchnoi River, 9=Teesta River

2.2. Macro-invertebrate sampling and identification

Macro-invertebrates were collected by sweeping 500-µm mesh D-shaped net and attached macro invertebrates were removed from rocks and other substrates by brushing and hand picking method[7]. All macro-invertebrates were preserved in the field in 70% ethyl alcohol. Identification of macro-invertebrate specimens in the laboratory up to family level was performed with the help of identification keys [10, 25, 5].

2.3. Data analysis

Macro-invertebrates were compared with different influencing environmental parameters at different sites. Diversity indices were used to obtain species diversity, dominance and evenness of macro-invertebrates between nine different sites (Primer version 6). In order to assess the interaction between different hydrological and physical parameters and assemblage of Macro-invertebrates, unimodal distribution of samples was used to explain the abundance of species with environmental variables (altitude, air temperature, water temperature, water current, dissolved oxygen, pH, total dissolved solids, boulders%, cobbles%, pebbles%, gravels%, sand%, woody debris%, algal mat cover%, bank vegetation cover%). Dissimilarity metrics was constructed to find the beta-diversity value between sampling sites[33]. The similarity in species composition at each site was studied by calculating the Bray-Curtis coefficient based on the fourth-root-transformed species abundance data. The result was displayed by non-metric multidimensional scaling (nMDS) plot [9]. Bray-Curtis similarity and Principal Component Analysis, a multivariate technique was used to describe the environmental dissimilarity between the sites (PRIMER-E Software (v. 6). Pearson correlation was plotted to get comparative results between macro-invertebrate abundances and environmental parameters and one way ANOVA represented significant differences between study sites according to ambient disparity between sites (SPSS version 17).

3. Results

A total of 1,500 individualsdistributed in nine different taxonomic groups belonging to 39 families were identified in different river tributaries ranges from high altitude mountain sites through the forest regions. The highest number of individuals (119) was obtained at Murti GNP, followed by Kalikhola (80), Jaldhaka GNP (79) Mahananda River (62) and Murti Banani (61). Subjected to spatial comparison Shannon diversity (2.197), Species density (18) and Species richness (4.135) were found to be highest in the site Murti Banani and lowest in Teesta River (0.7315, 4, 1.443 respectively). Teesta river represented as the highest (27.5) Whittaker Beta Index value whereas Kalikhola River and Murti Banani were found to be lowest (3.222) (Table 2). In terms of substrates and temporal factors, higher densities were observed in the cobbles, pebbles, gravels, algal mat cover, woody debris, air temperature and water temperature. Most of the environmental parameters were correlated with each other according to Pearson correlation coefficient (Table 3). Species richness (d) showed positive correlation with pebbles ($r=0.709$, $p<0.05$). Water temperature and air temperature were positively correlated with Species densities(S) ($r=0.845$, $p<0.01$), ($r=0.805$, $p<0.01$); Brilloiun index ($r=0.967$, $p<0.01$), ($r=0.849$, $p<0.01$); Shannon index (H') ($r=0.947$, $p<0.01$), ($r=0.745$, $p<0.05$)and Simpson index (1-Lamda') ($r=0.958$, $p<0.01$), ($r=0.680$, $p<0.05$) respectively but negatively correlated with Whittaker beta index ($r=-0.878$, $p<0.01$), ($r=-0.773$, $p<0.05$). Species richness (d) showed positive correlation with velocity ($r=0.846$, $p<0.01$)

Table 1: Environmental characteristics between nine different study sites (Mean SE±)

	Murti Banani	**Murti GNP**	**Jaldhaka GNP**	**Mahananda River**	**Kalikhola River**	**MurtiSamsing**	**Murti Rocky Island**	**Panchonoi River**	**Teesta River**
Alt(m)	139±0.57	357±1.73	330±5.77	664.5±0.89	528.3±0.17	1034±1.78	1762±1.15	443±0.76	465±0.57
AT(°C)	32.03±1.15	32.4±0.03	30.6±0.05	31±1.15	28.16±0.56	22.5±0.24	24.5±0.17	31.1±0.03	22.7±0.14
WT(°C)	26.6±0.05	26.85±0.58	23.9±0.54	23.8±0.57	23.89±0.003	21.5±0.26	20.7±0.11	21.5±0.02	12.9±0.03
WC(m/s)	2.66±0.005	0.95±0.01	1.13±0.07	0.95±0.06	0.324±0.01	0.36±0.009	1.2±0.14	0.024±0.0002	0.14±0.01
D.O	8.73±0.67	8.95±0.49	8.5±0.21	8.55±0.65	7.28±0.16	9.6±0.04	13±1.15	9.1±0.03	11.1±0.44
pH	8.16±0.15	8.33±0.51	7.7±0.43	9±1.15	7.8±0.11	7.6±0.17	8.8±0.51	7.2±0.05	7.4±0.03
TDS	28.16±0.57	2±0.57	2±0.05	47.5±1.12	10.4±0.26	0.004±0.001	12.25±0.14	90.3±0.54	0.002±0.001
Boulders (%)	2.66±0.09	4±1.15	4.5±0.86	5.6±0.05	57±0.57	74±0.89	72.6±0.72	3±0.03	9.9±0.26
Cobbles (%)	47.3±0.69	74.5±2.54	67.5±0.37	35±2.3	53.6±0.23	19.1±0.56	17.5±0.11	60.1±0.38	29.9±1.15
Pebbles (%)	32.64±1.23	10.06±1.09	17.5±0.86	5±1.15	26.3±0.02	4±0.13	4.5±0.2	14±0.24	10.2±0.95
Gravels (%)	10.06±1.67	7±1.15	6.5±0.49	1.5±0.2	10.4±0.05	2±0.44	3.5±0.09	19.8±0.16	25±0.57
Sand (%)	7.33±0.54	4.5±0.57	3±0.57	1±0.05	4±0.17	1±0.08	2±0.13	3±0.13	25.3±1.1
Wdy Deb (%)	10.6±0.73	33.5±1.7	26±1.15	13.5±0.86	31±0.57	1.9±0.46	1.5±0.12	25.3±0.55	0.003±0.002
AMC(%)	11±0.57	60.5±0.57	47.5±1.12	6±0.28	46.6±0.37	5±0.44	0.5±0.02	29.7±0.21	0.001±0.001
BVC(%)	15±1.15	3.5±0.77	2.5±0.11	30±1.73	94.3±0.17	5±1.34	9.5±0.28	47.1±0.38	0.002±0.001

Table 2: Diversity indices in different study sites

Diversity Indices	**Murti Banani**	**Murti GNP**	**Jaldhaka GNP**	**Mahananda River**	**Kalikhola River**	**Murti Samsing**	**Murti Rocky Island**	**Panchonoi River**	**Teesta River**
Species density (S)	18	17	12	14	17	6	13	13	4
Total individual (N)	61	119	79	62	80	23	25	44	8
Margalef's Index(d)	4.135	3.348	2.517	3.146	3.648	1.595	3.713	3.177	1.443
Shannon index (H')	2.197	2.128	1.737	1.963	1.919	1.434	1.845	1.666	0.7315
Brillouin	1.844	1.948	1.559	1.684	1.637	1.098	1.365	1.449	0.503
Whittaker's Beta Index	3.222	4.184	5.333	5.333	3.222	18	6.125	7.7692	27.5
1 Lamda	0.846	0.842	0.761	0.811	0.770	0.716	0.766	0.726	0.408

Note: The highest value of each parameter has been presented in bold

Table 3: Pearson Correlation matrix among Total abundance and physical parameters of study sites

	N	d	J'	Brillouin	Fisher	H'	1 Lamda	W Beta	Alt(m)	AT (°C)	WT (°C)	Velocity (m/s)	D.O	pH	TDS	% Bould	% Cobbles	% Pebbles	% Gravels	% Sand	Wdy Deb (%)	AMC (%)	BVC (%)
S	.549	.448	.424	.933**	.633	.931**	.831**	-.936**	-.260	.805**	.845**	.543	-.455	.455	.256	-.220	.558	.561	-.307	-.502	.641	.523	.441
N		-.322	.242	.653	-.106	.523	.512	-.576	-.309	.606	.607	-.083	-.545	.188	-.097	-.245	.762*	.049	-.301	-.405	.882**	.889**	.242
d			.277	.365	.428	.423	.335	-.296	-.372	.366	.404	.846**	-.159	.106	.099	-.271	.057	.709*	.009	.060	-.134	-.175	-.074
J'				.646	.198	.712*	.827**	-.545	.194	.273	.775*	.485	-.208	.480	-.066	.271	-.024	-.039	-.876**	-.802**	.084	.084	-.106
Brillouin					.442	.976**	.946**	-.946**	-.265	.849**	.967**	.542	-.525	.475	.222	-.243	.592	.398	-.517	-.683*	.668*	.573	.270
Fisher						.584	.475	-.602	.377	.238	.315	.529	.320	.580	.255	.181	-.104	.261	-.189	-.293	-.036	-.128	.220
H'							.972**	-.953**	-.095	.745*	.947**	.614	-.393	.577	.201	-.090	.420	.371	-.598	-.724*	.521	.424	.262
1 Lamda								-.917**	-.020	.680*	.958**	.547	-.396	.537	.197	-.002	.364	.253	-.711*	-.849**	.485	.401	.207
W Beta									.101	-.773*	-.878**	-.500	.416	-.496	-.276	.116	-.511	-.413	.501	.726*	-.632	-.518	-.391
Alt(m)										-.617	-.270	-.151	.739*	.433	-.156	.792*	-.727*	-.626	-.421	-.285	-.531	-.488	-.123
AT(°C)											.763*	.434	-.608	.218	.455	-.697*	.798**	.466	-.104	-.374	.735*	.599	.205
WT(°C)												.567	-.570	.391	.100	-.151	.539	.402	-.608	-.723*	.606	.552	.193
WC (m/s)													-.017	.489	-.109	-.225	.069	.482	-.373	-.161	-.096	-.091	-.295
D.O														.238	-.173	.360	-.638	-.556	.065	.267	-.708*	-.604	-.542
pH															-.043	.106	-.229	-.260	-.674*	-.397	-.112	-.189	-.112
TDS																-.373	.161	.062	.254	-.265	.184	-.075	.371
% Bould																	-.633	-.278	-.404	-.290	-.369	-.283	.184
% Cobbles																		.467	.173	-.133	.917**	.910**	.203
% Pebbles																			.246	.086	.380	.339	.431
% Gravels																				.774*	-.007	-.021	.110
% Sand																					-.356	-.273	-.249
Wdy Deb (%)																						.952**	.483
AMC(%)																							.303
BVC(%)																							

Note: *** Correlation is significant at the 0.01 level.* Correlation is significant at the 0.05 level.*

Abbreviations: Alt= Altitude, AT= Air Temperature, WT= Water Temperature, WC= Water Current, DO= Dissolved Oxygen, TDS= Total Dissolved Solute, WL= Water Length, % Bld= Percentage of boulders, % Peb= Percentage of pebbles, % Grav= Percentage of gravels, Wdy Deb (%)= Percentage of woody debris, AMC (%)= Percentage of algal mat cover, BVC (%)= Percentage of bank vegetation cover.

Table 4: Beta Dissimilarity Matrix of different study sites

	Murti Banani	Murti GNP	Jaldhaka GNP	MahanandaRiver	Kalikhola River	Murti Samsing	Murti Rocky Island	Panchonoi River	Teesta River
Murti Banani									
Murti GNP	0.5								
Jaldhaka GNP	0.57	0.55							
Mahananda River	0.47	0.45	0.47						
Kalikhola River	0.58	0.52	0.68	0.428					
Murti Samsing	0.66	0.64	0.61	0.57	0.72				
Murti Rocky Island	0.59	0.63	0.61	0.65	0.75	0.64			
Panchonoi River	0.76	0.57	0.68	0.65	0.8	0.64	0.63		
Teesta River	0.84	0.83	0.76	0.8	0.89	0.57	0.78	0.78	

Note: The value 0.8-1 shows high beta dissimilarity tendency

For differences between the study sites, formal significance tests for dissimilarity were performed using a dissimilarity matrix among sites obtained by computing the sample size value for all pairwise combinations of reaches [34]. The dissimilarity matrix of the nine different sites (Table4), illustrated the highest beta-diversity value (0.89) between river Teesta and Kalikhola followed by Murti (Banani)-Teesta, Murti (Gorumara National Park)-Teesta and Mahananda-Teesta(0.84, 0.83, 0.8 respectively). The significant dissimilarity value was 0.8-1. The lowest dissimilarity value was found between Mahananda and Kalikhola (0.428). S17 Bray Curtis Resemblance Matrices produced groups mostly according to macroinvertebrate sample size of the nine study sites. Two major clusters of sites were formed at the level of 40% similarity where River Teesta formed an isolated cluster andwhile seven major clusters of sites were observed considering 60% level of similarity (Fig. 2).

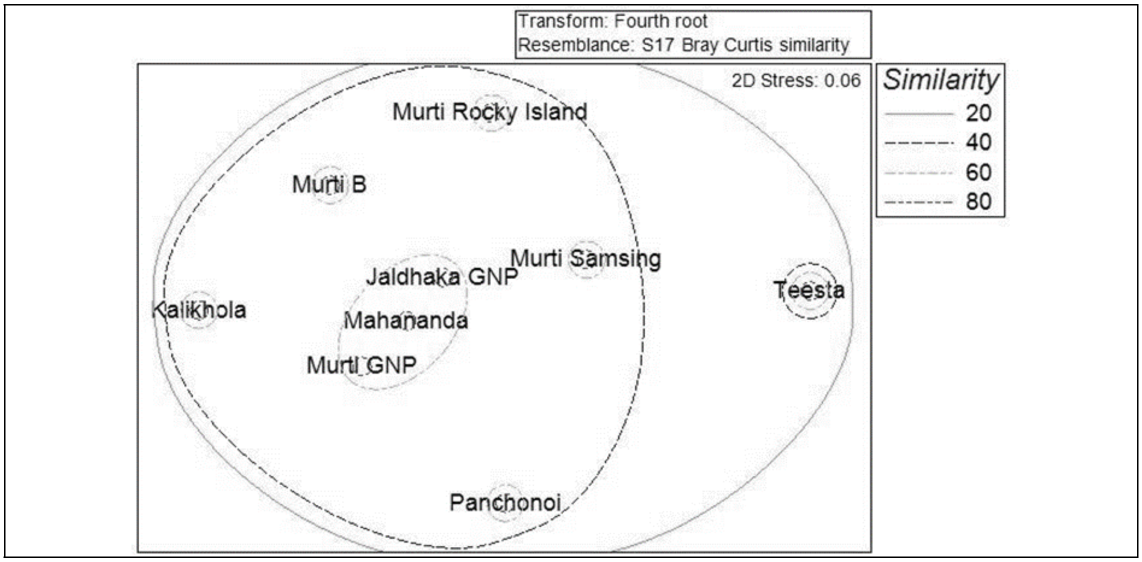

Fig 2: Two-dimensional nMDS plot of the macroinvertebrate assemblages (based on macroinvertebrate abundances) according to Bray-Curtis similarity. Stress value (2D): 0.06

The Principal Component Analysis (Fig. 3) allowed the nine study sites to be taken into account simultaneously aiming to visualise the environmental resemblance and dissimilarity within the total studied area. The plots of all the nine sites showed five principal components (PC1-PC5), with the first four components (factors) explaining 84.8% of total variation. The percentage of variation explain by each factor is presented in table 5.

Table 5: Results of principal components analyses (PCA) based on environmental condition of the nine study sites

PC axis	PC1	PC2	PC3	PC4	PC5
Eigenvalue	6.02	3.34	1.98	1.37	1.23
Proportion of variation	40.1	22.2	13.2	9.1	8.2
Cumulative variation	40.1	62.4	75.6	84.8	92.9
Eigenvectors					
Altitude (m)	0.314	-0.263	-0.208	-0.059	-0.064
Air Temp. (°C)	-0.364	-0.117	0.182	-0.217	-0.129
Water Temp. (°C)	-0.288	-0.366	0.059	0.048	0.073
Velocity (m/s)	-0.088	-0.258	0.542	0.032	0.314
D. O	0.338	-0.017	0.150	-0.046	-0.204
pH	0.050	-0.430	0.199	-0.151	-0.095
TDS	-0.119	0.049	-0.080	-0.790	-0.072
Boulders %	0.242	-0.209	-0.393	0.207	0.297
Cobbles %	-0.375	0.080	0.002	0.143	-0.246
Pebbles %	-0.257	0.095	0.140	0.071	0.627
Gravels %	-0.015	0.519	0.029	-0.146	0.029
Sand %	0.115	0.446	0.252	0.151	0.065
Wdy Deb %	-0.365	-0.020	-0.232	-.109	-0.190
AMC %	-0.329	-0.006	-0.205	0.340	-0.235
BVC %	-0.164	0.018	-0.473	-0.239	0.426

Considering this PC1 axis showed an opposition between three sites (Murti Samsing, Murti Rocky and Teesta) from six other sites (Murti Banani, Murti GNP, Jaldhaka GNP, Kalikhola River, Mahananda River and Panchonoi River). Axis PC1 clearly separated these sites on the basis of variables i.e. cobbles (-0.375), pebbles (-0.257), TDS (-0.119), BVC (-0.164), AMC (-0.329), woody debris (-0.365), air temperature (-0.364) and water temperature (-0.288). The second axis PC2 showed an opposition between two study sites (Panchonoi River and Teesta River) and seven sites (Murti Samsing, Murti Rocky, Murti Banani, Kalikhola River, Murti GNP, Jaldhaka GNP and Mahananda River) according to gravels (0.519) and sand (0.446).

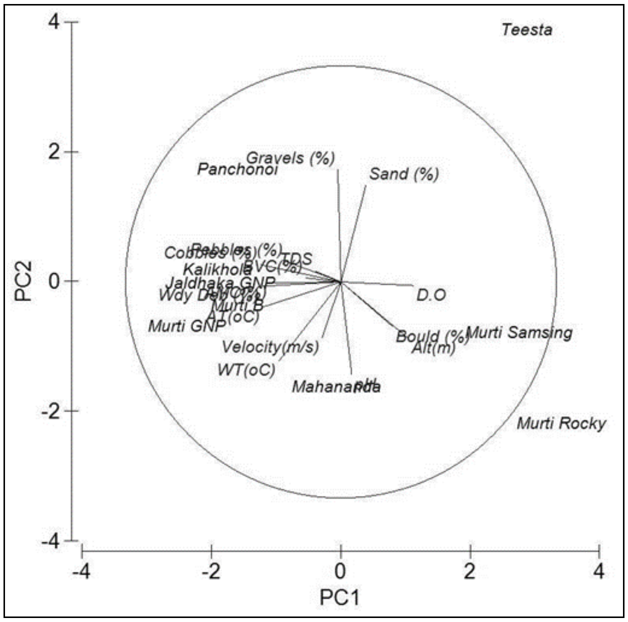

Fig 3: The PCA Graph showing environmental condition at nine study sites

Abbreviations: Alt= Altitude, AT= Air Temperature, WT= Water Temperature, D.O= Dissolved Oxygen, TDS= Total Dissolved Solid, Bould (%)= Percentage of boulders, Pebbles (%)= Percentage of pebbles, Gravels (%)= Percentage of gravels, Wdy Deb (%)= Percentage of woody debris, AMC (%)= Percentage of algal mat cover, BVC (%)= Percentage of bank vegetation cover.

One way ANOVA represented significant differences in macroinvertebrate assemblage structure and environmental condition between nine sites ($p<0.001$). Post hoc Duncan analysis revealed that altitude and species evenness were significantly different in each study sites ($p<0.05$) whereas high variability in environmental conditions across rivers also was evidenced by significant differences in habitat heterogeneity among the sites. In terms of resemblance, site 2(Murti, GNP), site 3(Jaldhaka, GNP) and site 4(Mahananda River) were not found to be significantly different according to air temperature, water velocity, dissolved oxygen, boulders percentage, species density, Whittaker beta diversity ($p>0.05$). With regard to beta diversity, site 9(Teesta River) showed highly significant difference in Whittaker beta diversity index, species density, water temperature, gravels, cobbles, boulders ($p<0.05$).

4. Discussion

A number of environmental factors such as water temperature, water velocity, substrate composition, hydro median depth and turbidity are likely to influence the diversity, abundance and larger differences in faunal composition of aquatic benthic invertebrates [36, 20]. Environmentally composite substrata such as leaves, gravel, wood and macrophytes generally support more richness than structurally simple substrates such as sand and bedrock [3]. Alteration of habitat quality leads to change of their assemblage structure [30]. Some specific types of rocky substrata such as gravel, stones provide different food resources to aquatic faunal species and support them to construct their population structure [20]. In some cases canopy type was found to be more important than substrate quality to have effect on total abundance and guild structure. It was reported that streams without shading had higher abundances of invertebrates than did shaded streams [15]. Based on these other previous studies, some contrasting results had come out and some studies also supported the present investigations.

Townsend*et al.* [31] suggested that elevated stream water currents homogenise organismal distribution on river bed, whereas [22, 23] investigated that outpouring of stream flow may drive aquatic species to disarrange insect association and some substrates (e.g. loose or fixed stones) on the stream bed. These findings supported the present investigation. Species richness (d) showed significant positive correlation with water velocity (0.846, $p<0.01$) which might help macro invertebrates to shift and concentrate in number on some particular substrata (cobbles, pebbles, woody debris).

Species growth and life history are restrained with the influence of water temperature variationin a specific temperature range[36]. Sharma *et al.* [29] represented an inverse relationship between aquatic insects and water temperature. However, these facts did not corroborate with the present study, while water temperature showed a remarkable positive correlation with species density, Brilloiun index, Shannon index, Simpson index and total abundance (0.845, $p<0.01$; 0.967, $p<0.01$; 0.958, $p<0.01$; 0.806, $p<0.01$).The high abundance of aquatic insects in higher water temperature might be due to higher growth of algae on substrates and greater number of litter patch, woody debris due to higher growth of canopy on river bed.

Dependence of spatial level of beta diversity component on substratum type appeared to be significant in most cases.In present context of the study, the beta dissimilarity value of site 9 appeared to be highest with site 5 and followed by the site 1, 2 and 4 (Table 3). One way ANOVA and Post Hoc Duncan analysis of nine study sites indicated that site 9 varied significantly ($p<0.05$) in terms of water temperature, boulders, cobbles, gravels and also species density. These faunal dissimilarities were observed to be lower among litter patches, intermediate among stonesand higher among gravel patches in the same riffle [28]. Whittaker beta diversity index value (27.5, $p<0.05$) also supported the fact of dissimilarity. In contrast, beta diversity was observed to be higher at the level of stream segments for all microhabitat types [20].

Hydrological parameters played a pivotal role to influence richness of benthic invertebrates which was supported by observations from different substrata of river bed [18]. Accordingly, Yazdian *et al.* [38] stated that different environmental variables such as DO and temperature appeared to be more important component to control macroinvertebrate diversity structure. Similarly, in the present study, air temperature, water temperature, velocity, cobbles, pebbles, woody debris, algal mat cover, bank vegetation cover were presented as PC1 which was found to deviate at site 6, 7 and 9 from the rest of study sites while sand and gravels appeared as PC2 to isolate site 8 and 9 from other seven study sites (Figure 3). ANOVA result of variety of substrata such as sand (0.202, $p>0.05$), cobbles (0.379, $p>0.05$), gravels (0.095, $p>0.05$), pebbles (0.432, $p>0.05$), boulders (0.172, $p>0.05$) led to the fact that the site 6 and 7 were to be placed together. In addition, the other substratum i.e. woody debris (0.191, $p>0.05$) also pointed to the aggregation of three sites(site 6, 7, 9). Although PC2 separated site 8 and 9 from other sites, the two sites varied significantly ($p<0.05$) in terms of gravel percentage. pH of site 8 ($p<0.05$) and sand percentage of site 9 ($p<0.05$) varied significantly from the rest of study sites.

The extent of stream macroinvertebrate community was

constructed by Bray-Curtis similarity analysis. Marchant *et al.* [21] showed that out of 10 ecoregions, 3 individual zones were deviated from other 7 zones according to macroinvertebrate composition.Similarly, in the current study of macroinvertebrate assemblage, site 2, 3 and 4 formed a separate cluster at 60% similarity (Figure 3). Site 9 showed an isolated single cluster at the level of 40% similarity which supports the Whittaker beta dissimilarity index, Beta dissimilarity matrix as well as Post Hoc Result of ANOVA.
Macroinvertebrate assemblage structure, within stream habitat discrepancy and beta diversity were significantly variable among streams. Different spatial and environmental gradients among riffles in some streams were shown to be quite divergent and also homogenous in some other streams [14, 2]. The streams of nine study sites in the rocky, forested and plain region of district Jalpaiguri and Darjeeling areimportant habitats for macro invertebrates. Benthic macro invertebrates contribute a favourable indigenous diet for most of insectivorous fishes [29].
The total riverine ecosystem is under several natural (landslides,Flash floods and sedimentation) and anthropogenic pressures (deforestation, intensification of agriculture, speeding of human settlement, soil erosion, extraction of sand, pebbles and stones in the catchment area) and these gradients have some influences on diversity and abundance of aquatic macroinvertebrate [29].
Eastern Himalayan regions perform pivotal ecological roles in maintaining the integrity of the ecosystems. Anthropogenic disturbances; habitat fragmentation and loss are causing a decline of many species at an alarming rate emphasizing the need to use macroinvertebrate as bioindicatiors. Constructions of physical barriers interrupting the riverine flow are expected to decrease macroinvertebrate diversity because they deeply vary downstream environment, especially in altitudinal rivers. However, the ecosystem requirements of biodiversity are frequently not considered in the development planning process.

5. Conclusion

Habitat heterogeneity along with different hydrological parameters influences a wide range of macroinvertebrate diversity. Correlation and ANOVA analysis between diversity indices and environmental variables viz. water and air temperature, water current, dissolved oxygen and percentage availability of algal mat cover, woody debris and bank vegetation cover revealed that the data was significant. The determinant role of the habitat characteristics in controlling macroinvertebrate species abundance and diversity has been postulated. Thus, functional diversity of macroinvertebrate would be explored further to ascertain the ecosystem services they provide.

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7. References

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