Habitat and microhabitat distribution of stream insect communities of the Western Ghats

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The diversity and distribution of stream insect communities in three habitats and 33 microhabitats were explored using data collected from 39 localities in the Western Ghats. The diversity and abundance of taxa vary across habitats. The microhabitat richness was positively correlated and altitude negatively correlated with taxa richness in the cascades and riffles. In pools and cascades, per cent canopy cover and average annual rainfall were both positively correlated with taxa richness. Structurally complex microhabitats harboured more taxa than the unstable and detritus poor microhabitats. The importance of habitat and microhabitat distribution in understanding the spatial distribution of stream insects and developing biomonitoring tools is discussed.

Keywords: Biomonitoring tools, habitat and microhabitat distribution, stream insects, Western Ghats.

THE habitats for aquatic insect communities in riverine ecosystems can be visualized within the framework of various spatio-temporal scales. They range in size from particles few millimetres across to the entire drainage basin. Temporally, changes in the habitats can be visualized from days to thousands of years. The permanence of the physical structures of the habitats varies with the spatial scale. This ranges from a few days for individual microhabitats to thousands of years for the drainage network[1]. Insect communities of the lotic system respond to this spatio-temporal variation as well. This response is more pronounced at an intermediate scale, the pool–riffle sequence. This sequence is denoted as habitat for the present study. The pool-riffle sequences extend from a few metres to hundreds of meters and persist for ten to hundreds of years[1]. The most common stream habitats within the pool-riffle sequence are cascades, riffles and pools. Cascades are habitats where the water flows turbulently through boulders and cobbles. Due to its physical structure, woody debris and litter get collected in the cascades. The riffle is a stretch of stream where the water flows with little turbulence over gravel and sand. Pools are habitats with minimum water flow and least turbulence[2].

Previous studies have shown that these habitats show a great variation in aquatic invertebrate diversity. For example, in the stable streams of New Zealand, riffles had higher taxa richness than pools, but there was no difference between the habitats in an unstable stream[3]. However, in a review of seventeen studies, there was no significant difference in taxa richness in pools and riffles[4]. In contrast, studies on temperate streams did find a significant inter-habitat variation[5–7].

Experimental studies on organism–substrate interactions show that the diversity and abundance of benthic invertebrates increase with median particle size[1]. However, experiments suggest that the diversity declines with increase in size of cobbles[8]. Furthermore, results from single-substrate studies were not adequate to predict the diversity of heterogeneous substrates[1]. These studies indicate that substrate stability and the amount of trapped detritus are important in determining the diversity and abundance of benthic invertebrates. The role of detritus in influencing the diversity and abundance of aquatic invertebrates is well demonstrated[1,9–11]. Experimental studies demonstrate that leaf litter is primarily used as a source of food rather than a refuge[12,13]. In addition to detritus, silt is found to benefit some species. However, in higher proportion, silt alters the substrate leading to a change in the community composition[1].

Field and experimental studies from various biomes show that diversity and community structure of stream insects could be largely influenced by habitat and microhabitat characteristics. Earlier studies on the stream insect communities of peninsular India documented the broad community patterns[14–16]. However, these studies did not address the diversity profiles of stream insects across habitats and microhabitats (substrates). This is a serious lacuna because documenting the diversity and community structure of stream insects at different spatial scales is important to design and monitor stream conservation measures. This could also provide crucial insights in understanding the community structure of stream insects at higher spatial scales. The present study aims at documenting the diversity and distribution pattern of aquatic insect communities in three major habitats (cascades, riffles and pools) and 33 microhabitats (Appendix 1) in the Western Ghats. It also discusses the implication of diversity profiles of the habitats in designing biomonitoring tools for the riverine ecosystems of the region.

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Methods

Study sites and sampling design

Aquatic insects were sampled from 39 localities in the Western Ghats (Figure 1; and Appendix 2). Stream insect communities were collected from August 1999 to February 2002. Previous studies have shown that aquatic insects are best sampled in the Western Ghats during this period[16]. At each sampling locality, a stretch of approximately 100–150 m was chosen for collection of samples from the three target habitats – cascades, low gradient riffles and pools. In addition to biological sampling, eight environmental variables were also recorded for each sampling session (Table 1). In cascades, where the water flows through boulders and cobbles with high turbulence, an 'all out search' method was used to collect aquatic insects.

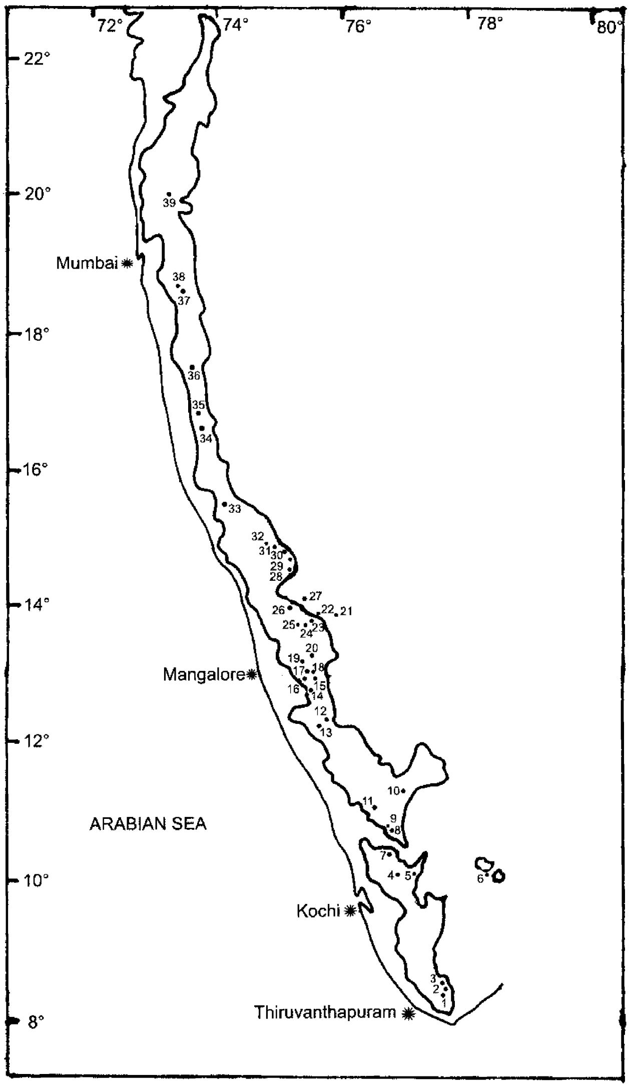

Figure 1. Location of study sites in the Western Ghats. For details of study sites see Appendix 2.

The effort in sampling in cascades was standardized by restricting the collection of aquatic insects from an area of 10 m^2 for 1 h. Within the sampling area, aquatic insects were searched and collected from substrata such as bedrocks, boulders, cobbles, leaf litter and dead wood. In low-gradient riffles, aquatic insects were sampled by taking three 1-minute kick-net samples (mesh size: 180 µm; net area 1 m^2). The methodology for sampling aquatic insects in this habitat has been standardized in the Western Ghats[16]. Aquatic insects on water surface of the pools were collected with a nylon pond net (mesh size: 500 µm; diameter: 30 cm; depth: 15 cm). An 'all out search' method was employed to collect aquatic insects from the substratum in the pools. Collected samples were preserved in 70% ethanol and assigned to family and genus using taxonomic keys for that particular group[17–23].

All the genera encountered during the study were assigned a functional feeding group category[24,25]. A taxon is assigned to a functional feeding group based on mode of food acquisition and nature of the food resource. This grouping reflects both convergent and parallel evolution leading to functionally similar organisms[24]. The three habitats were categorized into 33 microhabitats based on physical characters (Appendix 1). The microhabitat occupancy of a genus (presence–absence) was determined while sampling. Abundance of taxa within a microhabitat was not determined for the study.

Analysis

The distribution of family and genera across the habitats was measured as number of unique and shared taxa across the habitats and was depicted as Venn diagrams. Since the sample sizes were unequal, rarefied family and generic richness at 0.01 confidence interval was estimated using unbiased version of the rarefaction formula[26]. In addition, alpha or point diversity and beta or differentiation diversity were measured using Shannon, Simpson's and Jaccard's indices[27]. The environmental correlates of family and generic richness in cascades, riffles and pools were investigated using Spearman rank order correlation[28].

The abundance and functional group distribution of aquatic insects across the habitats was investigated using $\log_{10}$ transformation of the abundance. The presence–absence data of 85 genera were used to investigate distribution and richness across microhabitats.

Results

Habitat distribution

Diversity: A total of 15,260 individuals belonging to 12 orders, 59 families and 94 genera were collected during the study. Of these, 14,824 individuals were assigned to genera, 406 to families and the remaining 30 to orders. These

Table 1. Environmental variables used in the study

Variable	Measure	Description
Altitude	Metres	Metres above sea level
Microhabitat	Richness	Sum of presence of substrates: mud, sand, gravel, cobble, boulder, bedrock, leaf litter and peat
Width	Centimetres	Average stream width
Depth	Centimetres	Average stream depth
Canopy cover	Per cent canopy cover	Per cent area shaded by riparian vegetation
Temperature	°Celsius	Mid-column water temperature
pH	pH	Using Qualigens narrow-range pH paper
Turbidity	Ranking 0–3	Rank 0 is the least and 3 the most turbid

Table 2. Distribution of alpha diversity of taxa across habitats

			Diversity	
Taxon	Habitat	Rarefied richness	Simpson's	Shannon
Family				
	Cascades	50	0.91	2.84
	Riffles	42	0.79	2.27
	Pools	29	0.67	1.53
Genera				
	Cascades	71	0.94	3.30
	Riffles	57	0.84	2.64
	Pools	42	0.71	1.85
Ephemeroptera (mayflies)	Cascades	14	0.82	1.88
	Riffles	13	0.70	1.64
	Pools	8	0.66	1.38
Hemiptera (bugs)	Cascades	17	0.89	2.47
	Riffles	12	0.90	2.30
	Pools	9	0.80	1.84
Trichoptera (caddisflies)	Cascades	16	0.78	1.92
	Riffles	14	0.37	0.93
	Pools	10	0.11	0.33
Non-EHT*				
	Cascades	27	0.87	2.46
	Riffles	24	0.87	2.42
	Pools	22	0.86	2.41

*Indicates stream insects other than Ephemeroptera, Hemiptera and Trichoptera.

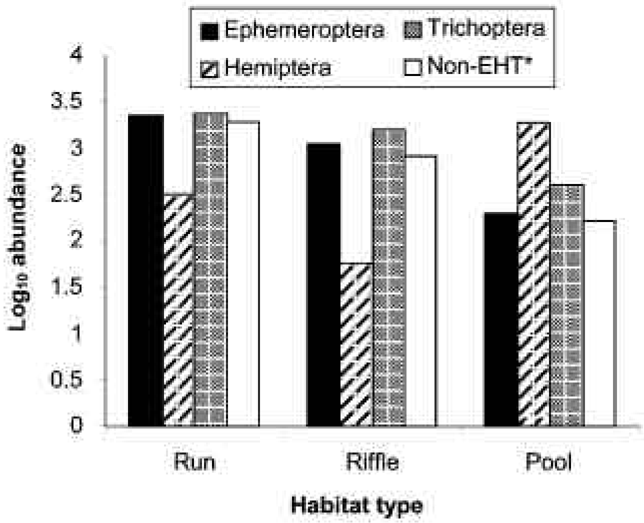

Figure 2. Abundance of aquatic insects across habitat types. *Indicates stream insects other than Ephemeroptera, Hemiptera and Trichoptera.

94 genera were classified into five functional feeding groups. At the level of family and genera, the rarefied richness, Simpson's and Shannon indices were highest for the cascades and lowest for the pools. This pattern remained unchanged even when insect orders such as Ephemeroptera (mayflies), Hemiptera (bugs), Trichoptera (caddisflies) and others were considered separately (Table 2).

The $\log_{10}$ abundance of Ephemeroptera, Trichoptera and other insects was highest in the cascades, followed by riffles and pools. On the other hand, the $\log_{10}$ abundance of Hemiptera peaked in the pools (Figure 2). The distribution of taxa across habitats shows that 30 families and 40 genera were common to all the habitats, and only 13 families and 25 genera were restricted to one habitat. The maximum number of unique families and genera was found in cascades. There was no family unique to the pools (Figure 3 *a* and *b*). Taxa turnover across the habitats shows that cascades and riffles are very similar in composition than pools. Cascades and riffles share about 71% of the families and 65% of the genera. However, cascades and pools share 59% of the families and 55% of the genera. Similarly, riffles and pools share 63% of the families and 53% of the genera.

Functional feeding group organization: In general, the abundance of all functional feeding groups was high in the cascades and low in pools. However, the abundance of macrophyte piercers was highest in pools and lowest in riffles (Figure 4). Across habitats, the abundance of functional feeding groups changes. In all the habitats, collectors, scrapers and predators dominate. Functional groups such as macrophyte piercers and shredders were least dominant.

Environmental correlates of diversity: In cascades and riffles, microhabitat richness was significantly positively correlated with family and generic richness (cascades: $N = 127$; $r = 0.202$ (family), $r = 0.216$ (genera); Riffles:

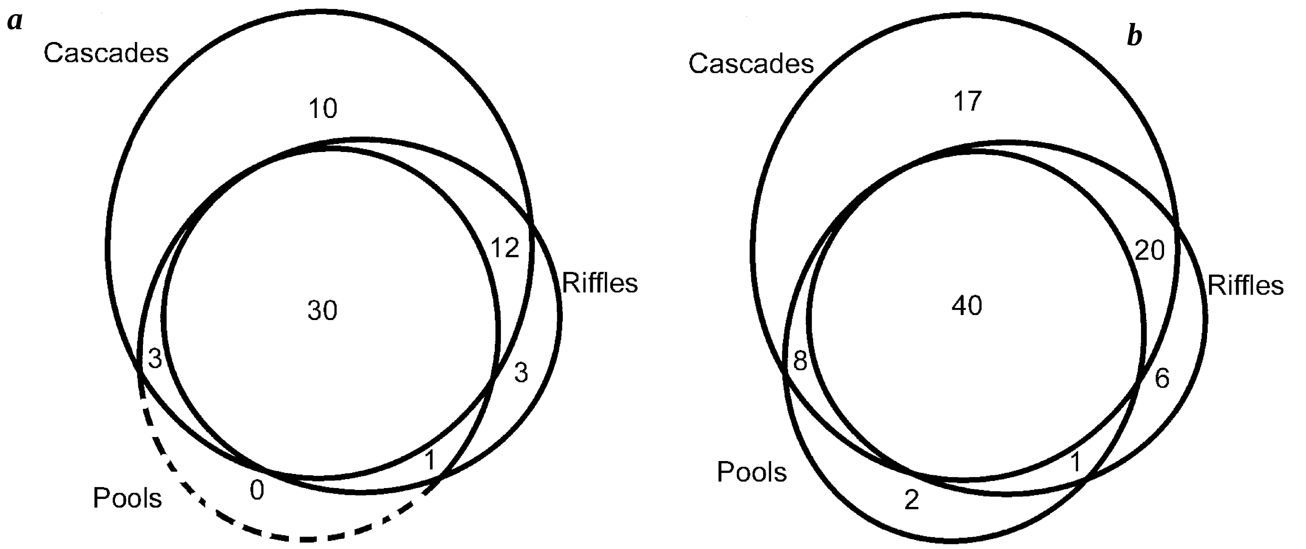

Figure 3. Venn diagram depicting family richness (***a***) and generic richness (***b***) across habitats.

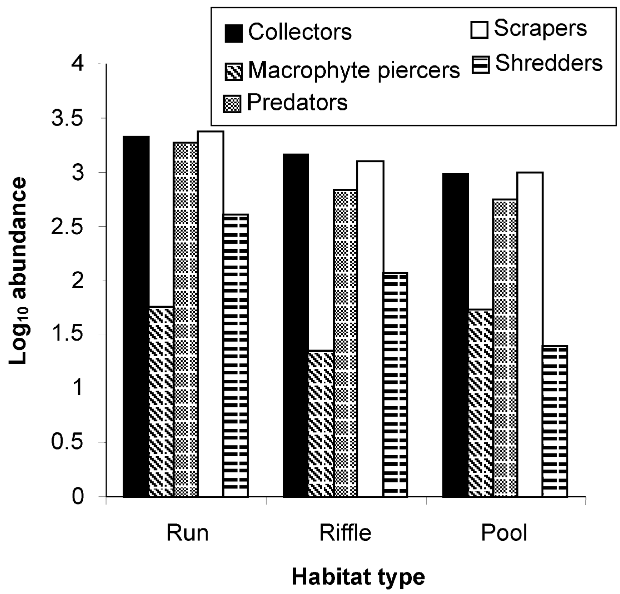

Figure 4. Abundance of functional feeding groups across habitats.

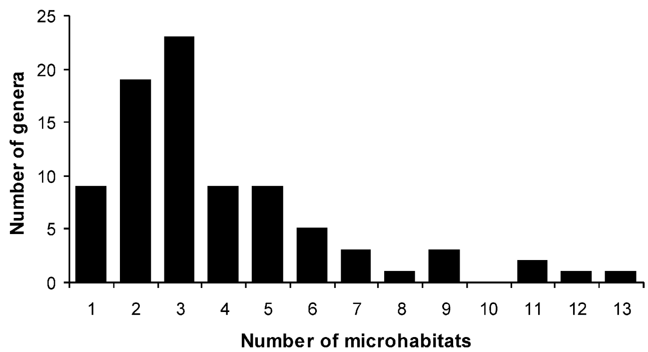

Figure 5. Frequency distribution of genera across microhabitats.

$N = 62$, $r = 0.383$ (family), $r = 0.343$ (genera); $P = <0.05$). On the other hand, in cascades and pools, the average annual rainfall and per cent canopy cover were respectively, significantly positively correlated with taxa richness (cascades: $N = 127$, $r = 0.232$ (family), $r = 0.304$ (genera); pools: $N = 46$; $r = 0.389$ (family), $r = 0.305$ (genera); $P = < 0.05$). Variables such as number of dry months and altitude in riffles ($N = 62$; no. dry months: $r = -0.431$ (family), $r = -0.40$ (genera); altitude: $r = -0.40$ (family), $r = -0.388$ (genera); $P = < 0.05$), and altitude in cascades ($N = 127$; $r = -0.222$ (family), $r = -0.237$ (genera); $P = < 0.05$) showed a significant negative correlation with taxa richness (Table 3).

Microhabitat distribution

Diversity: The frequency distribution of genera in 33 microhabitats shows that only nine genera occupy one microhabitat (Appendix 1). About 42 genera occupy two or three microhabitats and 34 genera are present in more than three microhabitats. Genera such as *Thraulus* (Ephemeroptera: Leptophlebiidae), *Mesovelia* (Hemiptera: Mesoveliidae), *Heleocoris* (Hemiptera: Naucoridae) and *Smicridea* (Trichoptera: Hydropsychidae) were restricted to one microhabitat. On the other hand, genera such as *Cybister* (Coleoptera: Dytiscidae), *Isca* (Ephemeroptera: Leptophlebiidae), *Hydropsyche* (Trichoptera: Hydropsychidae), *Petersula* (Ephemeroptera: Leptophlebiidae), *Choroterpes* (Ephemeroptera: Leptophlebiidae) and *Baetis* (Ephemeroptera: Baetidae) were present in five or more microhabitats (Figure 5).

The richness of genera in microhabitats varies within the cascades, riffles and pools. In the cascades, 41 and 29 genera were found among cobbles and trapped litter res-

Table 3. Correlation of family and generic richness with environmental variables across habitats. Marked (*) correlations are significant at $P < 0.05$ (Spearman rank order correlation)

Habitat		ALT	WID	DEP	MHR	CNC	TEM	pH	TUR	NDM	ARF
Cascade (*N* = 127)	Family	–0.222*	0.174	–0.089	0.202*	–0.166	0.094	0.061	–0.128	–0.092	0.232*
	Genera	–0.237*	0.171	–0.110	0.216*	–0.164	0.078	0.031	–0.133	–0.077	0.304*
Riffle (*N* = 62)	Family	–0.400*	–0.058	–0.173	0.383*	0.068	–0.075	–0.085	0.070	–0.431*	0.205
	Genera	–0.388*	–0.037	–0.159	0.343*	0.053	–0.082	–0.059	0.043	–0.400*	0.159
Pool (*N* = 46)	Family	0.179	0.143	–0.155	0.079	0.389*	0.099	0.139	–0.127	0.084	–0.116
	Genera	0.113	0.230	–0.039	0.192	0.305*	0.143	0.185	–0.109	0.118	–0.007

ALT, Altitude (m); WID, Width (m); DEP, Depth (m); MHR, Microhabitat richness; CNC, Canopy cover; TEM, Temperature (°C); TUR, Turbidity; NDM, Number of dry months; ARF, Annual average rainfall (mm).

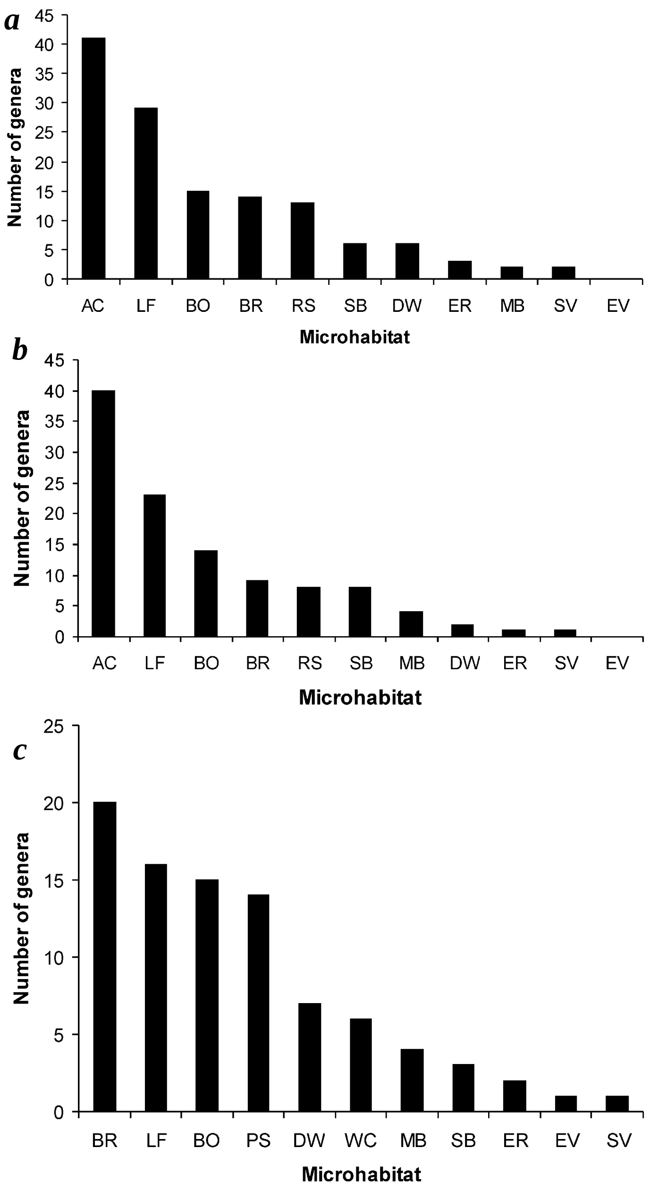

Figure 6. Generic richness across microhabitats in cascades (***a***) riffles (***b***) and pools (***c***). AC, Among cobbles; BR, Bedrock; LF, Leaf litter; BO, Boulder; PS, Pool surface; RS, Run/riffle surface; DW, Dead wood; WC, Water column; MB, Muddy bottom; SB, Sandy bottom; ER, Emergent rock; EV, Emergent vegetation; SV, Submerged vegetation.

pectively. Microhabitats such as sand, dead wood and emergent vegetation were very poor. Similarly in the riffles, high richness was observed among cobbles and trapped litter. However, in the pools, high richness was among bedrock and trapped litter. The pool surface, unlike the run and riffle surfaces, was rich in taxa. Most of the pool surface taxa comprise genera from Gerridae, Veliidae (Hemiptera) and Gyrinidae (Coleoptera). The generic richness across microhabitats in the cascades, riffles and pools is given in Figures 6 *a–c* respectively.

Discussion

Our study demonstrates that in the Western Ghats, aquatic insect diversity within a habitat is determined by the interplay of intrinsic habitat and extrinsic environmental parameters. At the scale of habitat, taxa vary in abundance and diversity. In general, the abundance and diversity of taxa were highest in the cascades (Table 2 and Figure 2). The high diversity of benthic macroinvertebrates in cascades was known from previous studies. Cascades also had maximum number of restricted families and genera (Figure 3 *a* and *b*). The high diversity in cascades is attributed to the habitat complexity, stability and food availability[1,10]. Cascade, because of its complex habitat structure, traps litter and woody debris. This decaying organic source and shelter in turn promotes colonization of insects. Across taxa, abundance and diversity vary with habitat. Hemiptera was most abundant in pools and cascades, whereas rarefied richness was high only in cascades (Table 2 and Figure 2). The low abundance and diversity of Hemiptera in riffles can be attributed to the physical structure of the habitat. Since aquatic Hemiptera live predominantly on still water surface, the turbulent nature of riffles may not suit them[24]. It is interesting to note that large hemipterans such as *Limnogonus* and *Amemboa* (Gerridae) are more frequent in pools. On the other hand, small hemipterans such as *Rhagovelia*, *Perittopus* (Veliidae) and *Mesovelia* (Mesoveliidae) were more frequent in cascades. Further studies are required to understand the distribution pattern of different genera across habitat.

The family and genera turnover across the habitats clearly demonstrate that cascades and riffles were similar in community composition than pools. This similarity was due to the presence of genera such as *Hydropsyche*, *Laccobius* (Coleoptera: Hydrophilidae), *Choroterpes*, *Petersula*, *Epeorus* (Ephemeroptera: Heptageniidae) and *Neoperla* (Plecoptera: Perlidae), which were adapted to fast-flowing waters. Stream insect communities respond to habitat morphology[10,25]. The community organization observed across habitats in the present study may reflect the different habitat morphologies of cascades, riffles and pools.

The functional feeding group organization of the stream insects shows variation across habitats. The abundance of functional groups increases in the cascades, owing to an overall increase in the abundance and diversity of the stream insects. Collectors and scrapers decrease in abundance from the cascades to the pools (Figure 4). Genera such as *Hydropsyche*, *Helicopsyche* (Trichoptera: Helicopsychidae), *Neoperla*, *Epeorus*, *Petersula* and *Glossosoma* (Trichoptera: Glossosomatidae) represent the collectors and scrapers in cascades and riffles. These genera feed mainly on the algae growing on cobbles and boulders. They cling to the substrate and are adept to life in fast-flowing waters[24,25]. Shredders such as *Anisocentropus* (Trichoptera: Calamoceratidae) were most abundant in cascades (Figure 4), being attracted by trapped leaf litter and woody debris. Predators belonging to the genus *Rhagovelia* (Hemiptera: Veliidae) dominate the cascades. Predators are less dominant in pools; they belong to genera like *Aquarius*, *Limnogonus*, *Meterocoris* (Hemiptera: Gerridae) and *Dineutus* (Coleoptra: Gyrrinidae). Most of these predators are skaters and are adapted to a life on the pool surface.

The role of small-scale spatial heterogeneity in determining the diversity of benthic invertebrates has been recorded[17]. However, studies on the Western Ghats and other tropical Asian streams[14,17,25] did not address the functional feeding group organization of the communities across heterogeneous habitats. The present study shows that the distribution of functional feeding groups changes with the habitat. Spatial configuration of the habitat and its relative abundance at any particular stretch of a stream may influence the diversity and functional feeding group organization of the stream insect communities. This variation in functional group distribution across habitats may have significant implications in understanding the longitudinal changes in stream insect communities discussed in the river continuum concept[29]. However, the importance of habitat heterogeneity in determining the longitudinal zonation of stream communities is not systematically investigated in tropical streams.

Investigations on the role of various factors in determining the diversity of aquatic insects demonstrate that both intrinsic habitat parameters and extrinsic environmental variables play a role. In habitats such as cascades and riffles, extrinsic factors such as altitude and average annual rainfall, and an intrinsic factor, the microhabitat richness influence diversity. However, in pools only one extrinsic factor, per cent canopy cover had significant positive correlation with diversity. The significant positive correlation between microhabitat richness and taxa diversity is consistent with earlier observations. It is known that habitat complexity increases species diversity in many groups of organisms, including aquatic insects[30–36]. The significant correlation between microhabitat richness and taxa diversity in cascades and riffles reaffirms the earlier observation that structurally complex habitats promote high diversity[1,10]. The influence of increasing altitude in decreasing the diversity of stream insects was also well established[9,35,37–44]. At a global scale[44], low diversity in high-altitude streams is attributed to factors such as short ice-free periods, low allochthonous inputs, and severe habitat conditions at elevations > 3000 m. However, in the Western Ghats, where snow cover or extremely low temperature is absent, factors other than low allochthonous input may not be relevant in decreasing diversity with increasing altitude. Per cent canopy cover could promote high diversity in pools by contributing more allochthonous input in the form of leaf litter. Since we have not quantified allochthonous input in different habitats, it is not yet clear from the present study how per cent canopy cover contributes towards high diversity in the pools.

Across 33 microhabitats, the frequency distribution of the genera shows that most them are confined to a few microhabitats (Figure 5). In general, high richness is observed in leaf litter, cobbles and bedrocks (Figures 6 *a–c*). The importance of substratum in determining species distribution and richness in streams has been known for a long time[1,10]. This high diversity in cobbles, leaf litter and bedrock is attributed to substrate stability and the availability of food and shelter[1]. The importance of litter or detritus in enhancing species richness is known from an earlier work[47]. This was later demonstrated in tropical and temperate streams[1,10,11]. Experimental studies from tropical Asian and Australian streams demonstrate that leaf litter was primarily used as a source of food rather than refuge[12,13]. Low diversity observed in microhabitats such as sand and mud was also reported in previous works. Low diversity in such habitats is attributed to its instability, and because of tight packing of sand grains, the available oxygen and detritus is limited[1,10]. In general, the observed generic richness of stream insects across microhabitats is in agreement with other studies on tropical and temperate streams.

Variation in the diversity and distribution of aquatic insects across habitats and microhabitats reported in the present study, has importance in understanding the spatial distribution of aquatic insect communities and in developing biomonitoring methods. Since the diversity of aquatic insects varies across habitats, the relative abundance and spatial configuration of habitats can determine the diversity of stream stretches and drainage basins. Extrinsic factors such as altitude and average annual rainfall interact with

Appendix 1. Distribution of genera across microhabitats

		Microhabitat																																
		Pool											Riffle											Cascade										
Family	Genera	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Baetidae	*Baetis*	–	–	–	–	–	–	–	–	+	+	–	–	+	+	–	–	–	–	–	–	+	+	–	+	+	–	–	–	–	+	–	+	+
Caenidae	*Caenis*	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–
Ephemerellidae	*Teloganodes*	–	–	–	–	+	+	–	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	+	–	–	–
Heptageniidae	*Ecdyonurus*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	+	–	–	–
Heptageniidae	*Epeorus*	–	–	–	–	+	+	–	–	–	–	–	–	+	+	–	–	–	+	+	–	–	–	–	+	+	+	–	–	–	+	–	–	+
Heptageniidae	*Thalerosphyrus*	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	+	+	–	–	–	–	–	+	+	–	–	–	+	–	–	–
Oligoneuridae	*Isonychia*	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Leptophlebiidae	*Choroterpes*	–	–	–	+	–	–	–	–	–	–	–	–	+	+	+	–	–	+	+	–	–	–	–	+	+	+	+	–	+	+	–	–	+
Leptophlebiidae	*Edmundsulla*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Leptophlebiidae	*Indialis*	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Leptophlebiidae	*Isca*	–	–	–	+	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Leptophlebiidae	*Notoplebia*	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Leptophlebiidae	*Petersula*	–	–	–	–	+	+	–	–	–	–	–	–	+	+	–	–	–	–	+	–	–	+	–	+	+	+	–	–	–	+	–	+	+
Leptophlebiidae	*Thraulus*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polymitracyidae	*Povilla*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+
Potamanthidae	*Rheonanthus*	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Trichorythidae	*Neurocaenis*	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Calopterygidae	*Calopterygidae**	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chlorocyphidae	*Rhinocypha*	–	–	–	+	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Cordulidae	*Cordulidae**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Euphaeidae	*Euphaea*	–	–	–	+	–	–	–	–	–	+	–	–	+	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Gomphidae	*Gomphidae**	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	+	–	–	–
Gomphidae	*Lamelligomphus*	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Libellulidae	*Libellulidae**	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Protoneuridae	*Protoneuridae**	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Perlidae	*Neoperla*	–	–	–	+	+	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Blaberidae	*Blaberidae**	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Tetrigidae	*Scelimenia*	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–

Contd…

Appendix 1. (*Contd..*)

			Microhabitat																																
			Pool											Riffle											Cascade										
Order	Family	Genera	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Hemiptera (bugs)																																			
	Corixidae	*Micronecta*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gerridae	*Amemboa*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gerridae	*Aquarius*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gerridae	*Cylindrostethus*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gerridae	*Limnogonus*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gerridae	*Metrocoris*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gerridae	*Ptilomera*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gerridae	*Tenagogonus*	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Hebridae	*Timasius*	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Mesoveliidae	*Mesovelia*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Naucoridae	*Heleocoris*	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Naucoridae	*Naucoris*	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
	Notonectidae	*Enithares*	+	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Notonectidae	*Nychia*	+	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Pleidae	*Paraplea*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
	Veliidae	*Rhagovelia*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Veliidae	*Perittopus*	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Megaloptera (alderflies)																																			
	Corydalidae	*Corydalidae**	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Coleoptera (beetles)																																			
	Curculionidae	*Curculionidae**	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
	Dytiscidae	*Cybister*	+	–	–	–	–	–	–	–	–	–	+	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Dytiscidae	*Hydaticus*	–	–	–	–	+	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Dytiscidae	*Laccophilus*	–	–	–	–	+	+	–	–	–	–	+	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
	Dytiscidae	*Sandracottus*	–	–	–	–	+	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Elmidae	*Leptelmis*	–	–	–	+	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Elmidae	*Stenelmis*	–	–	–	+	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Ephydridae	*Ephydridae**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	+	–	–	+	+	–	–	–	–	–
	Gyrinidae	*Dineutus 1*	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Gyrinidae	*Dineutus 2*	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
	Haliplidae	*Haliplidae*	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Hydrophilidae	*Laccobius*	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
	Noteridae	*Noteridae**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
	Psephenidae	*Eubrianax*	–	–	–	–	+	+	–	–	–	–	–	–	–	+	–	–	–	+	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–
	Psephenidae	*Psephenidae**	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–
	Staphylinidae	*Staphylinidae**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–

Contd…

Appendix 1. (*Contd..*)

Order	Family	Genera	Microhabitat: Pool 1	2	3	4	5	6	7	8	9	10	11	Riffle 12	13	14	15	16	17	18	19	20	21	22	Cascade 23	24	25	26	27	28	29	30	31	32	33
Trichoptera (caddisflies)																																			
	Calamoceratidae	*Anisocentropus*	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
	Glossosomatidae	*Agapetus*	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
	Glossosomatidae	*Glossosoma*	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
	Helicopsychidae	*Helicopsyche*	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	+	+	–	–	–	–	–	+	+	–	–	–	–	–	–	–
	Hydropsychidae	*Hydropsyche*	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	+	–	–	–
	Hydropsychidae	*Leptonema*	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	+	–	–	–
	Hydropsychidae	*Macronema*	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–
	Hydropsychidae	*Smicridea*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Hydroptilidae	*Hydroptilidae**	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Lepidostomatidae	*Goerodes*	–	–	–	+	–	–	–	–	–	+	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+
	Goeridae	*Goera*	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
	Limnephilidae	*Moselyana*	–	–	+	–	+	+	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–
	Philopotamidae	*Chimarra*	–	–	–	+	+	+	–	–	–	+	–	–	+	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	+	–	–	–
	Philopotamidae	*Wormaldia*	–	–	–	+	+	+	–	–	–	+	–	–	+	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	+	–	–	–
	Polycentropodidae	*Polycentropus*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
	Rhyacophilidae	*Rhyacophila*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
	Stenopsychidae	*Stenopsyche*	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	+	–	–	–
Lepidoptera (moths)																																			
	Pyralidae	*Aulocodes*	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	+	–	–	+	+	–	–	–
Diptera (flies)																																			
	Blephariceridae	*Philorus*	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	–
	Chironomidae	*Chironomidae**	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
	Simuliidae	*Simulium*	–	–	–	+	+	+	–	–	–	–	–	–	+	+	–	–	–	+	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–
	Tabanidae	*Tabanidae**	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
	Tipulidae	*Tipulidae**	–	+	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–

1, Pool surface; 2, Muddy bottom; 3, Sandy bottom; 4, Litter -filled; 5, Bed rock; 6, Boulder; 7, Emergent rock; 8, Emergent vegetation; 9, Submerged vegetation; 10, Deadwood; 11, Water column; 12, Riffle surface; 13, Trapped litter; 14, Among cobble; 15, Sandy bottom; 16, Muddy bottom; 17, Emergent rock; 18, Bed rock; 19, Boulder; 20, Emergent vegetation; 21, Submerged vegetation; 22, Deadwood; 23, Cascade surface; 24, Trapped li t-ter; 25, Among cobble; 26, Bed rock; 2 7, Sandy bottom; 28, Muddy bottom; 29, Emergent rock; 30, Boulder; 31, Emergent vegetation; 32, Submerged veg etation; 33, Deadwood.
*Identification only up to family level.

Appendix 2. Details of sampling localities in the Western Ghats

Sl. No.	Site	District	State	River basin	Altitude (m)	Latitude (°N)	Longitude (°E)	AARF (mm)	NDM
1	Neyyar	Trivandrum	Kerala	Neyyar	635	8.58	77.22	2500	2
2	Aghastyamalai	Trivandrum	Kerala	Karamana	333	8.67	77.15	2500	2
3	Bonnacaurd	Trivandrum	Kerala	Neyyar	892	8.68	77.20	2500	2
4	Thatekkad	Ernakulam	Kerala	Periyar	146	10.10	76.72	2500	3
5	Eravikulam	Idukki	Kerala	Cauvery	2350	10.13	77.09	3594	2
6	Karandhamalai	Madurai	Tamil Nadu	Vaigai	400	10.30	78.23	810	7
7	Topslip	Coimbatore	Tamil Nadu	Cauvery	599	10.48	76.86	1795	4
8	Dhoni	Palakkad	Kerala	Bharatapuzha	350	10.88	76.63	2090	4
9	Meenvallom	Palakkad	Kerala	Bharatapuzha	400	10.90	76.60	2500	4
10	Upper Bhavani	Nilgiri	Tamil Nadu	Cauvery	2300	11.22	76.52	2000	3
11	Muthapan Puzha	Calicut	Kerala	Chaliyar	530	11.43	76.08	3307	3
12	Makut	Coorg	Karnataka	Vallapattanam	205	12.08	75.75	3300	3
13	Aralarm	Kannur	Kerala	Vallapattanam	100	12.09	75.79	3300	3
14	Panaje	Dakshina Kannada	Karnataka	Chandragiri	60	12.66	75.17	5500	4
15	Subrahmanya	Dakshina Kannada	Karnataka	Netravati	167	12.68	75.63	5500	4
16	Koyyur	Dakshina Kannada	Karnataka	Netravati	49	12.95	75.29	5500	4
17	Mala	Udupi	Karnataka	Swarna	192	13.20	75.11	5500	4
18	Kudremukh	Chikkamagalur	Karnataka	Tungabhadra	774	13.21	75.23	5500	4
19	Kigga	Chikkamagalur	Karnataka	Tungabhadra	722	13.44	75.18	5500	4
20	Neralekoppa	Chikkamagalur	Karnataka	Tungabhadra	650	13.67	75.45	2500	6
21	Hosanagara	Shimoga	Karnataka	Sharavati	513	13.88	75.05	2500	6
22	Nagodi	Shimoga	Karnataka	Sharavati	550	13.91	74.86	2500	6
23	Nittur	Shimoga	Karnataka	Sharavati	550	13.93	75.90	2500	6
24	Nellibedu	Shimoga	Karnataka	Sharavati	550	13.94	74.85	2500	6
25	Mavinahole	Uttara Kannada	Karnataka	Sharavati	550	13.97	75.10	3500	6
26	Nandihole	Shimoga	Karnataka	Sharavati	530	14.00	75.13	981	6
27	Haridravathi	Shimoga	Karnataka	Sharavati	525	14.10	75.13	981	6
28	Malemanne	Uttara Kannada	Karnataka	Sharavati	500	14.28	74.73	4000	6
29	Kathlekan	Uttara Kannada	Karnataka	Sharavati	525	14.28	74.75	4000	6
30	Kodigathe	Uttara Kannada	Karnataka	Aghanasini	450	14.35	74.65	4000	6
31	Badal	Uttara Kannada	Karnataka	Aghanasini	450	14.36	74.79	4000	6
32	Hulidevarakodlu	Uttara Kannada	Karnataka	Aghanasini	150	14.44	74.64	4000	6
33	Bondla	South Goa	Goa	Rachol	134	15.40	74.06	3000	6
34	Radha Nagari WLS	Kholapur	Maharashtra	God	550	16.50	73.85	3000	8
35	Amba	Raigad	Maharashtra	Kajvi	550	16.98	73.78	3000	8
36	Koyana	Satara	Maharashtra	Krishna	630	17.57	73.76	5000	8
37	Tamhini	Pune	Maharashtra	Krishna	609	18.46	73.44	3500	8
38	Dongarvadi	Pune	Maharashtra	Krishna	600	18.48	73.42	3500	8
39	Triambak	Nasik	Maharashtra	Godavari	750	19.94	73.53	3000	8

AARF, Average annual rainfall; NDM, Number of dry months.

intrinsic factors such as microhabitat richness to determine the diversity of habitats.

In the current practice of biomonitoring in the Western Ghats, streams sites are selected based on their perceived level of human impact and much emphasis is given to select appropriate control sites to know the pristine condition[45]. However, in this approach there is no discussion on the variation across habitats. A sampling without due consideration of habitat variability could lead to erroneous conclusions. This is important in the current situation, where biomonitoring methods are increasingly being used to assess the health of riverine ecosystems[46]. In this context, we propose a habitat-based approach for sampling aquatic insects in stream stretches for biodiversity studies and biomonitoring. Another important issue not investigated in the present study is the temporal variation in the habitat structure and associated faunal change. Since all the sampling in the current study was done in the post-monsoon period, there was no significant change in habitat structure. However, it was observed during the study that physical properties of habitats change during summer (March–May). In summer, with minimum water flow, many of the cascades and riffles turn into pools and pools become shallower. Field observations suggest that faunal composition changes with this seasonal variation in water flow. Our current data do not reveal these patterns. We plan to focus on this issue in our future studies.

Conclusion

The diversity, abundance of taxa and functional groups of stream insects vary across habitats. This variation is possibly related to the interplay between intrinsic habitat parameters and extrinsic environmental variables. Our study on streams of the Western Ghats supports earlier observations on temperate streams, that the structurally complex habitats and microhabitats harbour high diversity. The variation in stream insect diversity across habitats should be considered while designing biodiversity and biomonitoring studies in riverine ecosystems.

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