J. Indian Inst. Sci., Nov.–Dec. 2000, 80, 537–552.

Aquatic insect diversity and ubiquity of the streams of the Western Ghats, India

K. G. SIVARAMKRISHNAN, K. VENKATARAMAN, R. K. MOORTHY, K. A. SUBRAMANIAM* AND G. UTKARSH*†
Centre for Research in Aquatic Entomology, Department of Zoology, Madura College, Madurai 625 011, India.
*Centre for Ecological Sciences, Indian Institute of Science (IISc), Bangalore 560 012, India.
email: utkarshgv@yahoo.com; Phones: 91-80-3336909/3434465; Fax: 91-80-3334167

Received on June 29, 2000; Revised on November 30, 2000.

Abstract

We studied the distribution of 4533 individuals of aquatic insects belonging to 72 genera, 45 families and 10 orders, collected from headwater stream riffles from 17 localities in the hills of southwestern India. The southern, wetter sites with lower human impacts favour specialised sensitive taxa. The ecological attributes are correlated across the taxonomic gradient, viz. family, genus and species levels, which would permit an efficient and participatory inventory as well as monitoring even at the family level.

Keywords: Macroinvertebrates, freshwater, taxic hierarchy.

1. Introduction

The study of biological diversity, often termed 'biodiversity', includes magnitude and distribution of organisms, besides aspects such as utility and conservation prescriptions.[1] Biodiversity has emerged as a major challenge of late both due to its value for biotechnological applications and its rapid erosion. To address this challenge, we must develop methodologies that can be widely replicated[2] thereby promoting decentralised monitoring and informed management decisions. Major methodological constraints include:

(a) Inability to completely measure species diversity of most organismic groups. The estimates of global species diversity vary between 8 and 30 million and only 1.7 million of the species have so far been described and named.[3]

(b) Limited understanding of how diversity patterns at various taxonomic levels resemble each other. For instance, the order coleoptera comprising beetles has many more species per genus or family, with much greater morphological resemblance than the other orders of insects or other phyla.[4]

(c) Limited resources especially in the biodiversity-rich tropical countries in terms of skilled manpower, infrastructure and finance[1] that critically constrain research.[2]

Given these constraints, even complete inventory, leave monitoring, of biodiversity all over the globe seems to be an increasingly illusionary endeavour. Hence, there is a marked preference for sampling-based approaches for diversity estimation.[2,5,6] Approaches focussing on organisms as environmental indicators, including aquatic insects, are also being favoured.[7–9]

†Author for correspondence: RANWA, C-26/1, Ketan Heights, Kothrud, Pune 411 029, India.

Insects contribute over half of all the recorded species and over three-fourths of the estimated species in the globe.[10] Although less than 3% of all species of insects begin their life cycle as aquatic larvae before emergence as winged land creatures[11] these insect nymphs may comprise over 95% of the total individuals or species of macroinvertebrates in suitable freshwater biotopes.[12] Aquatic insects play a unique role in aquatic ecosystems by effectively breaking down the organic deposits to release energy thereby serving as a vital link in the freshwater food chain as fish food. Aquatic insects are also important bioindicators of water pollution, triggering substantial applied ecological research.[9] Academically, some taxa of aquatic insects such as mayflies have been favoured subjects for biogeographic research due to their conservative dispersal habits.[13]

Western Ghats is one of the 18 biodiversity hot spots in the world with over two-thirds of the species of its amphibians[14] and about a third of its angiosperms[15] occurring nowhere else in the world. Endemism is hardly studied amongst insects except butterflies, a tenth of which are endemic to the Western Ghats.[16] A research lacunae of concern is the paucity of information on the impact of environmental changes on regional and local organismic diversity especially in the tropics.[17] Earlier studies on aquatic insects in southern India have focussed primarily on the preparation of taxonomic monographs, check lists, and study of life histories and control measures of vector species.[9] Community-level investigations highlighting variation at local-to-regional scales as attempted elsewhere[18] have largely focussed on local species.[19] We thus explore the regional patterns, in terms not only of individual taxa but also of their assemblage. We explore more replicable ways of studying distribution patterns with conservation design imperative, addressing the existing constraints.

2. Objectives

The objectives of this preliminary regional inventory include:

(a) Estimating how diverse the aquatic insect communities are across localities, at the level of genus, family and order.

(b) Exploring degree of regional distribution and abundance of each taxon and community.

(c) Exploring how the attributes such as distribution range, abundance and feeding guilds of individual taxon shape the community-level attributes.

(d) Exploring how environmental factors such as rainfall gradient and relative human influence affect the community attributes.

(e) Investigating if the diversity levels across various taxonomic hierarchies such as order, family and genus are correlated, so as to enhance the measuring and monitoring efficiency.

3. Materials and methods

3.1. *Study localities*

The study was conducted in 17 different village-level landscapes in the Western Ghats in collaboration with several local college teams from the Western Ghats Biodiversity Network[20] that has undertaken monitoring of several organismic groups including aquatic insects. Balancing the desire to study remote, unexplored areas with operational efficacy, each college chose a nearby village landscape for studies. Western Ghats is a mountain chain running north–south and parallel to the west coast of India.[21] The hill chain is 1600 km long and between 5 and 150 km wide, separated from the coast by a low land strip usually 40 to 60 km wide. The elevation here ranges up to about 2700 m ASL, and the hills south of 12°N often rise up to 2000 m ASL while the northern hills rarely rise above 1000 m ASL. Forests cover nearly one fourth of the total area in the Western Ghats[21] and give rise to east-flowing rivers that form the principal water source for the entire peninsular India.[22] The study landscapes generally measure about 25 sq. km in size and are scattered all over the length of the Ghats, from 8° N to 20° N, between 100 and 1000 m ASL. Altitudinal range within a given landscape does not exceed a few hundred meters. The distribution of study sites along the Western Ghats is neither systematic nor stratified but constrained by the availability of naturalists motivated to study various organismic groups. This design may not be best suited for thorough regional exploration of any one group such as the aquatic insects or intensive combing of any given locality for all the groups. However, the sampling design facilitated in launching a broad-based, participatory monitoring programme, besides a benchmark inventory of human impacts[23] and covariation across taxonomic groups[24] rather than the precise study of a given taxon or hypothesis.

Most study landscapes contain streams belonging to two consecutive orders, either the first two or the second and the third. The human impact is limited to fishing which includes the use of natural plant toxins and deforestation along the banks and the catchment. In a few cases, the forests on the banks of rivers have been converted to agriculture use with chemical inputs or into residential zones resulting in significant sewage pollution. The detailed ecological parameters[22] of each study site are shown in Table I. To facilitate latitudinal comparison, we arbitrarily term the zone between 8° and 12°N latitude (i.e. Kerala–Tamil Nadu states) as southern, that between 13° and 16°N latitude (i.e. Karnataka state) as central sector while that between 17° and 20°N latitude (i.e. Maharashtra state) as northern. The state of Goa (15° to 16°N) had no collaborators and hence could not be studied.

3.2. *Sampling strategy*

Nearly a third of the study sites were surveyed during November 1995 while another third were surveyed during November 1996. Remaining one third of the study sites were surveyed during January–February 1997. We preferred post-monsoon season for sampling as our earlier studies showed aquatic insects to be plentiful at this time of the year.[9, 19] The survey focussed on sampling headwater riffles at three locations, preferably across three streams in each site. Based on earlier experience, we preferred second-order streams and rocky substrate with algal incrustation that are likely to harbour greatest diversity within each site. These three sampling localities were chosen so as to maintain similarity in terms of their stream order and microhabitat conditions. Assisted by local college team, we sampled these spots and enumerated the insects trapped in three kick-net operations. For each kick-net operation, we kicked the substrate to loosen it and flushed out the insects that can be trapped in the net. The duration of each catch of the kick-net operation was five minutes. All the insects collected from the three replicates at a given spot were aggregated and stored together. The specimens were sorted, identified and preserved at the museum housed at the centre in the Madura College, Madurai. Our identification follows the prevalent global and regional schemes.[25, 26]

Table I
Environmental parameters of the study sites

Sl. no.	State	District	Site	Code	Latitude (°N)	Rainy Season (mth)	Rain-fall (mm/yr)	Altitude (m)	Bed Width (m)	Tempe-rature (°C)	Sampling period	Human impact	Substrate			
													Boulder	Cobble	Gravel	Others
1.	Maharashtra	Thane	Kashele	Ks	20.0	4.0	3000	150	12	19	N 96	2	0	0	1	1
2.	Maharashtra	Pune	Pavananagar	Pv	19.0	4.0	2000	600	6	18	N 96	3	1	0	1	1
3.	Maharashtra	Raigad	Phansad	Ph	18.5	4.5	3000	250	2	21	N 96	0	1	0	1	0
4.	Maharashtra	Pune	Shirwal	Sw	18.0	4.0	600	550	4	27	N 96	3	1	1	1	0
5.	Maharashtra	Satara	Koyna	Ky	17.5	4.5	5000	650	4	15	N 96	2	1	1	0	0
6.	Karnataka	Uttara Kannada	Sirsi	Ss	14.0	6.3	3500	550	12	17	N 96	1	0	1	1	1
7.	Karnataka	Uttara Kannada	Kumta	Km	14.0	6.0	4000	150	8	18	N 95	2	1	1	0	1
8.	Karnataka	Udupi	Udupi	Ud	13.0	6.3	3000	50	9	29	N 95	3	1	1	1	0
9.	Karnataka	Udupi	Karkala	Kk	13.0	6.8	5500	50	12	20	N 95	0	1	1	1	0
10.	Karnataka	Shimoga	Sringeri	Sg	13.0	6.8	6000	800	10	18	N 95	0	1	1	1	1
11.	Karnataka	Mangalore	Neria	Nr	12.5	7.0	5000	300	6	22	N 95	1	1	1	1	0
12.	Kerala	Calicut	Annakampoil	Cl	11.0	7.3	5000	400	9	25	N 95	1	1	1	1	0
13.	Kerala	Palghat	Mundur	Mn	10.0	7.5	3000	300	7	18	JF 97	0	1	1	1	0
14.	Kerala	Palghat	Dhoni	Dh	10.0	7.5	1200	100	7	18	JF 97	3	1	1	1	0
15.	Tamil Nadu	Nagercoil	Keeraiparai	Ng	8.5	7.0	1200	500	5	25	JF 97	2	1	0	0	0
16.	Tamil Nadu	Tirunelveli	Kalakkad	Tn	8.0	8.5	2000	700	3	18	JF 97	0	1	1	0	0
17.	Kerala	Trivandrum	Palode	Tm	8.0	8.5	2500	200	7	22	JF 97	1	1	1	1	0

Presence and absence of substrate component are indicated as 1 and 0.

JF: January–February, N: November, 95, 96, 97 indicate respective years.

3.3. *Analytical techniques*

Our basic data comprises nearly 4533 individuals belonging to 72 genera, 45 families and 10 orders, collected from 17 localities. We employ these data to compute various diversity parameters as described below.

(a) α-diversity of a given sample may be measured simply as taxonomic richness, or in terms of complicated indices such as Shannon–Weaver or Simpson's index.[27] As the values of such statistical indices are very strongly correlated to taxonomic richness (Simpson, 0.95; Shanon's 0.85, both $p < 0.01$), we prefer using only the richness index here. However, the richness, i.e. the number of taxa is strongly influenced by the number of individuals sampled ($r = 0.69$, $p < 0.01$) which varies from 116 to 226. We correct for this variation by rarefaction, by arriving at the expected number of taxa amongst 116 individuals.[27]

(b) We use the number of sites inhabited by a taxon as a crude index of its distribution nichewidth, i.e. environmental adaptability. Thus, taxa inhabiting more sites are assigned to wider niche. The niche width of a taxon can be resolved into geographical and habitat components, as indicated by the dispersion of the taxon along latitudinal and disturbance gradients, respectively. However, most of the study pertains to low human-impact zone such as first-order streams and the sites are too widely scattered. Thus, both these components have not been resolved from the single index of site frequency as above which is an index of restricted regional distribution, regardless of the data on global endemicity.

(c) We further characterize the rarity of taxa in terms of their abundance. Average abundance of a taxon is given as

$$D = \frac{\sum_{i=1}^{j} d}{j}$$

where D is the average abundance per site, d the number of individuals at site i and j the total number of sites.

(d) We also have information[11,12] on feeding categories, i.e. guilds such as collector, shredder, grazer and predator to which a given genus belongs. The collectors harvest the particulate organic matter (POM) employing filter-feeding strategy. The shredders cut the bottom debris of leaf litter while feeding, whereas grazers feed on such broken material, besides algae. Predators devour all these three kinds of larvae.

(e) Members of any given taxon may occur on several of the sites sampled. A particular set of taxa encountered at a given site may then be characterized in terms of the mean proportion of sites on which members of the set are encountered. If the study involves n sites, then the lowest value this index would take is $1/n$. To facilitate comparison amongst studies involving different numbers of assemblages sampled, we suggest an index called ubiquity[23, 24] and define it as

$$p_i = \frac{\sum_{j=1}^{m_i} f_{ij}}{m_i}$$

where p_i is the ubiquity for site i, f_{ij} the proportion of the total number of sites, n, over which a taxon j present on the site i is encountered, and m_i the total number of taxa encountered at site i. Ubiquity varies between 0 and 1, a value of 0 implying that none of the taxa encountered on that site were encountered elsewhere and 1 implies that all the taxa encountered at a given site were found at all other sites. The lower value of ubiquity indicates the majority of taxa found at a given site have restricted distribution. Ubiquity is therefore inversely related to and a surrogate measure of endemicity of a taxa within the region, regardless of its global endemicity, poorly studied for most aquatic insects.[11, 12]

(f) Similarly for characterising assemblage sampled at a site in terms of attributes of its constituent taxa, mean value for all the taxa inhabiting the site has been used. Thus, the value of community attributes for site j is given as:

$$A = \frac{\sum_{i=1}^{s} a}{s}$$

where A is the mean value of the given parameter a for site j, a the value of that parameter for species i and s the total number of taxa at site j. Thus, the average of taxic mean abundance and feeding category is estimated for each of the sites in this fashion.

(g) To gain an idea of similarity of taxic distribution and site composition the matrix depicting the occurrence of 72 genera in various localities was subjected to reciprocal averaging type of ordination and scores for genera and sites on the first axis were used for sorting them.[28] For the sake of brevity, only the 45 genera that occur in two or more sites have been depicted here, leaving out the 27 genera recorded from only one locality though their presence has been used to compute their ordination scores and also of the sites.

(h) At least three major environmental factors are known to influence the Western Ghats biota in general. The length of rainy season, though not the rainfall, reduces with increasing latitude.[22] Hence, southern streams are likely to stock water for longer periods, as compared to their northern counterparts. The temperature reportedly decreases with increasing altitude.[22] We have estimated the human impact indirectly and qualitatively as being inversely related to the relative tree canopy cover surrounding the sampled streams. The impact perceptions in the field were also based on the observed or reported presence of sewage, soap lather, agricultural effluents, etc. and are accorded four ranks. We could not study the physico-chemical parameters of water quality at present, though have perceptions about these based on our earlier studies.[9] The streams amidst forests appear least impacted, those amidst agricultural or residential settings seem to be impacted most while those in transitional areas show moderate impact.

(i) We also investigated from these data the patterns of covariation of diversity across various taxonomic levels to explore if studies at higher taxonomic level that are easier would yield similar results to that at the lower taxic level. We have computed various diversity attributes at the level of genus, family and order. We explored the correlation between various taxonomic levels, in case of each diversity attribute.

Table II
Ten most populous taxonomic units

Sl no.	Order	# Ind	# Sites	Ind/ Site	Family	# Ind	# Sites	Ind/ Site	Genus	# Ind	# Sites	Ind/ Site
1.	Trichoptera	2058	16	130	Hydropsychidae	1523	17	90	Macronema	564	8	71
2.	Ephemeroptera	1363	17	80	Leptophlebidae	456	8	57	Hydropsyche	425	16	27
3.	Plecoptera	340	12	28	Baetidae	414	12	35	Baeits	414	12	35
4.	Diptera	261	11	24	Perlidae	340	12	28	Neoperla	340	12	28
5.	Odonata	212	16	13	Heptagaenidae	326	10	33	Potamyia	183	6	31
6.	Coleoptera	163	11	15	Philopotamidae	138	5	28	Petersula	182	7	26
7.	Hemiptera	57	9	7	Gomphidae	133	14	10	Gerrus	165	7	24
8.	Lepidoptera	54	6	9	Lepidostomatidae	89	2	45	Parapsyche	164	4	41
9.	Megaloptera	17	6	3	Caenidae	85	4	21	Mesogomphus	133	14	10
10.	Orthoptera	8	2	3	Coenagrionidae	79	8	10	Ecdyonurus	114	4	29
	Total	4533										

Note: # Ind–Number of individuals recorded; Sites–Number of sites from where taxon is reported; Ind/Site–Mean number of individuals per site.

4. Results

4.1. *Distribution and abundance of taxa*

Table II lists the 10 most abundant genera, families and orders, and depicts their site frequency. At the order level, Ephemeroptera (Mayflies) have the widest niche, occurring in all the 17 study areas, followed closely by Trichoptera (Caddis flies) and the Odonata (Dragonflies and Damselflies) recorded from 16 sites each, followed further by the Plecoptera (Stoneflies) with 12 sites. Caddis flies contribute maximum, viz. nearly half the total individuals while Mayflies follow it with about a quarter of the individuals. Remaining orders have very few individuals. The sequence of order in terms of decreasing average abundance resembles that with the total abundance, as Caddis flies top the list having 130 individuals followed by Mayflies having 80 individuals per site.

At the family level, Hydropshychidae had widest niche as it inhabits 16 of the 17 sites sampled, followed by Gomphidae, Baetidae and Perlidae occurring in 14, 12 and 12 sites each. Hydropshychidae also contributes the maximum number of individuals, about a third of the total, followed by Leptophlebidae, Baetidae and Heptagaenidae with about tenth of the individuals. Hydropsychidae also tops the list of families in terms of average abundance per site with 90 individuals, followed by Leptophlebidae, Lepitostomatidae and Baetidae with 57, 35 and 34 individuals, respectively.

Genus *Hydropshyche* has the widest distribution niche, being recorded from 16 out of 17 sites followed by *Mesogomphus*, *Baetis* and *Neoperla* occurring in 14, 12 and 12 sites, respectively. The genus *Macronema* constituted the maximum number of individuals, about one

Table III
Reciprocal averaging ordination of genera and sites

Genus	Site		Pv	Ky	Ph	Sw	Km	Ks	Ud	Tn	Dh	Nr	Tm	Sg	Mn	Kk	Ss	Cl	Ng
	Latitude °N		19	17	18	18	14	20	13	8	10	12	8	13	10	13	14	11	9
	#	RA	100	98	88	66	57	53	50	42	20	19	18	17	16	16	8	2	0
Stenopsyche	3	92		1	1		1												
Ephemera	3	90	1		1				1										
Arctopsyche	2	89	1				1												
Gyrinus	2	80		1						1									
Gerrus	7	70	1	1	1		1	1			1			1					
Ecdyonurus	4	61			1	1				1		1							
Macronema	8	48		1		1	1		1		1		1	1	1				
Chironomus	2	48				1						1							
Arisocentrophus	4	47			1					1		1	1						
Hydropsyche	16	47	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1
Goerocles	2	46				1										1			
Baeits	12	46	1		1		1	1	1	1		1	1	1	1	1	1		
Glossosoma	2	42					1								1				
Corydolus	4	40					1		1			1				1			
Brachycentrophus	2	39							1			1							
Goera	2	37					1										1		
Neoperla	12	37			1		1	1	1	1	1		1	1	1	1	1	1	
Mesogomphus	14	34			1	1	1		1	1	1	1	1	1	1	1	1	1	1
Teloganudes	4	31					1					1		1		1			
Coenis	4	29					1				1			1			1		
Euthraulus	7	29					1			1		1	1	1		1	1		
Atopsyche	2	25								1								1	
Parapsyche	4	25						1				1		1					1
Psephenic	5	25					1					1			1	1		1	
Stenelonis	6	24							1		1	1			1	1	1		
Simulim	7	22							1		1	1	1		1	1			1
Polycentroplus	4	22								1		1				1		1	
Leptonema	4	22								1	1					1			1
Epeorus	6	21					1					1		1		1		1	1
Thalerosphirus	4	20									1	1		1		1			
Rhyacophila	2	20											1	1					
Atherox	3	19										1		1		1			
Dystisws	3	19										1			1	1			
Notophlebia	3	19											1	1	1				
Potamyia	6	19								1	1	1			1			1	1
Isca	4	17										1		1		1	1		
Enalogmma	8	16									1	1	1	1	1	1	1	1	
Prosopistoma	2	16									1						1		
Hexatoma	3	15												1		1	1		
Wormaldia	3	15									1		1					1	
Nancoridae	3	14									1		1						1
Petersula	7	13										1	1	1		1	1	1	1
Cynigmna	5	10												1	1		1	1	1
Chimmara	2	9												1					1
Alacodes	3	7														1		1	1
Total genera			5	5	10	7	18	5	12	13	16	29	17	22	18	23	15	15	13

Note: Only 45 genera which occur in two or more sites, out of the total 72, have been depicted here. The total genera also include 27 genera not depicted here as they were recorded from only one site each.
RA- Reciprocal averaging scores based on presence–absence. Explanation of site codes in Table I

Table IV
Diversity attributes of the sampled assemblages

Sl no.	Site	Code	Genus richness	Ubiquity	Mean abundance	Collectors (%)	Grazers (%)	Predators (%)	Shredders (%)
1.	Kashele	Ks	5	0.60	9.5	75	0	0	25
2.	Pavananagar	Pv	5	0.47	4.8	75	0	25	0
3.	Phansad	Ph	10	0.45	5.7	29	14	43	14
4.	Shirwal	Sw	7	0.39	7.8	33	0	67	0
5.	Koyna	Ky	5	0.42	12.0	67	33	0	0
6.	Sirsi	Ss	18	0.36	7.2	58	17	17	8
7.	Kumta	Km	15	0.35	5.4	42	17	25	17
8.	Udupi	Ud	12	0.43	7.5	60	0	30	10
9.	Karkala	Kk	23	0.36	5.6	53	11	26	11
10.	Sringeri	Sg	21	0.38	7.2	50	17	22	11
11.	Neria	Pt	29	0.29	5.3	59	5	23	14
12.	Annakampoil	Cl	15	0.36	5.2	46	23	8	23
13.	Mundur	Mn	16	0.39	6.2	62	8	15	15
14.	Dhoni	Dh	18	0.36	7.1	73	9	9	9
15.	Keeraparai	Ng	13	0.35	7.6	50	30	10	10
16.	Kalakkad	Tn	17	0.38	6.8	50	17	8	25
17.	Palode	Tm	13	0.40	7.1	60	0	20	20
	Mean		14	0.40	6.9	55	12	20	12
	SD		6	0.07	1.7	13	10	16	8

eighth of the total collection, but occurred in just 8 sites. *Hydropsyche*, *Baetis* and *Neoperla* followed it with about a tenth of the total individuals. *Macronema* had maximum average abundance per site with 71 individuals, followed by *Parapsyche* and *Baetis* with 41 and 35 individuals, respectively. Nearly one-third, viz. 26 out of 72 genera were recorded from a single study site while a seventh, viz. 11 genera were collected in only 2 sites.

4.2. *Community composition*

Table III depicts the ordination of genera and the sites in terms of their similarity of occurrence and composition, respectively. The ordination scores broadly reflect the latitudinal variation in generic composition. The northern sites such as from Maharashtra congregate at one extreme while many southern sites such as from Tamil Nadu and Kerala flock the other extreme, barring a few exceptions. The central Western Ghats, i.e. Karnataka sites mostly occur in between the two extreme clusters. Amongst the genera with moderate distribution, i.e. inhabiting 3 to 5 sites, *Stenopshyche*, *Ephemera* and *Hernus* frequent the northern part of the Western Ghats. Genera inhabiting as many sites but typifying the southern latitudes include *Alacodes*, *Wormaldia*, *Potamiya*, *Thalerophirus*, *Leptonema*, *Petersula*, etc. Genera frequenting as many sites but recorded from the central zone include *Corydolus*, *Telognudes*, *Atherox*, etc. No such clear geographical pattern of distribution was evident in the case of families and orders.

4.3. *Community diversity*

The survey yielded a collection of 4533 individuals belonging to 72 genera, 42 families and orders. The number of individuals collected at a locality varied from 116 to 626. Rarified richness, i.e. number of taxa observed per 116 individuals picked randomly from each collection at each site ranged from 5 to 29 genera, 8 to 20 families and 4 to 9 orders. The diversity values for each of the sites are provided in Table IV. Neria from Karnataka recorded the highest diversity with 29 genera while Kashele, Pavananagar and Koyna from Maharashtra recorded the lowest diversity levels with just 5 genera each.

4.4. *Community attributes*

Table IV further shows that Neria from central Western Ghats hosted genera having most restricted distribution, with a genus, on an average, inhabiting only about a third of the sites. Kashele from Maharashtra on the other hand hosted mostly widespread genera, generally inhabiting about two thirds of the sites. Pavananagar from northern sector harboured genera with the lowest average abundance (4.2 individuals/catch), while neighbouring Koyna hosted genera with maximum average abundance (12 individuals/catch).

Nearly half of the genera on an average belonged to the feeding guild collectors, ranging from a fourth at Phansad to three-quarters at Kashele and Pavananagar, all from Maharashtra. Least proportion of genera belonged to the categories of shredders and grazers, averaging barely a tenth and rarely ranging up to a fourth and third, respectively. The predators constituted a fifth of the genera.

4.5. *Environmental correlates*

Table V depicts the degree of correlation between various diversity attributes and environmental parameters. Genus-level diversity is significantly ($p < 0.05$) negatively correlated while ubiquity is significantly ($p < 0.01$) positively correlated with latitude. Thus, streams from the northern latitudes harbour less diverse assemblages and comprised taxa with wide distribution

Table V
Environment and diversity relationship

Sl no.	Parameter	Genus richness	Ubiquity	Collectors (%)	Grazers (%)	Predators (%)	Shredders (%)	Reciprocol average score
1.	Latitude	–581*	625**	10	–201	321	–409	754**
2.	Altitude	–97	–119	–124	437	–36	–311	191
3.	Rainfall	464	–217	–9	330	–249	109	–126
4.	Rainy season	670**	–598*	–19	134	–346	501*	–748**
5.	Stream width	271	125	347	–180	–263	204	–293
6.	Temperature	–46	–101	–388	–275	485*	18	–161
7.	Impact level	–407	545*	422	–283	181	–483*	–162
9.	Genus richness	–	–744**	375	–38	–309	57	–685**
11.	Ubiquity	–744**	–	100	–234	–634**	–78	562*
12.	Boulders	154	–465	–311	118	275	–189	–
13.	Cobbles	511*	–601*	–78	44	33	15	–
14.	Gravel	148	181	134	–672**	339	–37	–
15.	Others	–142	350	227	–102	–108	–22	–
16.	Ordination score	–685**	562*	–234	100	–435	–38	–

The values depict 1000 times the Pearsons's correlation coefficient
*Values above 482 are significant at $p < 0.05$
**Values above 606 are significant at $p < 0.01$

in the region. The reciprocal averaging score of the sites is significantly ($p < 0.01$) correlated with latitude. This indicates that taxonomic composition of communities changes continuously along the latitudinal gradient. Mean abundance of taxa per site is not significantly correlated with latitude. Proportions of taxa contributed by the four feeding categories are also not correlated with latitude.

None of the community attributes is significantly correlated with altitude or rainfall. Length of the rainy season is negatively correlated ($p < 0.01$) with latitude. Hence, parameters correlated with latitude are also correlated with the length of rainy season, but bear exactly the opposite sign. None of the attributes is correlated with the width of the stream sampled or water temperature, with two exceptions. Proportion of predators is significantly positively ($p < 0.05$) correlated with temperature, indicating their preference for warm waters. None of the attributes is correlated with increasing human impact except ubiquity being correlated positively ($p < 0.05$) and the proportion of shredders being correlated negatively ($p < 0.05$).

As regards the substrate, taxonomic richness was positively correlated ($p < 0.05$) with the proportion of cobbles while ubiquity was negatively correlated ($p < 0.05$). Thus, more cobbled substrate seems to support higher taxic diversity and having more restricted distribution. Other correlations between the community attributes and environmental parameters were not significant, but for the negative ($p < 0.01$) correlation between proportion of grazers and gravel.

4.6. *Attribute correlations*

As Table V shows the genus-level richness is significantly ($p < 0.01$) negatively correlated ($p < 0.01$) with ubiquity. This suggests that more diverse communities harbour taxa with rather restricted distribution while less diverse communities shelter more widespread taxa. The proportion of collectors in the assemblages is significantly ($p < 0.01$) negatively correlated with the proportion of predator taxa.

4.7. *Taxonomic correlations*

Table VI shows that the correlations between order, family and genus-level values for various community parameters are all positive ($p < 0.01$). The rank of a given assemblage may change from one taxonomic level to another. However, the overall pattern of ranks with respect to a given attribute does not change much across the taxonomic levels.

Table VI
Relationship between diversity attributes at various taxonomic hierarchical levels

From	Order	Order	Family
To	Family	Genus	Genus
Taxic richness	0.91	0.86	0.97
Rarified taxic richness	0.92	0.85	0.96
Ubiquity	0.95	0.97	0.97

Values depict Pearson's coefficient and all are significant at $p < 0.01$

5. Discussion

The results obtained here are preliminary in nature and need further examination given the limited sampling effort and its uneven distribution across latitudinal, seasonal and human-impact gradients. We ventured to sample across the late and post-monsoon season drawing on our experience, [19] besides seasonal studies elsewhere in Indian mountains[29, 30] and the fact that the most tropical aquatic insects have bi- or multi-voltine life cycle with asynchronous emergence and overlapping generations rather than univoltine life cycles of temperate biota.[5] Nevertheless, given the likely bias in our sampling scheme, we focussed on regional patterns rather than locality- or month- or year-specific analysis. We hope that our results would promote debate and further research along these lines.

The predominance of Ephemeroptera, Plecoptera and Trichoptera (EPT) that constitute nearly two-third individuals from our samples is clearly a signature of the unpolluted headwater assemblages, without any turbidity.[12] Plecoptera that are particularly susceptible to turbidity and associated low oxygen levels are well represented in our data. Given that there was hardly any pollution or floating vegetation often encountered at higher stream order, associated insect families like Naucoridae, Notonectidae, Chironomidae, Culicidae, etc. were nearly absent. Families such as Heptaginidae that have flat body and appendages adopted for clinging to rocks under rapid water current are present but not predominant as we focussed on sampling riffles, rather than the rapids nearby. The predominance of Hydropsychidae is only expected given its tolerance towards a variety of environmental conditions including bank deforestation or organic pollution. Widespread distribution despite low abundance (just 5%) of the order Odonata and genera therein such as *Mesogomphus* is only expected given their predatory nature. Our results are in conformity with the river continuum hypothesis[19], which underlines ubiquitous distribution of predators like dragonflies across a variety of habitats and localities. The study confirms the role of shredders as indicators of catchment deforestation[25] that result in lower leaf litter input in the streams. Thus, while shredders that depend on food produced outside the stream, i.e. in allochtonous fashion, are susceptible to catchment deforestation, it hardly impacts collectors, grazers and predators that are autochtonous, i.e. dependent on food produced within the stream. Further, human impact also favours ubiquitous taxa, i.e. proportion of widespread taxa increases as evident in the case of other organismic groups like butterflies, birds or trees.[24] Similarly, moderate human impact favours widespread, stress-tolerant taxa without complete loss of sensitive taxa, that accounts for higher diversity. Higher taxic diversity favoured by cobbles can be attributed to their geometric architecture that provides suitable clinging surface to the insect nymphs while the accompanying algal incrustation provides the vital dissolved oxygen. Algae rarely inhabit the gravel due to lack of support, which explains the lack of grazers that feed on algae, amongst others.

The impoverishment of taxonomic diversity as well as increasing proportion of widespread taxa in the northern latitudes has been reported in the case of other taxa as well.[14, 15] Such impoverishment is probably due to shorter rainy season in the northern latitudes (4–5 months) than the southern region (6–8 months). Thus, northern streams are more likely to dry up during summer, making survival of delicate taxa very difficult resulting in their absence there, leaving out the widespread, more adaptive taxa in higher proportion. The prevalance of many taxa having restricted distribution towards the southern latitudes corresponds to greater richness of those assemblages. The distribution of study sites was not adequate to assess the impact of altitude or the kind of human impact. However, preliminary trends indicate that the role of altitude is likely to be limited in influencing community structure while the level of human impact induces changes similar to those caused by increasing latitude, i.e. exclusion of sensitive taxa like Plecoptera due to higher turbidity and low oxygen. Human impacts like pollution that affect the pH also promote stress-specialist taxa like chironomids along with tolerant taxa like Stenopsychids and Hydropsychids that manage to survive stress.

The approach of characterising communities in terms of ubiquity of the communities adds a new dimension to the study of diversity and conservation evaluation. Communities with greater proportion of environmentally sensitive taxa having restricted distribution may be assigned greater value and priority for conservation purpose.[23, 24] Incidentally, these assemblages are also likely to be more diverse where many rarer taxa with narrow habitat preference cooccur. More investigations would permit further prioritisation in terms of not just various zones but also microhabitat types and kinds of human impact.

The most useful conclusion is the coherence between diversity attributes measured at various taxonomic levels. Such a correlation might seem intuitively obvious, but its strength was questioned in the case of other taxa such as plants, even prompting the development of new diversity measures to address the observed weakness.[31] Quantitative verification of the correlation here would permit collection and analysis of data at higher taxonomic level of aquatic insects in many places and extrapolation of the results. There have been proposals for such participatory, regional monitoring, involving parataxonomists such as college students.[32] Our results encourage such an approach by saving considerable costs and risks involved in taxonomic identification at lower levels such as genus and species. We therefore advocate a two-phase sampling programme wherein a few sites can be intensively studied by experts, across seasons and genera, while only order-level and post-monsoon studies can be replicated at many places by involving amateurs providing them with basic training and resources.[26]

Acknowledgement

The study was encouraged and supported by Prof. Madhav Gadgil through the Centre for Ecological Sciences, Indian Institute of Science (IISc), Bangalore. The network of college teachers and students and villagers studying various aspects of biodiversity under this coordinated programme provided local guidance and support in their respective localities. Mr H. Nagendran, Dr S. Balasubramaniam, Mr M. Dinakar and other colleagues from Madura College greatly helped in data collection. Drs N. V. Joshi, P. Pramod, and others from IISc helped in many ways. The Ministry of Environment and Forests and the Department of Biotechnology, Government of India, and the PEW Foundation, Michigan, supported this endeavour financially. Forest departments of the states of Tamil Nadu, Kerala, Karnataka and Maharashtra obliged by permitting this research and with other help. Madura College hosted the research unit. The anonymous referee has put life into the manuscript by seeking more biological than statistical inputs. We are indebted to all of them.

References

1. Heywood, V. H. *Global biodiversity assessment*, Cambridge University Press, 1995.

2. GADAGKAR, R., CHANDRASEKARA, K. AND NAIR, P. — Insect species diversity in the tropics: Sampling methods and a case study, *J. Bombay Nat. Hist. Soc.*, 1990, **87**, 337–353.
3. STORK, N. E. — How many species are there? *Biodiversity Conserv.*, 1993, **2**, 215–232.
4. GANESHAIAH, K. N. — Haldane's God and the honoured beetles: The cost of a quip, *Curr. Sci.*, 1998, **74**, 656–660.
5. FLOWER, R. W. — Diversity of stream-living insects in northwestern Panama, *J. N. Am. Bintaol. Soc.*, 1991, **10**, 322–334.
6. NORRIS, R. H. AND GEORGES, A. — Analysis and interpretation of benthic macroinvertebrate surveys. In *Freswater biomonitoring and benthic macroinvertebrates* (D. M. Rosenberg and Resh, V. H., eds), Chapman and Hall, 1993, pp. 234–286.
7. HELLAWELL, J. M. — *Biological indicators of freshwater pollution and environmental management*, Elsevier, 1986.
8. JOHNSON, R. K., WIEDERHOLM, T. AND ROSENBERG, D. M. — Freshwater biomonitoring using individual organisms, populations and species assemblages of benthic macroinvertebrates. In *Freshwater biomonitoring and benthic macroinvertebrates* (D. M. Rosenberg and V. H. Resh, eds), Chapman and Hall, 1993, pp. 213–222.
9. SIVARAMAKRISHNAN, K. G., HAMMAFORD, M. J. AND DESH, U. H. — Biological assessment of the Kaveri river catchment of south India using benthic macroinvertebrates: Applicability of water quality monitoring approach developed in other countries, *Int. J. Ecol. Environmental Sci.*, 1996, **22**, 113–132.
10. HAMMOND, P. M. — *Species inventory in global biodiversity: Status of the Earth's living resources* (B. Groombridge, ed.), Chapman and Hall, 1992, pp. 17–39.
11. DALY, H. V. — General classification and key to the order of aquatic and semi-aquatic insects. In *An introduction to the aquatic insects of North America*, Kendall/ Hunt, Dubuque, Iowa, USA, 1996, pp. 108–112.
12. WARD, J. V. — *Aquatic insect ecology: Biology and habitat*, Wiley, 1992, p. 438.
13. SIVARAMAKRISHNAN, K. G. — Continental drift and mayflies, *Biol. Education*, 1987, **4**, 7–10.
14. DANIELS, R. J. R. — Geographical distribution patterns of amphibians in the Western Ghats, India, *J. Biogeogr.*, 1992, **19**, 521–529.
15. NAYAR, N. C. AND DANIEL, P. — The floristic diversity of the Western Ghats and its conservation: A review, *Proc. Indian Acad. Sci.* (Anim./Pl. Sci., Suppl.), 1986, **95**, 127–163.
16. GAONKAR, H. — *Butterflies of the Western Ghats, India; including Sri Lanka: Biodiversity assessment of a threatened mountain system*, Centre for Ecological Sciences, Indian Institute of Science, Bangalore and the Natural History Museum, London, 1996.
17. GASTON, K. J. AND WILLIAMS, P. H. — Spatial patterns in taxonomic diversity. In *Biodiversity and biology of numbers and difference* (K. J. Gaston, ed.), Blackwell Science, 1996, pp. 202–229.
18. VRISON, M. R. AND HAWKINS, C. P. — Biodiversity of stream insects: Variation at local, basin and regional scales, *A. Rev. Entomol.*, 1998, **43**, 271–293.

19. BURTON, T. M. AND SIVARAMAKRISHNAN, K. G — Composition of the insect community in the stream of the Silent Valley National Park in Southern India, *Trop. Ecol.*, 1993, **34**, 1–16.

20. GADGIL, M. — Documenting diversity: An experiment, *Curr. Sci.*, 1996, **70**, 36–44.

21. DIXIT, K. R. — *Environment, forest ecology & man in the Western Ghats: the case study of Mahabaleshwar plateau*, Rawat Publications, Jaipur, 1993.

22. PASCAL, J. P. — *Bioclimates of the Western Ghats*, Institut Francais, Pondicherry, 1982.

23. PRAMOD, P., DANIELS, R. J. R., JOSHI, N. V., UTKARSH, G. AND GADGIL, M. — Evaluating bird communities of the Western Ghats for a biodiversity friendly planning, *Curr. Sci.*, 1997, **73**, 156–162.

24. KUNTE, K., JOGLEKAR, A., UTKARSH, G. AND PRAMOD, P. — Patterns of butterfly, bird and tree diversity in the Western Ghats, *Curr. Sci.*, 1999, **77**, 577–586.

25. MERRITT, R. W. AND CUMMINS, K. W. — *An introduction to the aquatic insects of North America*, Kendel Hunt, Dubuque, Iowa, USA, 1996, p. 862.

26. SIVARAMAKRISHNAN, K. G. MADHYASTHA, N. A. AND SUBRAMANIAN, K. A. — *Field guide to aquatic macroinvertebrates, Lifescape*, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, 1998, p. 58.

27. LUDWIG, J. A. AND REYNOLDS, J. F. — *Statistical ecology*, Wiley, 1998, p. 337.

28. GAUCHE, H. G. — *Multivariate analysis in community ecology*, Cambridge University Press, 1982.

29. KRISHNAMURTHY, S. V. AND REDDY, R. — Seasonal fluctuations and periodicity in the insect drift in an unpolluted tropical river Tunga, Western Ghats, India, *Int. J. Ecol. Environmental Sci.*, 1996, **22**, 261–270.

30. JULKA, J. M., VASISHTA, H. S. AND BALA, B. — Distribution of aquatic insects in small streams in northwest Himalaya, India, *J. Bombay Nat. Hist. Soc.*, 1999, **96**, 55–63.

31. GANESHAIAH, K. N., CHANDRASHEKHARA, K. N. AND KUMAR, A. R. V. — Avalanche index: New measure of biodiversity based on biological heterogenity of the communities, *Curr. Sci.*, 1997, **73**, 128–133.

32. GADGIL, M. — Deploying student power to monitor India's lifescape, *Curr. Sci.*, 1996, **71**, 688–697.