Tropical Ecology **57**(2): 243-253, 2016 ISSN 0564-3295

www.tropecol.com

Assemblage of coleoptera and hemiptera community in a stream of Chakrashila Wildlife Sanctuary in Assam

BIJITA BARMAN & SUSMITA GUPTA*

Department of Ecology and Environmental Science, Assam University, Silchar 788011

Abstract: The composition and structure of aquatic Coleoptera and Hemiptera assemblages in a small stream, Mauriagaon, flowing through Chakrashila Wildlife Sanctuary, a Key Biodiversity Area under the Critical Ecosystem Partnership Fund 2005 situated in Assam, India were analysed. The objectives were to describe the aquatic Coleoptera and Hemiptera from the stream, seasonal variation in their abundance and dominance, and also examine to their relationship with the environmental variables of the water. A total of 7 species (2 Coleoptera and 5 Hemiptera) were recorded from the system. Three Hemipteran species (*Ptilomera assamensis*, *Metrocoris nigrofashioides*, *Rhagovelia sumatrensis*) and one Coleopteran species (*Orectogyrus* sp.) occurred throughout the year. Shannon Weiner diversity index values in different seasons ranged from 0.36 in post monsoon to 0.52 in pre monsoon, while Berger Parker Index of Dominance ranged from 0.46 in pre-monsoon to 0.72 in post monsoon. Canonical Correspondence Analysis (CCA) showed that the species-environment correlations of axis 1 and 2 were high, and the majority of species responded negatively to total alkalinity. The study on the aquatic insects of a lotic system is a pioneer study in the Sanctuary as no work has been done so far on this and the study add data of the faunal diversity of the Sanctuary. This study suggested that species richness and density of aquatic insects may indicate the conservation value of the habitats because of their significant responses to environmental factors.

Key words: Aquatic insects, density, diversity, Mauriagaon stream, season.

Handling Editor: Emma J. Rochelle-Newall

Introduction

The maintenance of biodiversity is one of the principal goals of conservation (Margules & Pressey 2000; Myers *et al.* 2000). Resources for measuring the overall biodiversity within a given area are limited (Kerr *et al.* 2000; Williams & Gaston 1994), and areas of high biological diversity are increasingly identified by means of biodiversity surrogates (Caro & O'Doherty 1999; Humphries *et al.* 1995). Among such surrogates, a wide range of biodiversity measures (such as climatic or vegetation data), higher taxonomic groups (genera or families) or indicator taxa are frequently used (Heino *et al.* 2005; Reyers & van Jaarsveld 2000; Williams 1996).

Aquatic bugs and beetles (Heteroptera and Coleoptera, Insecta) can be found in almost every freshwater biotope. They have many morphological adaptations to their aquatic environment, making them excellent subjects for ecological and biogeography studies (Millán *et al.* 2006; Moreno *et al.* 1997). Additionally, water beetles are important indicators of spatial and temporal changes in the environment. This is why some authors have used them as bio-indicators of habitat quality in terms of nutrient enrichment or the presence of potential pollutants; they are also used for selecting areas for conservation (Davis *et al.* 1987; Eyre & Foster 1989; Hufnagel *et al.* 1999; Sánchez-

**Corresponding Author*; e-mail: susmita.au@gmail.com, susmita_au@rediffmail.com

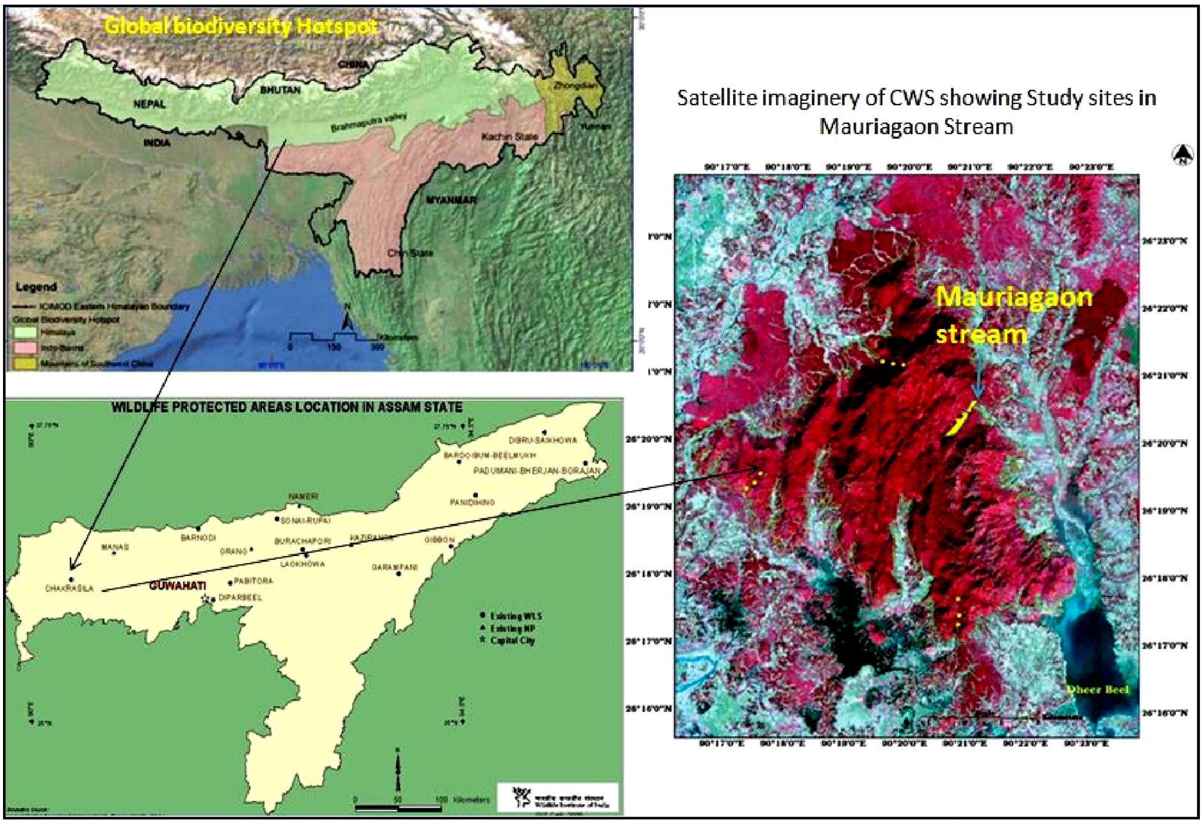

Fig. 1. Map showing the position of Chakrashila Wildlife Sanctuary in Himalayan Biodiversity Hotspot and Mauriagaon stream in the sanctuary.

Fernández *et al.* 2004). Assemblages of water bugs are generally poorer in species than those of water beetles, and seem to be more resilient to environmental changes (Eyre & Foster 1989; Karaouzas & Gritzalis 2006; Roback 1974).

Numerous studies have evaluated macroinvertebrate assemblages in relation to aquatic or semiaquatic habitats (Melo & Froehlich 2001; Palmer *et al.* 1991; Purkayastha & Gupta 2015; Rabeni & Doisy 2000; White & Irvine 2003), and some studies have concentrated on particular insect groups such as beetles (Coleoptera) (Fairchild *et al.* 2000), black flies (Diptera: Simuliidae) (McCreadie *et al.* 1997), "EPT" taxa (Ephemeroptera, Plecoptera and Trichoptera) (Dewalt *et al.* 1999), and true bugs (Hemiptera: Heteroptera) including the Gerromorpha (Das & Gupta 2010, 2011, 2012; Karaouzas & Gritzalis 2006).

The study of Coleoptera and Hemiptera community of a stream of Chakrashila Wildlife Sanctuary (CWS) assumes great importance as the Wildlife Sanctuary falls in Eastern Himalayan region and in the biodiversity hotspot Himalaya (CEPF 2005) which is a data deficient region as information on current status of diversity and distribution of species is lacking (Allen *et al.* 2010). The Wildlife Sanctuary was introduced as a Key Biodiversity Area (KBA) by CEPF (2005) and no study on aquatic insects and water quality of streams of the Sanctuary is on record. This paper of aquatic Coleoptera and Hemiptera assemblages in a small stream, Mauriagaon in CWS, Assam, and evaluates their relative adequacy to provide information about the conservational value of a freshwater habitat.

Materials and methods

CWS (26° 15' to 26° 26' N and 90° 15' to 90 ° 20' E), located in the Dhubri and Kokrajhar district of Assam, North East India is the second home of Golden Langur (*Trachypithecus geei* Khajuria 1956) in the foothills of Himalaya. CWS has dry winter and hot summer followed by heavy rainfall. The diverse ecosystems of CWS support various mammalian species like tiger, leopard, golden langur, gaur, mongoose, porcupine, pangolins, flying squirrel, civet cat, etc. Mauriagaon (26° 20' N and 90° 20' E) is one of the perennial streams in the Wildlife Sanctuary (Fig. 1). Aquatic insects and water samples in three replicates were collected seasonally; i.e., Pre-monsoon (March 2011 - May 2011), Monsoon (June 2011 - August 2011), Post-monsoon (September 2011 - November 2011) and Winter (December 2011 - February 2012) from three different stretches of the stream by three different methods such as "all out search" method, a nylon pond net method (Subramanian & Sivaramakrishnan 2007) and 1 minute kick method (Brittain 1974). Three such drags constituted a sample. The insects were sorted, counted and identified by using standard keys (Bouchard 2004, 2009; Epler 2006; Jessup *et al*. 2003; Niesser 2004; Thirumalai 1999, 2002). Density of the insects represents the number of individuals of insects in a sample found in a unit time (three minutes) and the species richness represents the number of species of insects found in a sample in a unit time (three minutes). The dominance status of insect species was evaluated following Engelmann's scale based on relative abundance (Engelmann 1978). Rainfall data (RF) were collected from meteorological station of Choibari tea state, Kokrajhar, water temperature (WT), flowrate (FR), pH, electrical conductivity (EC), dissolved oxygen (DO), total alkalinity (TA), free-CO_2, nitrate and phosphate were estimated by standard methods (APHA 2005; Michael 1984; Trimmer 1994). Diversity indices like Shannon -Wiener Index (H'), Evenness Index (J), and Berger Parker Index of Dominance (d) for the insect community were worked out using the package Biodiversity Professional Version 2 for Windows 1997 (The Natural History Museum and Scottish Association for Marine Science). SIGNAL (Stream Invertebrate Grade Number - Average Level), is a measure of water quality using the factors of indicator animals and abundance. Animals are identified to family level, with each family assigned a grade between 1 and 10 depending on the tolerance to common pollutants (higher values represent lower levels of tolerance). Each species is then assessed for abundance on a 4-point scale. Scores for each type are calculated from the product of grade and abundance (Chessman 1995). BMWP (Biological Monitoring Working Party) and ASPT (Average Score Per Taxon) score were computed (Subramanian & Sivaramakrishnan 2007). BMWP provides single values, at the family level, representative of the organisms' tolerance to pollution. The greater their tolerance towards pollution, lower the BMWP scores. BMWP was calculated by adding the individual scores of all families represented within the community for a season (Friedrich *et al*. 1996). The Average Score Per Taxon (ASPT) represents the average tolerance score of all taxa within the community, and was calculated by dividing the BMWP by the number of families represented in the sample. A high ASPT usually characterizes clean sites with relatively large numbers of high scoring taxa. Disturbed sites generally have low ASPT values and do not support many high scoring taxa (Sivaramakrishnan 1992). Statistical analyses were done by SPSS 16.0 for Windows 7. Canonical Correspondence analysis (CCA) was done using CANOCO for windows 4.5 (ter Braak 1988).

Results and discussion

Diversity and density

Experiences from USA and European programs have demonstrated that benthic macro-invertebrates are most useful in monitoring fresh-water ecosystems (De Pauw *et al.* 1992; Hellawell 1986; Rosenberg & Resh 1993). Density and relative abundance of order Hemiptera were higher in all the seasons than that of Coleoptera (Fig. 2). This may be because of their ability to survive in water bodies with low levels of dissolved oxygen by utilizing atmospheric oxygen (Bouchard 2004) and their broad range of habitats within a water body (Dolling 1991). Hemipterans belonging to family Gerridae were relatively abundant in pre-monsoon and monsoon whereas hemipterans belonging to family Veliidae were relatively abundant in the post-monsoon and winter seasons (Fig. 3). According to Engelmann's Scale the eudominant species recorded in pre-monsoon and monsoon season was *Ptilomera assamensis* (Amyot & Serville 1843) while *Rhagovelia sumatrensis* (Lundblad 1922) was eudominant in post-monsoon and in winter seasons (Engelmann 1978) (Table 1, Fig. 4). This is because during winter, adults of Gerridae move to protected sites on land (Colorado Insects of Interest 2013) as hibernating water striders have been found in leaf litter, under logs and rocks, and in other sheltered sites near water (Riley 1921, 1925). Winged Gerrids were also found at over-wintering sites far removed from the nearest water (Brinkhurst 1959; Riley 1925; Torre-Bueno 1917). The causes of fluctuations in insect abundance and distribution include macroclimatic and micro-climatic changes and variation in the availability of

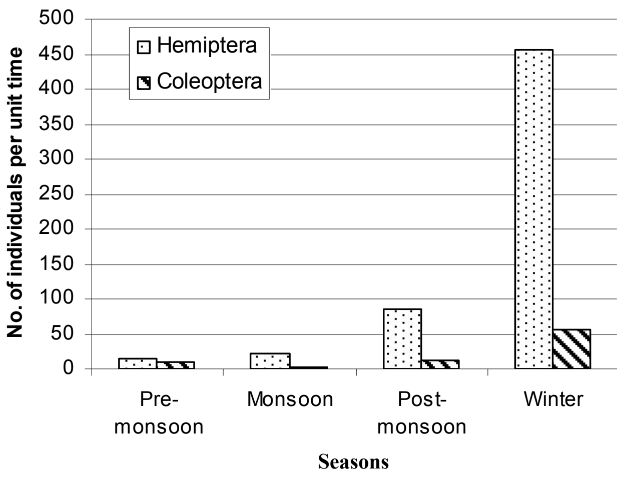

Fig. 2. Seasonal variation in the density of Coleoptera and Hemiptera of the two orders in Mauriagaon stream.

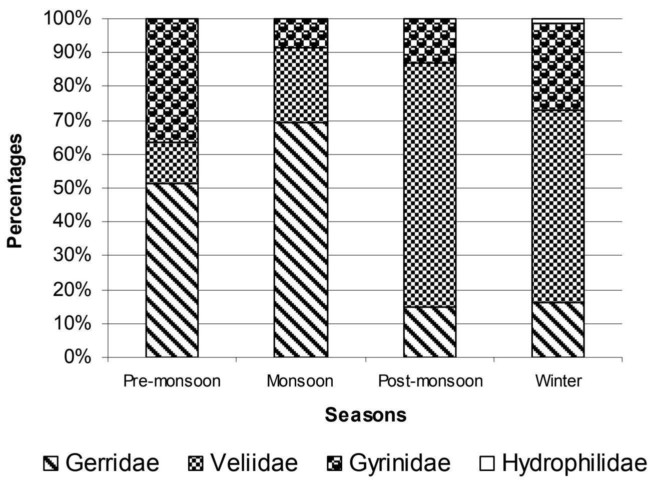

Fig. 3. Seasonal variation in relative abundance of different families of Coleoptera and Hemiptera in Mauriagaon stream.

food resources (Danks 2006; Kai & Corlet 2002; Nakamura & Numata 2006; Tanaka 2000; Vineesh 2007).

Diversity indices provide important information about rarity and commonness of species in a community which in turn helps to understand community structure. The seasonal variation in the diversity indices of Coleoptera and Hemiptera are presented in Table 2. The Shannon Weiner Diversity Index was found to be maximum in pre-monsoon (0.52) and minimum in post-monsoon (0.36). Maximum Berger - Parker Index of Dominance value in post-monsoon (0.72) indicated that the system was occupied by dominant species thus justified the lowest Shannon H' in that season. Evenness index was highest in monsoon (0.83), which was near to 1.

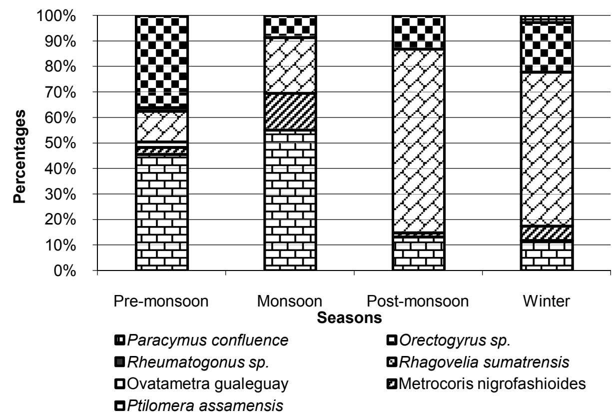

Fig. 4. Seasonal variation in relative abundance of Coleoptera and Hemiptera species in Mauriagaon stream.

Biological monitoring

The Biological Monitoring Working Party score (BMWP) (20 - 25) for the stream indicated a moderate water quality of the system (Chester 1980) (Table 3). The ASPT score of the stream was more than 6 in all the seasons indicating a good water quality (Friedrich *et al.* 1996; Mandaville 2002). However, the SIGNAL scores of the sites (3.56 - 3.77) being closer to 4 indicated that the system was severely to moderately polluted (Gooderham & Tsyrlin 2002).

Environmental variables, correlation and Canonical Correspondence Analysis

Benthic aquatic insects are sensitive indicators of environmental changes in streams because they express long term changes in water and habitat quality rather than instantaneous conditions (Johnson *et al.* 1993). The environmental variables such as WT, FR, DO, F- CO_2, TA, pH, EC, nitrate and phosphate of water were estimated in different seasons (Table 4). Water flow, temperature and substrates are the major factors determining the composition and abundance of benthic invertebrates (Stanford & Ward 1983). In the present study, water temperature of the stream fluctuated from 10 °C to 25 °C. Density of Coleoptera showed significant positive correlation

Table 1. Seasonal variation in dominance status of different species of aquatic insects in Mauriagaon stream based on Engelmann's Scale (Relative abundance and Dominancy) (Engelmann 1978).

Orders	Families	Taxa	Pre- M	M	Post- M	W
Hemiptera	Gerridae	*Ptilomera assamensis* (Amyot & Serville 1843)	45.94 ED	55.07 ED	13.13 D	12.06 D
		Rheumatogonus sp. (Kirkaldy 1909)	1.35 R			
		Metrocoris nigrofascioides (Chen & Nieser 1993)	2.7 R	14.49 D	1.68 R	5.82 SD
		Ovatametra gualeguay (Bachmann 1966)	1.35 R			
	Veliidae	*Rhagovelia sumatrensis* (Lundblad 1922)	12.16 D	21.73D	72.05 ED	61.95 ED
Coleoptera	Gyrinidae	*Orectogyrus* sp. (Régimbart 1883)	36.48 ED	8.7 SD	13.13 D	19.96 D
	Hydrophilidae	*Paracymus confluence* (Wooldridge 1966)				0.21 SR
Total no. of insects			74	69	297	481

Relative Abundance < 1 % = Subrecedent (SR); 1.1 - 3.1 % = Recedent (R); 3.2 - 10 % = Subdominant (SD); 10.1 - 31.6 % = Dominant (D), > 31.7 % = Eudominant (ED). Pre-M = Pre-monsoon, M = Monsoon, Post-M = Post-monsoon, W = Winter.

Table 2. Seasonal variation in the diversity indices based on aquatic insects of Mauriagaon stream.

Season	Diversity Indices		
	Shannon H' Log Base 10	Evenness'(J)	Berger-Parker Dominance (d)
Pre-monsoon	0.52	0.67	0.46
Monsoon	0.502	0.83	0.55
Post- monsoon	0.364	0.605	0.72
Winter	0.457	0.653	0.62

with pH and DO during monsoon while density of Hemiptera, which are all Gerromorpha, was found to have significant positive correlation with DO only in winter season (Table 5). During winter, the habitats and also the food availability of insects become limited. It could be said that the increased DO of the system favoured the life of most taxa which in turn has increased density of Hemiptera as they are predatory in nature. A study on macro-invertebrates of river Yamuna at Kalsi Dehradun of Uttarakhand also found positive correlation of Hemiptera density with DO (Ishaq & Khan 2013a). The DO values of stream water ranged from 8.05 - 9.2 mg L^{-1}. Similar range of DO values were also recorded by Edokpayi & Osimen (2002) in the Ibiekuma stream in Southern Nigeria. Species richness showed significant positive correlation with EC in pre-monsoon. Species richness and RF were positively correlated in post-monsoon. This explained that nutrients accumulated in the system by surface runoff from the catchment area were conducive for survival of variety of species. The ranges of TA (22.5 - 34.72 mg L^{-1}), pH (6.07 - 7.15), nitrate (0.13 - 0.26 mg L^{-1}) and phosphate (0.05 - 0.22 mg L^{-1}) of the stream water were within the desirable limit of drinking water as per BIS (2004) and WHO (2011). TA showed significant negative correlation with total species richness in winter and with total insect density in post-monsoon. A significant negative correlation of nitrate with density of Hemiptera occurred in monsoon. Ishaq & Khan (2013b) also found negative relationship between nitrate concentration and DO in their study at river Yamuna in Doon Valley Uttarakhand. The low values of nitrate recorded during pre-monsoon period might be due to its utilization by phytoplankton (Das *et al.* 1997; Govindasamy *et al.* 2000; Rajashree & Panigrahy 1996).

The association between aquatic insect species and environmental variables as revealed by CCA is shown in Table 6. The eigen values associated

Table 3. Seasonal variation of different Biomonitoring Scores for Mauriagaon stream.

Score	Season	Hemiptera		Coleoptera		Total
		Gerridae	Veliidae	Gyrinidae	Hydrophilidae	
BMWP Score	Pre-Monsoon	5	10	5	-	20
	Monsoon	5	10	5	-	20
	Post-Monsoon	5	10	5	5	25
	Winter	5	10	5	-	20
SIGNAL Grade	Pre-Monsoon	4	3	4	-	
	Monsoon	4	3	4	-	
	Post-Monsoon	4	3	4	2	
	Winter	4	3	4	-	
Weight Factor	Pre-Monsoon	5	3	5	-	13
	Monsoon	5	4	3	-	12
	Post-Monsoon	5	5	5	1	16
	Winter	5	5	5	-	15
SIGNAL Grade X Weight Factor	Pre-Monsoon	20	9	20	-	49
	Monsoon	20	12	12	-	44
	Post-Monsoon	20	15	20	2	57
	Winter	20	15	20	-	55

	Pre-monsoon	Monsoon	Post-monsoon	Winter
ASPT score (BMWP score/ scoring taxa)	6.67	6.67	6.25	6.67
SIGNAL Score = Total of SIGNAL grade X Weight Factor/ Total of Weight factor	3.77	3.67	3.56	3.67

BMWP Score: 0 - 16 = Poor water quality; 17 - 50 = Moderate water quality; 51 - 100 = Good water quality; 101 - 150 = High water quality; 151+ = Very high water quality (Source: Mandaville 2002).
ASPT Score: > 6 = Clean water, 5 - 6 = Doubtful quality, 4 - 5 = Probable moderate pollution,< 4 = Probable severe pollution (Source: Mandaville 2002).
SIGNAL Score: Greater than 6 = Healthy habitat, Between 5 and 6 = Mild pollution, Between 4 and 5 = Moderate pollution, Less than 4 = Severe pollution (Source: Gooderham & Tsyrlin 2002).

Table 4. Mean and standard deviation of environmental variables of water of stream of Mauriagaon in different seasons.

Environmental variables	Season			
	Pre-monsoon	Monsoon	Post-monsoon	Winter
RF (cm)	23.17 ± 0.23	17.92 ± 0.05	12.9 ± 0.04	0
WT (°C)	25.43 ± 1.02	24.87 ± 0.25	21.69 ± 1.2	10.58 ± 0.47
FR ($cm^3 sec^{-1}$)	11797.53 ± 92.8	13060.85 ± 56.8	19683.56 ± 57.57	16350.22 ± 29.33
DO ($mg l^{-1}$)	9.19 ± 0.35	8.05 ± 0.25	8.69 ± 0.82	9.2 ± 4.1
F-CO_2 ($mg l^{-1}$)	12 ± 2.2	4.78 ± 0.15	0.7 ± 0.02	6.11 ± 0.48
TA ($mg l^{-1}$)	34.72 ± 3.6	26.31 ± 0.76	28 ± 2.04	22.5 ± 0.83
pH	6.81 ± 0.09	7.15 ± 0.42	6.07 ± 0.34	6.14 ± 0.08
EC ($mg l^{-1}$)	40.32 ± 4.3	29.38 ± 2.2	37.44 ± 3.8	46.44 ± 2.18
Phosphate ($mg l^{-1}$)	0.05 ± 0.02	0.10 ± 0.05	0.07 ± 0.05	0.22 ± 0.08
Nitrate ($mg l^{-1}$)	0.13 ± 0.039	0.15 ± 0.04	0.20 ± 0.13	0.26 ± 0.08

RF = Rainfall, WT = Water temperature, FR = Flow rate, DO = Dissolved oxygen, F-CO_2 = Free-carbondioxide, TA = Total alkalinity, EC = Electrical conductivity.

Table 5. Significant Pearson's correlations of environmental variables with density and species richness of Coleoptera and Hemiptera of the Mauriagaon stream.

	Seasons	TA	EC	DO	WT	pH	Nitrate	RF
Coleoptera	Pre-monsoon	0.99*						
Species density	Monsoon			0.99*		0.99**		
Hemiptera	Monsoon						-0.99*	
Species density	Winter			0.99*				
Total insect density	Post-monsoon	-0.99*			0.99*			
Total species richness	Pre-monsoon		0.998*					
	Post-monsoon							1**
	Winter	-0.1*						

*= Correlation is significant at the 0.05 level (2-tailed). **= Correlation is significant at the 0.01 level (2-tailed). TA = Total Alkalinity, EC = Electrical Conductivity, DO = Dissolved Oxygen, WT = Water Temperature, RF = Rainfall.

Table 6. Summary statistics of CCA between aquatic insect species and environmental variables for first two axes in Mauriagaon stream.

	Axis 1	Axis 2	Axis 3	Total
Eigen values	0.116	0.026	0.017	0.159
Cumulative Percentage variance	73.2	89.4	100	
Species-environment correlations	1.000	1.000	1.000	

Table 7. Monte-Carlo test of significance of first canonical axis: eigen value, test of significance of all canonical axes: Trace and P-value.

Test of significance of first canonical axis: eigen value	0.116
P-value	1
Test of significance of all canonical axes : Trace	0.158
P-value	1

with each axis actually represent the correlation coefficient between sites and environmental variables (Pielou 1984). An eigen value near to 1 will represent a high degree of correspondence between sites and environmental variables. High eigen values (greater than 1) are always associated with long and strong environmental gradient lines (Palmer 1993). In the present study, the correspondence was measured between seasons and variables, thus the total eigen value 0.16 indicated a medium to low degree of correspondences between species and season.

The eigen values 0.116 and 0.026 for the axis 1 and axis 2 explained 73.2 % and 89.4 % of variance, respectively. The species-environment correlations of CCA axis 1 and 2 were high. The CCA associations of the insect species data with the environmental variables are graphically displayed in Fig. 5. The CCA ordination diagram clearly separated the seasons on the basis of the aquatic insect community structure. The direction and length of each arrow indicate the direction and rate of maximum change in each variable. During pre-monsoon, most of the species showed dependence on TA and F-CO_2, again in winter *Paracymus confluence* showed strong dependence on concentration of phosphate and nitrate. The rest of the species assembled in the center of the two axes. The environmental variables except pH and Flow-rate seem to be equally affecting the distribution of the insect species. Principe (2008), in his study in different habitats of tropical streams, Costa Rica found that aquatic macroinvertebrate assemblages were determined by stream habitat type.

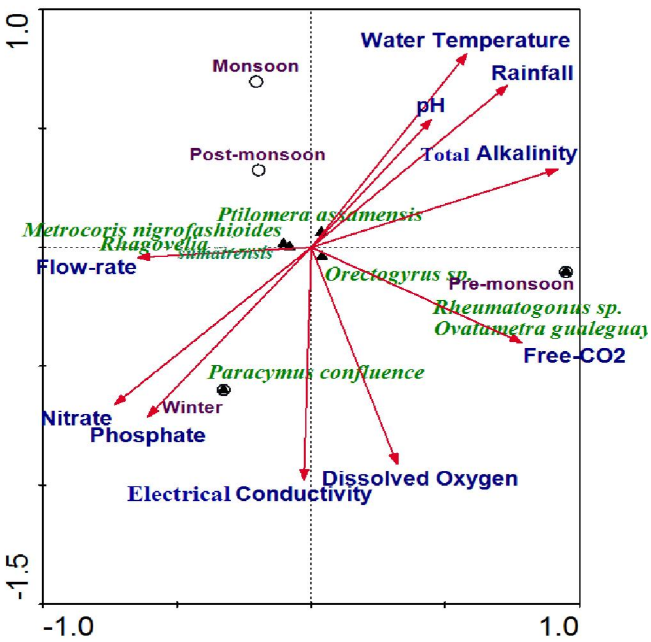

Fig. 5. Triplot of a Canonical Correspondence Analysis (CCA) showing associations among different species of aquatic insects (triangle ▲), water quality variables and seasons (Circle O). Relationships among variables or similarity of samples are indicated by close clusters of points.

Conclusions

This investigation found that different biological monitoring scores based on tolerance values of different Coleoptera and Hemiptera species and their density could be of great value in determining the health of the ecosystems. According to Shannon H', BMWP, SIGNAL and ASPT score the water quality of the Mauriagaon stream ranged from moderate to good. Understanding responses of aquatic insects to environmental changes could be of help to the planners or policy makers to put into practice a scientific-based management of water quality.

Acknowledgements

We thank the Head, Department of Ecology and Environmental Science for providing laboratory facilities and Principal Chief Conservator, Wild Life, Assam, for providing permission of collection of samples from the wildlife sanctuary. The first author thanks the University Grants Commission, New Delhi, India, for financial assistance and also thanks all the members of the team involved in the field work for their help.

References

Allen, D. J., S. Molur & B. A. Daniel. (Compilers). 2010. *The Status and Distribution of Freshwater Biodiversity in the Eastern Himalaya.* Cambridge, UK and Gland, Switzerland: IUCN, and Coimbatore, India: Zoo Outreach Organisation.

APHA (American Public Health Association). 2005. *Standard Methods for the Examination of Water and Wastewater*. 21st edn. Washington DC, USA.

Biodiversity Professional Version 2 for Windows. 1997. The Natural History Museum and Scottish Association for Marine Science.

BIS. 2004. *Indian Standard Specification for Drinking Water IS 10500:2004*. Bureau of Indian Standards.

Bouchard, R. W. 2004. *Guide to Aquatic Macroinvertebrates of the Upper Midwest.* Water Resources Centre, University of Minnesota, St. Paul, Mn.

Bouchard, R. W. 2009. *Guide to Aquatic Invertebrate Families of Mongolia Identification, Manual for Students, Citizen Monitors, and Aquatic Resource Professionals.* Chironomidae Research Group, University of Minnesota, St. Paul, Mn 55108.

Brinkhurst, R. O. 1959. Alary polymorphism in the Gerroidea. *Journal of Animal Ecology* **28**: 211-230.

Brittain, J. E. 1974. Studies on the lentic Ephemeroptera and Plecoptera of southern Norway. *Norsk Geografisk Tidsskrift* **21**: 135-151.

Caro, T. M. & G. O'doherty. 1999. On the use of surrogate species in conservation biology. *Conservation Biology* **13**: 805-814.

CEPF. 2005. *Ecosystem Profile: Indo-Burman Hotspot, Eastern Himalayan Region.* WWF, US-Asian Program/ CEPF.

Chessman, B. 1995. Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification, and a biotic index. *Australian Journal of Ecology* **20**: 122-129.

Chester, R. K. 1980. *Biological Monitoring Working Party*. The 1978 National Testing Exercise, Technical Memorandum 19.

Colorado Insects of Interest. 2013. http://bspm.agsci.colostate.edu/files/2013/03/Water-Striders.pdf.

Danks, H. V. 2006. Key themes in the study of seasonal adaptations in insects. II. Life-cycle patterns. *The Japanese Journal of Applied Entomology and Zoology* **41**: 11-13. (http://odokon.ac.affrc.go.jp).

Das, J., S. N. Das & R. K. Sahoo. 1997. Semidiurnal variation of some physico-chemical parameters in the Mahanadi estuary, east coast of India. *Indian*

Journal of Marine Sciences **26**: 323-326.

Das, K. & S. Gupta. 2010. Aquatic hemiptera community of agricultural fields and rain pools in Cachar district, Assam, north east India. *Assam University Journal of Science & Technology*: *Biological and Environmental Sciences* **5**: 123-128.

Das, K. & S. Gupta. 2011. Hemipteran insect community of an oxbow lake in Barak Valley, Assam, North East India: An ecological study. *Ecology, Environment & Conservation* **17**: 69-73.

Das, K. & S. Gupta. 2012. Seasonal variation of Hemiptera community of a temple pond of Cachar district, Assam, northeastern India. *Journal of Threatened Taxa* **4**: 3050-3058. (www.threatenedtaxa.org).

Davis, J. A., S. W. Rolls & S. A. Balla. 1987. The role of the Odonata and aquatic Coleoptera as indicators of environmental quality in wetlands. pp. 31-42. *In*: D. Majerj (ed.) *The Role of Invertebrates in Conservation and Biological Survey*. Western Australian Department of Conservation and Land Management, Australia.

De Pauw, N., P. F. Ghetti, P. Manzini & R. Spaggiari. 1992. Biological assessment methods for running water. pp. 217-249. *In*: P. J. Newman, M. A. Piavaux & R. A. Sweeting (eds.) *River Water Quality Ecological Assessment and Control.* Commission of the European Communities Bruxelles, Belgium.

Dewalt, R. E., D. W. Webb & M. A. Harris. 1999. Summer Ephemeroptera, Plecoptera and Trichoptera (EPT) species richness and community structure in the lower Illinois river basin of Illinois. *Great Lakes Entomologist* **32**: 115-132.

Dolling, W. R. 1991. *The Hemiptera.* Oxford University Press. Oxford.

Edokpayi, C. A. & E. C. Osimen. 2002. The impact of impoundment on the physical and chemical hydrology of Ibiekuma stream in southern Nigeria. *Tropical Ecology* **43**: 287-296.

Engelmann, H. D. 1978. Zur Dominanzklassifikazierung von Bodenarthropoden. *Pedobilogia* **18**: 378-380.

Epler, J. H. 2006. *Identification Manual for the Aquatic and Semi-aquatic Heteroptera of Florida (Belosto matidae, Corixidae, Gelastocoridae, Gerridae, Hebridae, Hydrometridae, Mesoveliidae, Naucoridae, Nepidae, Notonectidae, Ochteridae, Pleidae, Saldidae, Veliidae).* Florida Department of Environmental Protection, Tallahassee, FL.

Eyre, M. D. & G. N. Foster. 1989. A comparison of aquatic Hemiptera and Coleoptera communities as a basis for environmental and conservation assessments in static water sides. *Journal of Applied Entomology* **108**: 355-362.

Fairchild, G. W., A. M. Faulds & J. F. Matta. 2000. Beetle assemblages in ponds: effects of habitat and site age. *Freshwater Biology* **44**: 523-534.

Friedrich, G., D. Chapman & A. Beim. 1996. *The Use of Biological Material in Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*. 2nd edn. E & FN Spon, New York.

Gooderham, J. & E. Tsyrlin. 2002. *The Waterbug Book: a Guide to the Freshwater Macroinvertebrates of Temperate Australia.* CSIRO Publishing.

Govindasamy, C., L. Kannan & J. Azariah. 2000. Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel coast. *Indian Journal of Environmental Biology* **21**: 1-7.

Heino, J., R. Paavola, R. Virtanen & T. Muotka. 2005. Searching for biodiversity indicators in running waters: do bryophytes, macroinvertebrates, and fish show congruent diversity patterns? *Biodiversity and Conservation* **14**: 415-428.

Hellawell, J. M. 1986. *Biological Indicators of Freshwater Pollution and Environmental Management.* Elsevier Publishers, London.

Hufnagel, L., G. Bakony & T. Vásárhelyi. 1999. New approach for habitat characterization based on species lists of aquatic and semiaquatic bugs. *Environmental Monitoring and Assessment* **58**: 305-316.

Humphries, C. J., P. H. Williams & R. I. Vane-Wright. 1995. Measuring biodiversity value for conservation. *Annual Review of Ecology and Systematics* **26**: 93-111.

Ishaq, F. & A. Khan. 2013a. Seasonal limnological variation and macro benthic diversity of river Yamuna at Kalsi Dehradun of Uttarakhand. *Asian Journal of Plant Science and Research* **3**: 133-144.

Ishaq, F. & A. Khan. 2013b. Diversity pattern of macrozoobenthos and their relation with qualitative characteristics of river Yamuna in Doon valley Uttarakhand. *American-Eurasian Journal of Toxicological Sciences* **5**: 20-29. DOI: 10.5829/idosi.aejts.2013.5.1.72125

Jessup, B. K., A. Markowitz, J. B. Stribling, E. Friedman, K. Labelle & N. Dziepak. 2003. *Family-Level Key to the Stream Invertebrates of Maryland and Surrounding Areas.* 3rd edn. Maryland Department of Natural Resources. Section 10.

Johnson, R. K., T. Wiederholm & D. M. Rosenberg. 1993. *Freshwater Biomonitoring using Individual Organisms, Populations, and Species Assemblages of Benthic Macro-invertebrates.* Chapman & Hall, New York.

Kai, H. K. & T. R. Corlett. 2002. Seasonality of forest invertebrates in Hong Kong, South China. *Journal* *of Tropical Ecology* **18**: 637-644.

Karaouzas, I. & K. C. Gritzalis. 2006. Local and regional factors determining aquatic and semi-aquatic bug (Heteroptera) assemblages in rivers and streams of Greece. *Hydrobiologia* **573**: 199-212.

Kerr, J. T., A. Sugar & L. Packer. 2000. Indicator taxa, rapid biodiversity assessment, and nestedeness in an endangered ecosystems. *Conservation Biology* **14**: 1726-1734.

Mandaville, S. M. 2002. *Benthic Macroinvertebrates in Freshwaters-Taxa Tolerance Values, Metrics, and Protocols*. Soil & Water Conservation Society of Metro. Halifax.http://lakes.chebucto.org/H1/tolerance.pdf.

Margules, C. & R. Pressey. 2000. Systematic conservation planning. *Nature* **405**: 243-253.

Mccreadie, J. W., P. H. Adler & J. F. Burger. 1997. Species assemblages of larval black flies (Diptera: Simuliidae): random or predictable? *Journal of the North American Benthological Society* **16**: 760-770.

Melo, A. S. & C. G. Froehlich. 2001. Macroinvertebrates in neotropical streams: richness patterns along a catchment and assemblage structure between 2 seasons. *Journal of the North American Benthological Society* **20**: 1-16.

Micheal, P. 1984. *Ecological Methods for Field and Laboratory Investigations*. Tata McGraw - Hill Publishing Company Ltd., New Delhi.

Millán, A., P. Abellán, I. Ribera, D. Sánchez & J. Velasco. 2006. The Hydradephaga of the Segura basin (SE Spain): twenty five years studying water beetles (Coleoptera). *Memoriedella Societa Entomologica Italiana* **85**: 137-158.

Moreno, J. L., A. Millán, M. L. Suárez, M. R. Vidal-Abarca & J. Velasco. 1997. Aquatic coleoptera and heteroptera assemblages in waterbodies from ephemeral coastal streams (»ramblas«) of south-eastern Spain. *Archiv für Hydrobiology* **141**: 93-107.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. Da Fonseca & J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

Nakamura, K. & H. Numata. 2006. Effects of photoperiod and temperature on the induction of adult diapause in *Dolycoris baccarum* (L.) (Heteroptera: Pentatomidae) from Osaka and Hokkaido, Japan. *The Japanese Journal of Applied Entomology and Zoology* **41**: 105-109.

Niesser, N. 2004. Guide to aquatic Heteroptera of Singapore and Peninsular Malaysia. III. Pleidae and Notonectidae. *The Raffles Bulletin of Zoology* **52**: 79-96.

Palmer, C. G., J. H. O'keeffe & A. R. Palmer. 1991. Are macroinvertebrate assemblages in the Buffalo river, southern Africa, associated with particular biotopes? *Journal of the North American Benthological Society* **10**: 349-357.

Palmer, M. W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. *Ecology* **74**: 2215-2230.

Pielou, E. C. 1984. *The Interpretation of Ecological Data: a Primer on Classification and Ordination*. Wiley, New York, USA.

Principe, R. E. 2008. Taxonomic and size structures of aquatic macroinvertebrate assemblages in different habitats of tropical streams, Costa Rica. *Zoological Studies* **47**: 525-534.

Purkayastha, P. & S. Gupta. 2015. Ecology of Monabeel, a flood plain ecosystem of Cachar, Assam with special reference to aquatic insect community. *Tropical Ecology* **56**: 245-255.

Rabeni, C. F. & K. E. Doisy. 2000. Correspondence of stream benthic invertebrate assemblages to regional classification schemes in Missouri. *Journal of the North American Benthological Society* **19**: 419-428.

Rajashree, G. & R. C. Panigrahy. 1996. Ecology of phytoplankton in coastal waters of Gopalpur, east coast of India. *Indian Journal of Marine Sciences* **2**: 13-18.

Reyers, B. & A. S. Van Jaarsveld. 2000. Assessment techniques for biodiversity surrogates. *South African Journal of Science* **96**: 406-408.

Riley, C. F. 1921. Responses of the large water-strider, *Gerrisremigis* Say, to contact and light. *Annals of the Entomological Society of America* **14**: 231-289.

Riley, C. F. 1925. Some aspects of the general ecology and behavior of the waterstrider, *Gerrisrufoscutellatus* Latreille. *Entomologist's Record and Journal of Variation* **37**: 65-72, 86-93, 107-115.

Roback, S. S. 1974. Insects (Arthropoda: Insecta). pp. 313-376. *In*: C. W. Hart Jr. & S. L. H. Fullter (eds.) *Pollution Ecology of Freshwater Invertebrates*. Academic Press, Inc.: New York.

Rosenberg, D. M. & V. H. Resh. 1993. Introduction to freshwater biomonitoring and benthic macroinvertebrates. pp. 1-9. *In*: D. M. Rosenberg & V. H. Resh (eds.) *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman and Hall, New York.

Sánchez-Fernández, D., P. Abellán, J. Velasco & A. Millán. 2004. Selecting areas to protect the biodiversity of aquatic ecosystems in a semiarid Mediterranean region using water beetles. *Aquatic Conservation: Marine and Freshwater Ecosystems* **14**: 465-479.

Sivaramakrishnan, K. G. 1992. *Composition and Zonation of Aquatic Insect Fauna of Kaveri and its Tributaries and the Identification of Insect Fauna as Indicator of Pollution*. D.O.E. Project Number 22/18/89-Re.

Stanford, J. A. & J. V. Ward. 1983. Insect species diversity as a function of environmental variability and disturbance in stream systems. pp. 265-278. *In*: J. R. Barnes & G. W. Minshal (eds.) *Stream Ecology: Application and Testing of General Ecological Theory*. Plenum, New York.

Subramanian, K. A. & K. G. Sivaramakrishnan. 2007. *Aquatic Insects for Biomonitoring Freshwater Ecosystems - A Methodology Manual.* Asoka Trust for Research in Ecology and Environment (ATREE), Bangalore, India.

Tanaka, S. 2000. The role of moisture in the control of diapause and mating and aggregation in a tropical insect. *Entomological Science* **3**: 147-155.

terBraak, C. J. F. 1988. CANOCO - an extension of DECORANA to analyze species - environment relationships. *Vegetation* **75**: 159-160.

Thirumalai, G. 1999. Aquatic and semi-aquatic Heteroptera of India. *Indian Association of Aquatic Biologists, Hyderabad* **7**: 74.

Thirumalai, G. 2002. A check list of Gerromorpha (Hemiptera) from India. *Record of Zoological Survey of India* **100**: 55-97.

Torre-Bueno, J. R. 1917. Life history and habits of the larger water-strider, *Gerrisremigis* Say. *Entomological News* **28**: 201-208.

Trimmer, W. L. 1994. *Estimating Water Flow Rates.* Oregon State University, the U.S. Department of Agriculture, U.S.

Vineesh, P. J. 2007. *Ecology and Diversity of Entomo-Fauna in the Litter Stands of Monoculture and Natural Forests in Kannur District.* Ph.D. Dissertation. University of Calicut, Kerala, India.

White, J. & K. Irvine. 2003. The use of littoral mesohabitats and their macroinvertebrate assemblages in the ecological assessment of lakes. *Aquatic Conservation*: *Marine and Freshwater Ecosystems* **13**: 331-351.

WHO. 2011. *Guidelines for Drinking Water Quality*. 4th edn., World Health Organization.

Williams, P. H. 1996. Measuring biodiversity value. *World Conservation* **1**: 12-14.

Williams, P. H. & K. J. Gaston. 1994. Measuring more of biodiversity: can higher taxon richness predict wholesale species richness? *Biological Conservation* **67**: 211-217.

(Received on 09.03.2014 and accepted after revisions, on 08.07.2014)