Impact of riparian land-use patterns on Ephemeroptera community structure in river basins of the southern Western Ghats, India

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ABSTRACT

Key-words:

Ephemeroptera,
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This study analysed the impact of riparian land use in structuring the larval ephemeropteran communities from 25 sites in streams and rivers of Kalakad-Mundanthurai Tiger Reserve (KMTR) of the southern end of the Western Ghats, India. A total of twenty-eight species belonging to twenty-four genera of six families were collected across all the sites. Baetidae and Leptophlebiidae were the most numerous and ubiquitous families, comprising eight genera in each family and eleven and nine species, respectively. The physico-chemical parameters and species richness and abundance of mayflies varied across streams and rivers with different riparian land-use types. Species distribution was influenced by the environmental gradients. Canonical Correspondence Analysis revealed a clear separation of the mayfly assemblages along water quality and riparian land-use gradients. The results of this study suggest that Ephemeroptera taxa can be potentially used as sensitive indicators of riparian land use in lotic ecosystems.

RÉSUMÉ

Impact des modes d'utilisation des terres riveraines sur la structure de la communauté d'éphéméroptères dans les bassins hydrographiques des Ghâts occidentaux du sud, Inde

Mots-clés :

Ephéméroptère,
utilisation
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riveraines,
bioindicateurs,
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Ghâts
occidentaux

Cette étude a analysé l'impact de l'utilisation des terres riveraines dans la structuration des communautés de larves d'éphéméroptères de 25 sites dans les ruisseaux et les rivières de la Kalakad-Mundanthurai Tiger Reserve (KMTR) de l'extrémité sud des Ghâts occidentaux, en Inde. Un total de vingt-huit espèces appartenant à vingt-quatre genres de six familles a été collecté sur l'ensemble des sites. Baetidae et Leptophlebiidae étaient les familles les plus nombreuses et omniprésentes, comprenant huit genres dans chaque famille et onze et neuf espèces, respectivement. Les paramètres physico-chimiques et la richesse en espèces et l'abondance des éphémères variaient entre ruisseaux et rivières de différents types d'utilisation des terres riveraines. La distribution des espèces est influencée par les gradients environnementaux. L'analyse canonique des correspondances a révélé

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une nette séparation des assemblages d'éphémères le long du gradient de qualité de l'eau et d'utilisation des terres riveraines. Les résultats de cette étude suggèrent que les taxons d'Ephéméroptères peuvent être potentiellement utilisés comme indicateurs sensibles à l'utilisation des terres riveraines dans les écosystèmes lotiques.

INTRODUCTION

Around the world, freshwater habitats are being subjected to increased levels of human disturbance (Saunders *et al.*, 2002). A global assessment of the status of inland water ecosystems shows that most threatened river catchments are to be found in the Indian subcontinent (Groombridge and Jenkis, 2000). Dudgeon (1994; 2000) stressed the importance of biomonitoring and identifying areas of riverine biodiversity for long-term conservation. Biological assessment of the freshwater habitats aims to characterise and monitor the conditions of the aquatic resources (Sivaramakrishnan *et al.*, 1996). The assessments are commonly associated with human impacts (Resh *et al.*, 1995). The use of living organisms for monitoring water quality originated in Europe and it is widely used in developed and developing countries (Cairns and Pratt, 1993; Metcalfe-Smith, 1994; Bonada *et al.*, 2006). A spectrum of biological communities including plankton, periphyton, microphytobenthos, macrozoobenthos, aquatic macrophytes and fishes have been used in the assessment of river water quality (De Pauw *et al.*, 1992; Bae *et al.*, 2005; Li *et al.*, 2010).

The systematic development and testing of rapid bioassessment tools on river basins using benthic macroinvertebrates in developing countries like India (Sivaramakrishnan *et al.*, 1996; Sivaramakrishnan, 2000; Subramanian *et al.*, 2005; Dinakaran and Anbalagan, 2007a; 2007b; Sharma *et al.*, 2008; Muralidharan *et al.*, 2010), Thailand (Boomsoong *et al.*, 2008; 2009), Malaysia (Ahmad *et al.*, 2002) and Brazil (Callisto *et al.*, 1998; Buss, 2001; Buss *et al.*, 2002; Silveira *et al.*, 2005; Buss and Salles, 2007) are quite recent. However, due to limited knowledge of the taxonomy and distribution of macroinvertebrates in these countries, these studies have mostly been confined to supraspecific taxonomic levels. Many monitoring programs utilise the EPT (Ephemeroptera, Plecoptera, Trichoptera) index, which is widely used for monitoring efforts.

Several studies in the past revealed that mayfly community structure successfully reflected the environmental conditions in terms of water quality and habitat selection (Gupta and Michael, 1992; Bauernfeind and Moog, 2000; Medina and Vallania, 2001; Ogbogu and Akinya, 2001; Baptista *et al.*, 2001; Rueda *et al.*, 2002; Nelson and Roline, 2003; Buss and Salles, 2007; Arimoro and Muller, 2009; Pond, 2010; Savić *et al.*, 2010; 2011; Kumar *et al.*, 2012) and mayflies are widely used for monitoring efforts. As such, the importance of mayfly communities as biological indicators of organic pollution in the riverine basins of the KMTR was evaluated and the impact of riparian land use in structuring larval ephemeropteran communities was assessed.

MATERIALS AND METHODS

> STUDY AREA

Kalakad-Mundanthurai Tiger Reserve (KMTR), a valuable repository of biodiversity, is in the southern end of the Western Ghats, India, in the Ashambu hills of the Agasthiyamalai region (Figure 1). The KMTR, at about 841 km², comprises a cluster of Protected Areas and Managed Forests on both sides of the interstate border of Kerala and Tamil Nadu and attracts international conservation efforts. The reserve is located between latitude 8° 25' and 8° 53' N

KALAKKAD - MUNDANTHURAI TIGER RESERVE (KMTR)

Figure 1
Map of the study area showing location of the sampling sites in KMTR.

and longitude 77° 10' and 77° 35' E. The reserve spans a range of 40 to 1 800 m in elevation. Agasthiyamalai (1681 m) is in the core zone of the reserve. The Western part of the KMTR, especially along the crest, receives between 2000 and 5000 mm of rainfall during the summer monsoon (south-west monsoon), and has a 2- to 3-month dry period. After crossing the crest of the Ghats, rainfall diminishes abruptly to 1200–2000 mm and at the foot of the Ghats it is between 900–1200 mm. The temperature remains higher than 23 °C along the eastern slope, below 900 m and varies between 16 and 23 °C above 900 m. It is more than 15 °C below 1450 m and less than 15 °C above 1450 m. KMTR has vegetation types ranging from thorn scrub to montane (wet) evergreen forests, all within an altitudinal range from sea level to 1866 m above sea level (Johnsingh, 2001). It gives rise to as many as 14 rivers and there are eleven dams in and around KMTR catering to the agricultural and drinking water needs of the 3 districts.

The headwaters of the KMTR have been protected and there is minimal human impact on these riverine systems. However, the human population has increased in the last two decades. Unsustainable agricultural activities, in particular stream bank cultivation, coupled with the catchment's high slope factor, have increased sedimentation, and there is clear evidence of structural degradation in many watercourses draining the human-inhabited areas. Located on top of the Manimuthar dam and the Manimuthar water falls, the Manjolai area comprises tea plantations established by the British during the colonial era with small settlements around them. However, the KMTR streams/rivers are still reasonably unimpacted because of the aforementioned protection.

From the KMTR catchment, 25 sites were selected to cover a disturbance gradient from intact forested sites in protected areas to degraded sites in downstream areas. The rivers sampled in this study area are Ramanathi, Gadana, Tamiraparani, Manimuthar and Nambiyar. Each site was placed into one of the three land-use categories: native forest, tea plantation and agriculturally impacted (Table I).

> SAMPLE COLLECTION

A total of 25 sites were sampled on three occasions: July (2011), December (2011) and May (2012) for aquatic insects in ten reference sites, five tea plantation sites and ten agriculturally-impacted sites from streams/rivers of the KMTR sanctuary. Standard kicknet methodology with triplicate sampling was followed (Burton and Sivaramakrishnan, 1993). Co-occurring habitat and physico-chemical measurements (air temperature, water temperature, pH, conductivity and dissolved oxygen) were recorded for each sampling site. Water samples were collected from each site at the time of sampling and brought to the laboratory. Water samples were analysed for other parameters such as alkalinity, hardness, biological oxygen demand, chemical oxygen demand, total solids, total dissolved solids and total suspended solids (APHA, 1998). All insects were preserved in 80% ethyl alcohol. Mayfly larvae are particularly fragile because the gills and terminal filaments detach from the body very easily. To minimise damage to specimens, mayflies were collected in containers separate from other aquatic insects. Collected samples were brought to the laboratory and were examined under microscopes (Zeiss, Stemi DV4 and Olympus MIC-D), and identified using standard taxonomic literature.

> DATA ANALYSIS

The structure of the Ephemeroptera assemblage was evaluated by species richness and abundance. The physico-chemical and mean abundance values were transformed into log values. Canonical Correspondence Analysis (CCA) was performed to determine relationships between environmental variables and respective biotic components. CCA was performed by the PAST (1.89) freeware package (Hammer *et al.*, 2001).

Table I

Land use and co-occurring habitat parameters of reference, tea plantation and agricultural impact sites of streams and rivers of KMTR.

River name	Site code	Altitude (m)	Land use	Co-occurring habitat parameters
Ramanathi	R1	237	Native forest	Bedrock, boulders, cobble, gravel, sand
	R2	224	Native forest	Bedrock, boulders, cobble, gravel, sand
	R3	109	Agriculture impact	cobble, gravel, sand
	R4	75	Agriculture impact	cobble, gravel, sand
Gadana river	G1	172	Native forest	Bedrock, boulders, cobble, gravel, sand
	G2	144	Native forest	Bedrock, boulders, cobble, gravel, sand
	G3	81	Agriculture impact	cobble, gravel, sand
	G4	69	Agri./Human impact	cobble, gravel, sand
Tamiraparani	T1	263	Native forest	Bedrock, boulders, cobble, gravel, sand
	T2	254	Native forest	Bedrock, boulders, cobble, gravel, sand
	T3	108	Agriculture impact	cobble, gravel, sand
	T4	105	Agriculture impact	cobble, gravel, sand
Manimuthar	M1	232	Native forest	Bedrock, boulders, cobble, gravel, sand
	M2	210	Native forest	Bedrock, boulders, cobble, gravel, sand
	M3	74	Agriculture impact	cobble, gravel, sand
	M4	68	Agriculture impact	cobble, gravel, sand
Nambiyar	TP1	1266	Tea plantations	Bedrock, sand, mud
	TP2	1055	Tea plantations	Boulders, cobble, gravel, sand
	TP3	1037	Tea plantations	Cobble, gravel, sand
	TP4	1011	Tea plantations	cobble, gravel, sand
	TP5	998	Tea plantations	Boulders, cobble, gravel, sand
	N1	669	Native forest	Bedrock, boulders, cobble, gravel, sand
	N2	445	Native forest	Bedrock, boulders, cobble, gravel, sand
	N3	227	Agriculture impact	boulders, cobble, gravel, sand
	N4	182	Agriculture impact	Boulders, cobble, gravel, sand

RESULT

> PHYSICO-CHEMICAL CHARACTERISTICS OF RIVERS

The air temperature and water temperature (at the time of sampling) did not differ across two land-use categories (*i.e.* reference sites and tea plantation sites) but differed at agriculturally-impacted sites. The pH and conductivity, alkalinity and hardness differed in the three riparian land-use categories. Dissolved oxygen was higher at reference sites than in the other two land-use categories. Biological oxygen demand (BOD) and chemical oxygen demand (COD) were lower at reference sites and tea plantation sites but higher at agriculturally-impacted sites. Total solids, total dissolved solids and total suspended solids were lower at reference and tea plantation sites compared with agriculturally-impacted sites. However, the riparian zone width and bank vegetation cover within the agriculturally-impacted site category were noticeably different from reference and tea plantation sites. Summary statistics for physico-chemical variables are given in Table II.

> SPECIES COLLECTED

A total of twenty-eight species belonging to twenty-four genera of six families were collected across all the stream and river types sampled. Baetidae and Leptophlebiidae were the most numerous and ubiquitous families, comprising eight genera in each family and eleven

Table II

Minimum, mean and maximum of physico-chemical values of three riparian land use categories.

PHYSICO-CHEMICAL PARAMETERS	REFERENCE SITES			TEA PLANTATIONS SITES			AGRICULTURAL IMPACT SITES		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Air temperature (°C)	25.7	29	31.9	25.9	29	30.8	28.8	32.2	34.2
Water temperature (°C)	20.2	23	31.6	20.4	23	25.7	22.4	26.7	31.4
pH	5.7	6.7	8.4	5.9	6.8	7.9	5.2	6.9	8.4
Conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$)	10	17.5	35	12	21.5	31	13.8	26.9	50
Alkalinity (mg·L)	20	25	40	25	35	40	30	40	50
Hardness (mg·L ⁻¹)	20	28	40	30	35	40	30	45	60
DO (mg·L ⁻¹)	6.2	7.6	8	6.5	6.9	7.5	6	6.4	6.8
BOD (mg·L ⁻¹)	4	6	7	4.3	6.8	9.5	6.1	6.3	8
COD (mg·L ⁻¹)	12	14	18	12	14	16	11	15.5	18
TS (mg·L ⁻¹)	20	25	48	25	25.5	40	15	29.8	50
TDS (mg·L ⁻¹)	7.2	14.2	28	10	15.7	20	10	18.1	30
TSS (mg·L ⁻¹)	12.8	17.5	20	15	17.7	20	5	14.6	20

Micro Siemens per centimetre ($\mu\text{S}\cdot\text{cm}^{-1}$).

and nine species, respectively (Tables III and IV). *Baetis conservatus* Muller-Liebenau and Hubbard (1985), *Chopralla similis* Muller-Liebenau (1983), *Liebebiella vera* Muller-Liebenau (1982), *Thalerosphyrus flowersi* Venkataraman and Sivaramakrishnan (1987), *Choroerpes (Euthraulius) nambiyarensis* Kumar, Arunachalam and Sivaramakrishnan (2013), *Edmundsula lotica* Sivaramakrishnan (1985), *Nathanella saraswathiae* Sivaramakrishnan, Venkataraman and Balasubramanian (1996), *Petersula courtallensis* Sivaramakrishnan (1984), *Thraulius gopalani* Grand and Sivaramakrishnan, (1985), *Dudgeodes* sp. (2008) and *Teloganodes kodai* Sartori (2008) were restricted to reference sites. *Baetis frequentus* Muller-Liebenau and Hubbard (1985), *Platybaetis arunachalae* Kumar, Sundar and Sivaramakrishnan, 2012, *Afronurus kumbakkaraensis* Venkataraman and Sivaramakrishnan (1989), *Epeorus petersi* Sivaruban, Venkataraman and Sivaramakrishnan (2013), *Choroerpes (Euthraulius) nambiyarensis* and *Petersula courtallensis* had the highest mean abundance at reference sites (Figure 2). There were significant declines in the densities of *Baetis acceptus* Muller-Liebenau and Hubbard (1985), *Baetis frequentus*, *Labiobaetis geminatus* Muller-Liebenau and Hubbard (1985), *Platybaetis arunachalae*, *Afronurus kumbakkaraensis*, *Epeorus petersi*, *Indialis badia* Peters and Edmunds (1970), *Isca purpurea* Gillies (1951) and *Notophlebia jobi* Sivaramakrishnan and Peters (1984) at tea plantation sites compared with reference sites. *Indobaetis michaelohubbardi* Kumar, Sundar and Sivaramakrishnan (2012) and *Labiobaetis pulchellus* Muller-Liebenau and Hubbard (1985) occurred in both reference and agriculturally-impacted sites. *Cloeon bimaculatum* Eaton (1885), *Procloeon regularum* Muller-Liebenau and Hubbard (1985), *Caenis* sp. Stephens (1853), *Clypeocaenis bisetosa* Soldan (1978), *Torleya nepalica* Allen and Edmunds (1963), and *Choroerpes (Euthraulius) alagarensis* Dinakaran, Balachandran and Anbalagan (2009) were present only at agriculturally-impacted sites, while the other species were either extirpated or were poorly represented at these sites (Figure 2).

> CANONICAL CORRESPONDENCE ANALYSIS

In order to determine which physico-chemical parameters were associated with mayfly species distribution, Canonical Correspondence Analysis was performed. The agriculturally-impacted portion of the ordination represented sites with high water temperature, air temperature, biochemical oxygen demand, total solids, total dissolved solids, concentration of hardness, conductivity and alkalinity, and low concentration of dissolved oxygen and total suspended solids. CCA revealed a clear separation of the mayfly assemblages along

Table III
Distribution of the species of the Ephemeroptera at reference sites and tea plantation sites.

FAMILY	GENUS AND SPECIES	Reference sites										Tea plantation sites				
		R1	R2	G1	G2	T1	T2	M1	M2	N1	N2	TP1	TP2	TP3	TP4	TP5
Baetidae	<i>Baetis acceptus</i>	5	3	4	2	6	2	8	4	5	4	3		5	5	4
	<i>Baetis conservatus</i>	4	4	1	4	2	2	5	5	2	4					
	<i>Baetis frequentus</i>	8	4	4	7	2	6	4	5	7	4	3	5	3	5	4
	<i>Chopralia similis</i>	2		7	3											
	<i>Cloeon bimaculatum</i>															
	<i>Indobaetis michaelohubbardi</i>	12		6	3	8		6		4	8					
	<i>Labiobaetis geminatus</i>	4	1	8	7	6	2	5	5	6	4	5	4	7	2	3
	<i>Labiobaetis pulchellus</i>	2														
	<i>Liebiella vera</i>	4	5	3	2	6	4	6	3	8	2					
	<i>Platybaetis arunachalae</i>	8		12	5	5		6	4	6	8	3	4	5	4	5
Caenidae	<i>Procloeon regularum</i>															
	<i>Caenis</i> sp.															
	<i>Glypeocaenis bisetosa</i>															
Ephemerellidae	<i>Torleya nepalica</i>															
Heptageniidae	<i>Afronurus kumbakkaraensis</i>	11	15	6	8	2	8	6	1	6	4	2	7	4	2	6
	<i>Epeorus petersi</i>	6	7	4	6	8	6	4	2	6	7	3	4	2	6	5
	<i>Thalerosphyrus flowersi</i>	3	2	2	9	8	5	6	3	4	2					
	<i>Choroterpes (Euthraulius) alagarensis</i>															
	<i>Choroterpes (Euthraulius) nambiyarensis</i>	7	9	8	2	6	2	8	3	2	5					
Leptophlebiidae	<i>Edmundsula lotica</i>			4		6		5								
	<i>Indialis badia</i>			16	9	5	12						3		5	5
	<i>Isca purpurea</i>	4						3		3	2				1	3
	<i>Nathanella saraswathiae</i>									1						
	<i>Notophlebia jobi</i>	6	5	2	6	6	4	2	3	4	5	4	3	3	2	5
	<i>Petersula courtallensis</i>	5	1	4	4	12	2	21	18	11	8					
	<i>Thraulius gopalanii</i>						1				5					
Teloganodidae	<i>Dudgeones</i> sp.	7	4	7	3	3	6	6	3	4	8					
	<i>Teloganodes kodai</i>	8	5	4	2	2	1	6	7	5	5					

Table IV

Distribution of the species of the Ephemeroptera at agricultural impact sites.

FAMILY	GENUS AND SPECIES	Agricultural impact sites									
		R3	R4	G3	G4	T3	T4	M3	M4	N3	N4
Baetidae	<i>Baetis acceptus</i>										
	<i>Baetis conservatus</i>										
	<i>Baetis frequentus</i>			6	4		4		4	2	
	<i>Chopralla similis</i>										
	<i>Cloeon bimaculatum</i>	8		6	7	8	6	9	5	4	7
	<i>Indobaetis michaelohubbardi</i>			4	8	8		4		4	
	<i>Labiobaetis geminatus</i>	4		8	4	4	9	5		5	6
	<i>Labiobaetis pulchellus</i>	4		6		4		6		5	
	<i>Liebebiella vera</i>										
	<i>Platybaetis arunachalae</i>				8	6		6		6	
	<i>Procloeon regularam</i>	6	3	5	4	8	6	3	8	7	5
Caenidae	<i>Caenis</i> sp.	6	5	4	5	6	2	7	3	4	3
	<i>Clypeocaenis bisetosa</i>	2	1	6	3	4	5	4	2	6	5
Ephemerellidae	<i>Torleya nepalica</i>					5	4				
Heptageniidae	<i>Afronurus kumbakkaraiensis</i>										
	<i>Epeorus petersi</i>										
	<i>Thalerosphyrus flowersi</i>										
Leptophlebiidae	<i>Choroterpes (Euthraulus) alagarensis</i>	2	18	3	4	2	4		3		3
	<i>Choroterpes (Euthraulus) nambiyarensis</i>										
	<i>Edmundsula lotica</i>										
	<i>Indialis badia</i>					7	12	6		6	
	<i>Isca purpurea</i>										
	<i>Nathanella saraswathiae</i>										
	<i>Notophlebia jobi</i>										
	<i>Petersula courtallensis</i>										
	<i>Thraulius gopalani</i>										
	<i>Dudgeodes</i> sp.										
Teloganodidae	<i>Teloganodes kodai</i>										

water quality and riparian land-use gradients. The occurrence of the Heptageniidae, Leptophlebiidae and Teloganodidae was highly correlated to axes 1 and 2. Caenidae and Ephemerillidae were correlated to axis 3, but Baetidae was correlated to all axes (Figures 3 and 4). At the generic level, *Choprella*, *Liebebiella*, *Thalerosphyrus*, *Edmundsula*, *Nathanella*, *Petersula*, *Thraulius*, *Dudgeodes* and *Teloganodes* were correlated to reference sites. *Platybaetis*, *Afronurus*, *Epeorus*, *Isca* and *Notophlebia* were correlated to tea plantation sites. *Cloeon*, *Procloeon*, *Caenis*, *Clypeocaenis*, *Torleya* and *Choroterpes* were highly correlated with agriculturally-impacted sites (Figure 3). Many species, with the exception of *Cloeon bimaculatum*, *Labiobaetis pulchellus*, *Procloeon regularam*, *Caenis* sp., *Clypeocaenis bisetosa*, *Torleya nepalica* and *Choroterpes (Euthraulus) alagarensis*, which were strongly correlated with agriculturally-impacted sites, were strongly correlated with reference sites with a high percentage of native forest and riparian integrity. *Baetis acceptus*, *Baetis frequentus*, *Labiobaetis geminatus*, *Platybaetis arunachalae*, *Afronurus kumbakkaraiensis*, *Epeorus petersi*, *Indialis badia*, *Isca purpurea* and *Notophlebia jobi* specifically preferred reference sites and tea plantation sites but not agriculturally-impacted sites (Figure 4). This pattern suggests that agricultural activities have a greater degrading impact than forestry conversion.

Figure 2
Abundance (log value) of Ephemeroptera species at three riparian land use sites of KMTR.

DISCUSSION

> STREAM TYPE AND MICROHABITAT QUALITY

This study highlights the biomonitoring potential and impact of riparian land use in structuring the larval ephemeropteran communities in the riverine systems of the KMTR. The distribution of *Baetis conservatus*, *Chopralla similis*, *Liebebiella vera*, *Thalerosphyrus flowersi*, *Choroterpes (Euthraulus) nambiyarensis*, *Edmundsula lotica*, *Nathanella saraswathiae*, *Petersula courtallensis*, *Thraulius gopalani*, *Dudgeodes sp.* and *Teloganodes kodai* was restricted to upstream sites (Figure 2). Streams and rivers of upstream sites are characterised by high altitude, water transparency and higher dissolved oxygen concentration, and low water temperature and turbidity. In contrast, downstream sites are characterised by flow variability, high water temperature, silt load and low altitude. The harsh environmental conditions of downstream sites could have acted as a filter for taxa that are intolerant of low dissolved oxygen concentration and higher water temperatures (Table II). A similar observation was made by Chakona et al. (2009) on caddisfly (Trichoptera) communities of riverine systems of eastern and northwestern Zimbabwe. The following species were mainly distributed in downstream sites: *Cloeon bimaculatum*, *Labiobaetis pulchellus*, *Procloeon regularam*, *Torleya nepalica*, *Caenis sp.*, *Clypeocaenis bisetosa* and *Choroterpes (Euthraulus) alagarensis*.

Figure 3

Canonical Correspondence Analysis (CCA) based on the Ephemeroptera genera and physico-chemical parameters. Reference sites (Ref): *Choprella* (Ch); *Liebebiella* (Li); *Thalerosphyrus* (Th); *Edmundsula* (Ed); *Nathanella* (Na); *Petersula* (Pe); *Thraulius* (Thr); *Dudgeodes* (Du); *Teloganode* (Te). Tea plantation sites (Tea): *Platybaetis* (Pl); *Afronurus* (Af); *Epeorus* (Ep); *Isca* (Is); *Notophlebia* (No). Agriculturally impacted sites (Agri): *Baetis* (Ba); *Cloeon* (Cl); *Indobaetis* (In); *Labiobaetis* (La); *Procloeon* (Pr); *Caenis* (Ca); *Clypeocaenis* (Cly); *Torleya* (To); *Choroterpes* (Cho); *Indialia* (Ins); Air Temperature (AT); Water Temperature (WT); pH (pH); Conductivity (C); Alkalinity (Al); Hardness (Ha); Dissolved Oxygen (DO); Biological Oxygen Demand (BOD); Chemical Oxygen Demand (COD); Total Solids (TS); Total Dissolved Solids (TDS); Total Suspended Solids (TSS).

> LARVAL EPHEMEROPTERAN COMMUNITY COMPOSITION AND RIPARIAN LAND USE

The assemblage pattern of mayfly species in a particular site is ultimately determined by the synergistic effects of broad regional factors, altitudinal, latitudinal, stream size and longitudinal gradients along the stream continuum, as well as local physico-chemical factors, habitat heterogeneity and adjoining biotic factors, mainly predator potential. However, the surrounding land-use pattern also in addition to sedimentation inputs within streams exerts an impact in terms of allochthonous food input. The turnover of mayfly species in the streams with different riparian land-use types showed that taxa composition changed with the riparian land use. The assemblage of Ephemeroptera species differed among the riparian land-use categories. There was a trend towards higher species richness and abundance at reference sites and a significant decline in species richness at tea plantation sites. The abundance of Heptageniidae, Leptophlebiidae and Teloganodidae in the reference sites is a result of good water quality and the dominance of native forest along the river banks and within the catchment.

The absence of the Heptageniidae species *Thalerosphyrus flowersi*, Leptophlebiidae species *Choroterpes* (*Euthraulius*) *nambiyarensis*, *Edmundsula lotica* and *Petersula courtallensis*, and Teloganodidae species *Dudgeodes* sp. and *Teloganodes kodai* at tea plantation sites may therefore be attributed to replacement of native shrubs and trees with tea plants. Species of Heptageniidae, Leptophlebiidae and Teloganodidae are filter-feeders/scrapers and are known to be important in organic matter breakdown in streams of fallen decaying leaves from adjoining riparian plants. Their absence at deforested agriculturally-impacted sites may

Figure 4

Canonical Correspondence Analysis (CCA) based on the Ephemeroptera species and physico-chemical parameters. Reference sites (Ref): *Baetis conservatus* (Bc); *Baetis frequentus* (Bf); *Choprella similis* (Cs); *Liebbebiella vera* (Lv); *Thalerospkyrus flowersi* (Tf); *Choroterpes (Euthraulius) nambiyarensis* (Cn); *Edmundsula lotica* (El); *Nathanella saraswathiae* (Ns); *Petersula courtallensis* (Pc); *Thraulius gopalanii* (Tg); *Dudgeodes* sp. (Ds); *Teloganodes kodai* (Tk). Tea plantation sites (Tea): *Baetis acceptus* (Ba); *Afronurus kumbakkaraensis* (Ak); *Epeorus petersi* (Ep); *Isca purpurea* (Ip); *Notophlebia jobi* (Nj). Agriculturally impacted sites (Agri): *Cloeon bimaculatum* (Cb); *Indobaetis michaelohubbardi* (Im); *Labiobaetis geminatus* (Lg); *Labiobaetis pulchellus* (Lp); *Platybaetis arunachalae* (Pa); *Proclaeon regularum* (Pr); *Caenis* sp. (Cs); *Clypeocaenis bisetosa* (Cb); *Torleya nepalica* (Tn); *Choroterpes (Euthraulius) alagarensis* (Ca); *Indialis badia* (Ib). Air Temperature (AT); Water Temperature (WT); pH (pH); Conductivity (Con); Alkalinity (Al); Hardness (Ha); Dissolved Oxygen (DO); Biological Oxygen Demand (BOD); Chemical Oxygen Demand (COD); Total Solids (TS); Total Dissolved Solids (TDS); Total Suspended Solids (TSS).

be attributed to lack of plant material and an unsuitable habitat and water quality. Land-use parameters that were found to be important descriptors of species distribution patterns were percentage of agricultural land use, percentage of native forest and riparian integrity, as pointed out by Chakona et al. (2009).

The occurrence and abundance of *Cloeon bimaculatum*, *Labiobaetis pulchellus*, *Proclaeon regularum*, *Torleya nepalica*, *Caenis* sp., *Clypeocaenis bisetosa* and *Choroterpes (Euthraulius) alagarensis* at agricultural sites suggest that these species are potential indicators of agricultural impact. A closer look at the distribution of the Ephemeroptera taxa from this study reveals that there were significant declines in species richness and abundance in tea plantation sites. It is quite likely that forest conversion from native to tea plantations might have caused declines in taxa that were recorded from reference sites. Our analysis shows a decrease in species richness and abundance of heptageniids (*Afronurus kumbakkaraensis*, *Epeorus petersi* and *Thalerospkyrus flowersi*) and leptophlebiids (*Choroterpes (Euthraulius) nambiyarensis*, *Edmundsula lotica*, *Indialis badia*, *Notophlebia jobi*, *Petersula courtallensis* and *Thraulius gopalanii*) with decreasing streambed complexity and amount of coarse substrates expressed as percentage of cobbles, percentage of embeddedness and percentage of fine sediments. These mayflies showed a strong preference for a rocky substratum and marginal vegetation, and they use plant material for their food. Heptageniidae, Leptophlebiidae and

Teloganodidae are filter-feeders/scrapers and they generally preferred a 'clean' cobble substratum for attachment and high to turbulent flow to facilitate filtering (Sivaramakrishnan and Venkataraman, 1987).

The abundance of *Cloeon bimaculatum*, *Labiobaetis geminatus*, *Labiobaetis pulchellus*, *Procloeon regularam*, *Caenis* sp., *Clypeocaenis bisetosa* and *Choroterpes (Euthraulius) alagarensis* at agriculturally-impacted sites in this study was related to an increase in the percentage of filamentous algae, which are an important food source, as pointed out in previous work (e.g. Sivaramakrishnan and Venkataraman, 1987). Furthermore, their occurrence at silted sites also suggests that these species may be tolerant to increased sedimentation compared with other ephemeropteran taxa collected during this study. The decline in specialist forest taxa and dominance of simplified and/or generalist taxa following removal of riparian vegetation is well documented (Subramanian et al., 2005). This change in community structure is mainly due to changes in the geomorphology and the associated destruction of in-stream physical habitats as a result of increased sedimentation and poor water quality owing to unsustainable land-use practices. Similarly, previous research has documented the negative effects of riparian land-use change (i.e., natural vegetation to agricultural production) on the diversity, richness and distribution of stream insects (Sivaramakrishnan et al., 1996; Subramanian et al., 2005).

> MAYFLY AS BIOINDICATOR TAXA

With respect to useful bioindicator taxa for measuring riparian land-use impacts in river systems of the study catchments, the results suggest that occurrence of *Cloeon bimaculatum*, *Labiobaetis pulchellus*, *Procloeon regularam*, *Torleya nepalica*, *Caenis* sp., *Clypeocaenis bisetosa* and *Choroterpes (Euthraulius) alagarensis* belonging to the genera *Cloeon*, *Labiobaetis*, *Procloeon*, *Torleya*, *Caenis* and *Clypeocaenis* may be the best bioindicators of agricultural impact. The presence of *Baetis conservatus*, *Chopralla similis*, *Liebebiella vera*, *Thalerosphyrus flowersi*, *Choroterpes (Euthraulius) nambiyarensis*, *Edmundsula lotica*, *Nathanella saraswathiae*, *Petersula courtallensis*, *Thraulius gopalani*, *Dudgeodes* sp. and *Teloganodes kodai* belonging to *Baetis*, *Chopralla*, *Liebebiella*, *Thalerosphyrus*, *Choroterpes*, *Edmundsula*, *Nathanella*, *Petersula*, *Thraulius*, *Dudgeodes* and *Teloganodes* indicate pristine forest conditions with intact riparian vegetation and a high percentage of marginal vegetation.

The Ephemeroptera species *Baetis acceptus*, *Baetis conservatus*, *Chopralla similis*, *Liebebiella vera*, *Afronurus kumbakkaraensis*, *Epeorus petersi*, *Thalerosphyrus flowersi*, *Choroterpes (Euthraulius) nambiyarensis*, *Edmundsula lotica*, *Notophlebia jobi*, *Petersula courtallensis*, *Thraulius gopalani*, *Dudgeodes* sp. and *Teloganodes kodai* were intolerant of fine substrates at agriculturally-impacted sites, and they were reliable indicators of in-stream habitat degradation resulting from increased sedimentation. Overall, the results from this study suggest that Ephemeroptera taxa can be potentially used as reliable bioindicators of organic pollution in running water systems, with biomonitoring potential being progressively more precise when analysed at genus and species levels. However, there is a need for further refined studies by designing experiments to separate land-use change impacts from specific stressors/disturbance to highlight overall synergistic efforts contributing to further deterioration in water quality. However, since many species of these ephemeropteran assemblages are endemic to this ecoregion, the species that are more sensitive to anthropogenic disturbance recorded in this study are particularly relevant to the river catchments of this and adjacent ecoregions and may not be applicable elsewhere in the tropics. Obviously, water quality and riparian land use along with habitat parameters play a significant role in structuring the mayfly assemblages in riverine systems of KMTR.

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