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Research Article

Plecoptera community of two small streams of Shillong, Meghalaya, North-East India

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ABSTRACT

A study on diversity and ecology of Plecoptera larvae was carried out at two small streams, Wahdienglieng and Umrisa of Shillong, Meghalaya, North-east India for the year 2014 and 2015. The total number of families and genera recorded during the study were 3 families and 8 genera. During the first year at Wahdienglieng, the Principal Component Analysis (PCA) revealed that the high weighted variables are total alkalinity, pH, electrical conductivity, water temperature and sand while at Umrisa, free carbon dioxide and *electrical* conductivity were strong variables. The next year at Wahdienglieng, PCA showed pH as the highly weighted variable while at Umrisa, the PCA indicated dissolved oxygen, water temperature and rainfall as influential variables. The CCA (Canonical Correspondence Analysis) dendrogram revealed that *Indonemoura* spp and *Kamimuria* spp have positive impact with sandy substratum in Wahdienglieng; while *Amphinemura* spp showed positive correlation with dissolved oxygen in Umrisa during the first year. In the next year, water temperature showed positive relation with *Indonemoura* spp and *Tetropina* spp at Wahdienglieng and Umrisa, respectively. The presence of Plecoptera larvae in these streams indicated that the water is unpolluted and the substratum type enabled the larvae to reside at various microhabitats with diverse species.

INTRODUCTION

Aquatic biodiversity is disproportionate in number, hence sensitivity of these biodiversity and its ecosystem is more than any terrestrial ecosystems (Roberto, 2016) and the need of conservation of such ecosystems is much required. The members of the order Plecoptera commonly known as stonefly are hemimetabolous insects having 3,497 described species of Plecoptera belonging to 286 genera and 16 families. Ecologically they are of significance in the lotic ecosystems and occur at all the continents except Antarctica. A catalogue of Indian Stoneflies (Insecta: Plecoptera) (Kailash *et al*., 2019) listed 146 species including 27 genera and 8 families all over India. Himalayan Region (87 species) has the highest diversity of stoneflies followed by the Northeast region (51 species) where Meghalaya has 25 species. The plecopterans that represent 80% of the known species in India are Perlidae (49 species, 9 genera) and Nemouridae (69 species, 7 genera). In temperate Asia, Perlidae is also one of the most species-rich (16 families and 1120 species) (DeWalt & Ower, 2019). Burmeister (1839) was the first person to describe the order and name it as Plecoptera. Needham (1909), an American Enotomologist worked first on Indian Plecoptera. Babu *et al*. (2018) recorded 128 species under 24 genera and 8 families of Plecoptera from India. Diversity of Plecoptera maximizes in cool, fast flowing and stony streams (Sivec & Yule, 2004) and declines drastically towards temperate Asian latitudes and tropical latitudes (Sivaramakrishnan *et al*., 2011). Their status differs in northern and southern part of India, where 8 families are known from northern states and two families from southern states (Stark & Sivec, 2014). DeWalt *et al*. (2013) also concurred that family Nemouridae is rich in northern part (Himalayan ranges). Also, recently a new genus and species of Nemourinae (Plecoptera, Nemouridae) was recorded from Sichuan, China which is widely distributed in lotic systems of Holarctic and Oriental regions (Mo *et al*., 2020).

Studies related to Plecoptera are very sparse at northeastern and eastern region where 29 species from Arunachal Pradesh (Kimmin, 1950; Aubert, 1967), 5 species from Darjeeling, West Bengal and 1 species of Nemouridae from West Garo Hills, Meghalaya (Muranyi & Li, 2013) were recorded. Many stoneflies survive better at low temperature at higher altitude as water temperature plays a vital role in egg hatching and adult emergence (Sivaramakrishnan *et al*., 2011). Streams of Shillong which had crystal clear water once upon a time are no more in the pristine state due to human intervention and development. Though Shillong is located in the Biodiversity Hotspot Indo-Burma, the region is data deficient. In this paper, Plecoptera community and their distribution which are pollution sensitive taxa in two streams of Shillong, Meghalaya has been reported for the first time which added knowledge on the diversity of Plecoptera of this region and their preferred habitat. Furthermore plecopterans as one of the sensitive aquatic insect group to any environmental changes, act as bioindicator and hence their occurrence and abundance can reflect the health status of a stream. An attempt also has been made to study the ecology of the streams.

Hence conservation of aquatic insects in general and Plecoptera in particular is important, not only because they are bioindicators but they are also responsible in breaking down organic matter.

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MATERIALS AND METHODS

Study area

Two streams were selected from Shillong (25°34′N, 91°52′ E), Meghalaya. They are Wahdienglieng and Umrisa originating from the foothills of Shillong peak at an altitude of 1646m and 1611m with rocky and sandy substratum flowing through the forests of Risa Colony and Lumparing, respectively, then through the city and finally connect with River Umiam. Shillong peak is the interfluve for many headwater streams flowing through the forests. Small drainages that pass through the city join these streams and pollute them (Figure 1).

Sampling methods

Plecoptera larvae, water and sediment samples were collected for two years (2014 and 2015) from different stretches of the selected streams of Shillong. The four sites of Wahdienglieng are: W1 & U1 – cascades of upstream, W2 & U2 – riffles of midstream, W3 & U3 – pools of midstream, W4 & U4 - pools of downstream (Table 1). Collections were done using hand net (mesh size 40µm) by Kick method (no. per unit time) in the riffles area, nylon pond net in the pool area as well as all out search method by restricting the collection of aquatic insects from an area of 10 m^2 for 1 h in different stretches (Subramanian & Sivaramakrishnan, 2007). The larvae were fixed in 4% formalin and stored in 70% ethanol. Identification was done by consulting standard literature (Subramanian and Sivaramakrishnan, 2007; Jaihao & Phalaraksh, 2013).The hydrological classification was done by following Strahler (1957) and Bispo *et al*. (2002) (Table 1).

Environmental variables of water were analysed by different methods like Dissolved Oxygen (DO) was determined by Winkler method while Total Hardness (TH), Total Alkalinity (TA) and Free Carbon dioxide (FCO_2) were determined by titrating with suitable reagents. pH and Electrical Conductivity (EC) were measured by Systronic µ pH system 362 and Systronics Conductivity TDS meter 308 respectively. Water temperature (WT) was measured using handheld thermometer. Sediment (SAND, SILT, CLAY) analysis was done using Bouyoucos Hydrometer method (Bouyoucos, 1927; APHA, 2005). Rainfall (RF) data were collected from Indian Meteorological Department website (http://www.imd.gov.in).

Data Analyses

The significance of variations of environmental variables during the two years of sampling was determined by non-parametric Kruskal-Wallis test. Further Spearman's rho correlation was computed among environmental variables, the taxa richness and density of Plecoptera larvae of the two streams. Principal Component Analysis (PCA) was also done for the environmental variables for each of the two streams. All the statistical analyses were done using SPSS 20.0 version. Canonical Correspondence Analysis (CCA) was performed using CANOCO for windows 4.5(terBraak, 1995).

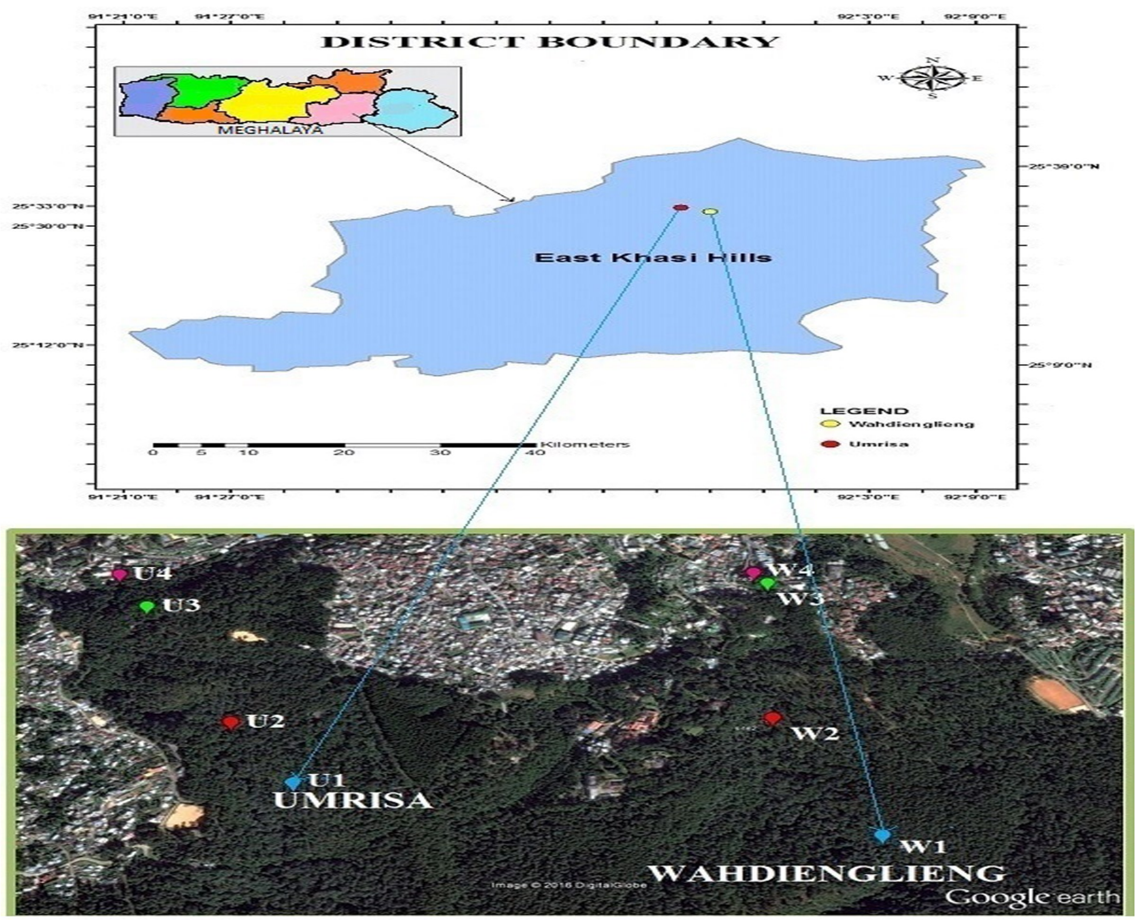

Figure 1. Map of Meghalaya state, East Khasi Hills district showing locations of origin of two streams Wahdienglieng and Umrisa in Shillong and Google earth image of the four stretches of each stream

Table 1. Characteristics of the sampling sites of Wahdienglieng and Umrisa streams

Streams	Sites	Altitude (m)	Latitude N	Longitude E	Degree of canopy cover	Degree of anthropic influence
Wahdienglieng	W1	1646	25˚37′	91˚63′	Medium	Small
	W2	1616	25˚40′	91˚42′	None	Medium
	W3	1554	25˚44′	91˚63′	Medium	Large
	W4	1582	25˚45′	91˚63′	None	Large
Umrisa	U1	1611	25˚36′	91˚54′	Medium	Medium
	U2	1600	25˚41′	91˚53′	Small	Medium
	U3	1551	25˚45′	91˚69′	Small	Medium
	U4	1515	25˚46′	91˚68′	None	Medium

(Scale for degree of canopy cover and degree of anthropic influence range from 0 – 3; 0 – none, 1 – small, 2 – medium, 3 – large) (Strahler, 1957; Bispo *et al*., 2002)

RESULTS AND DISCUSSION

Diversity and distribution of Plecoptera larvae

In the present study, Wahdienglieng and Umrisa comprise of pebbles, gravels, boulders, cobbles and sandy bottom forming variety of microhabitats and availibility of food (Bo *et al*., 2010; Tierno de Figueroa & Lopez-Rodriguez, 2019) that are suitable for shredder and predator plecopterans.This benthic fauna prefer relatively rough and strong bounded structure, stable substrates as found in the upstream because they represent sites of minimal disturbance (Rempel *et al*., 1999). Altogether 3 families and 8 genera of Plecoptera larvae were recorded during the two years study period in Wahdienglieng and Umrisa streams. In the first year, 3 families and 7 genera were found while during the second year, 3 families and 8 genera of the larvae were recorded from both the streams (Table 2). W1, W2, U1 and U3 were the sites where these larvae showed highest number of genera in different years.Two common taxa recorded in both the streams were *Indonemoura* spp and *Neoperla* spp in the first year and additionally two common taxa recorded in the second year were *Amphinemura* spp and *Tetropina* spp.

Genera richness of Plecoptera larvae in Wahdienglieng was observed to be higher in the upstream stretch (W1) (riffle area) and upper midstream (W2) in both the years while in Umrisa, the upstream stretch (U1) and lower midstream (U3) were the sites to have higher number of taxa during the first year. In the second year higher number of genera were recorded in U2 (upper midstream) and U3 (lower midstream). At W4 (downstream) in the first year Plecoptera larva was totally absent while in the second year two genera were recorded (Figure 2). Plecoptera larvae collected from both the streams are shown at Plate 1.

The term "functional feeding group" (FFG) is based on the variety of feeding adaptations among the benthic macroinvertebrates for basic categories of food resources. In the present study in the first year functional feeding groups (FFG) included 1 shredder and 3 predators at Wahdienglieng, while 3 shredders and 2 predators at Umrisa. In the second year the FFG included 3 shredders and 4 predators at Wahdienglieng while at Umrisa it remained the same. Out of 8 genera of Plecoptera recorded in the present study 4 were shredders who prefer dead leaves and plant matters at streambed and 4 were predators favouring usually riffles habitat of upstream and upper midstreams for food. Forest streams are characterized by heavy leaf litter which is readily decomposed by microorganisms and consumed by macroinvertebrates shredders (Hudson *et al*., 2012). Predators encountered during the study were found clinging to stones and pebbles along with their prey like smaller insects of order Ephemeroptera and Diptera (Bo *et al*., 2008).

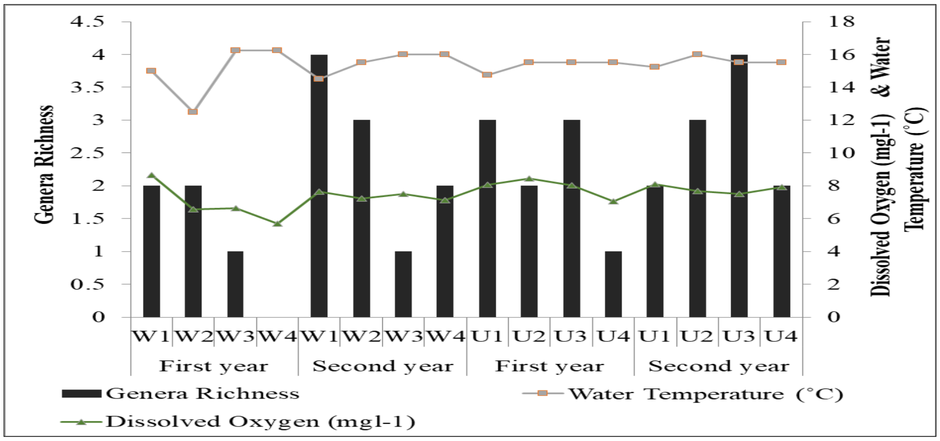

Figure 2. Genera Richness of Plecoptera larvae in primary axis, and Water Temperature (˚C) and Dissolved Oxygen (mgl^{-1}) in secondary axis in Wahdienglieng and Umrisa streams during 2014 and 2015

It was seen that there were variations at the distribution and richness of Plecopteran larvae in the different sites of Wahdienglieng (W1, W2, W3 and W4) and Umrisa (U1, U2, U3 and U4) during the study period. Stoneflies increase in diversity with cool temperature and in riffle area of streams (Hynes, 2000). Many studies have reported that Plecoptera diversity and density is higher with higher elevation (800 m above sea level) (Silveri *et al*., 2008; Boggero *et al*., 2014). It is to be mentioned here that in the present study both the streams are located 1500 m above sea level and as they are rocky streams boulders, cobbles, pebbles and gravels are abundant in all the stretches. All the above facts justified the occurrence of higher number of taxa at W1, W2, W3, and U1, U2 and U3 of the streams. No Plecoptera larvae at site W4 during the first year must be due to certain abiotic factors such as altered water chemistry (Maiolini & Lencioni, 2001) that is not favourable for plecoptera larvae to sustain and exist at such site. This could be due to frequent interference and disturbance in the system because the area has habitation nearby. Among all the sites and two years, highest density was recorded at U4 in the second year.In the first year it was highest at W1 and U1, and in the second year W2 and U4 showed highest density (Figure 3). The density of Plecoptera larvae was found higher in Umrisa stream than that of Wahdienglieng, and further it was more on the second year in both the streams. The factors causing such differences between the two years could be rapid recolonization by these organisms after sudden precipitation, completion of life cycle or availability of food resources as well as refuge (Bojkova *et al*., 2012). Annual rainfall in the second year was observed to be much higher as compared to the first year.

Physicochemical Properties of Water

In streams, water chemistry and habitat quality strongly influence its biota (Hussain, 2011). In the present study estimated values of environmental variables in different sites of both the streams were found well within the acceptable limit (WHO, 2017) (Table 3). DO showed a decreasing trend towards downstream in both the years, which fluctuated between 8.66 mg l^{-1} to 5.69 mg l^{-1}in Wahdienglieng and between 8.46 mg l^{-1} to 7.05 mg l^{-1} in Umrisa. The range of WT had same pattern in both the streams. pH was seen to be slightly acidic which is preferred by Plecopterans. Certain environmental parameters such as temperature or pH that influence the diversity and abundance of Plecoptera larvae (Tixier *et al*., 2012; Tierno de Figueroa & Lopez-Rodriguez, 2019). The Plecopterans can be used as bioindicators as they are more efficient with reliable measurement of physical and chemical parameters. They can help to evaluate water quality for an integrated assessment of ecological effects caused by multiple sources of pollution (Holt & Miller, 2011; Heth & Heth, 2018).

Principal Component Analysis

During the two year study, 11 variables mentioned earlier were selected as factors that has the influence on the occurrence and assemblage of aquatic larvae of the two streams. We have used Principal Component Analysis and further Varimax rotation to find out clearly defined vari factors for easy interpretation. Kaiser-Meyer-Olkin (KMO) (Kaiser, 1974) and Barlett's test of sphericity (Barlett, 1954) were followed to measure the sampling adequacy. The range of KMO is from 0.0 to 1.0, although 0.5 score is taken as the minimum value for a good PCA (Hair *et al*., 2006). The PCA taking Varimax rotation as factors, and the Kaiser's criterion or eigenvalues rule, that is components with eigenvalues 1 or more were retained (Halim *et al*., 2007).The PCA results with Varimax rotation (eigenvectors), eigenvalues, % of Variance and Cumulative % are shown in the Table 4. Three principal components with 81.450% and 75.776% of the total variance were obtained during the first year from Wahdienglieng and Umrisa, respectively. In the second year, four principal components with 85.311%, and 80.413% of the total variance were accounted respectively from both the streams. During the first year, the high weighted variables included TA, pH, EC, WT and SA from Wahdienglieng; while from Umrisa, they were TA, pH, WT, SI and RF. On the second year, the highweighted variables comprised of DO, FCO_2, TA, pH and EC from Wahdienglieng, and DO, WT, SA and RF were the variables from Umrisa. From the loadings of the two years of Wahdienglieng stream, the high weighted variables indicated prominent urban influence i.e anthropic influence. Unlike Wahdienglieng, Umrisa stream showed some important loadings such as RF, WT and DO, an indication that this stream is less affected by any such influences.

Plate 1 (**photograph a-h**). Plecoptera larvae (dorsal view) collected from Wahdienglieng and Umrisa streams – **a**. *Indonemoura* spp , **b**. *Amphinemura* spp , **c**. *Sphaeronemoura paraproctalis* , **d**. *Neoperla* spp , **e**. *Paragnetina* spp , **f**. *Kamimuria* spp , **g**. *Tetropina* spp , **h**. *Paraleuctra* spp.

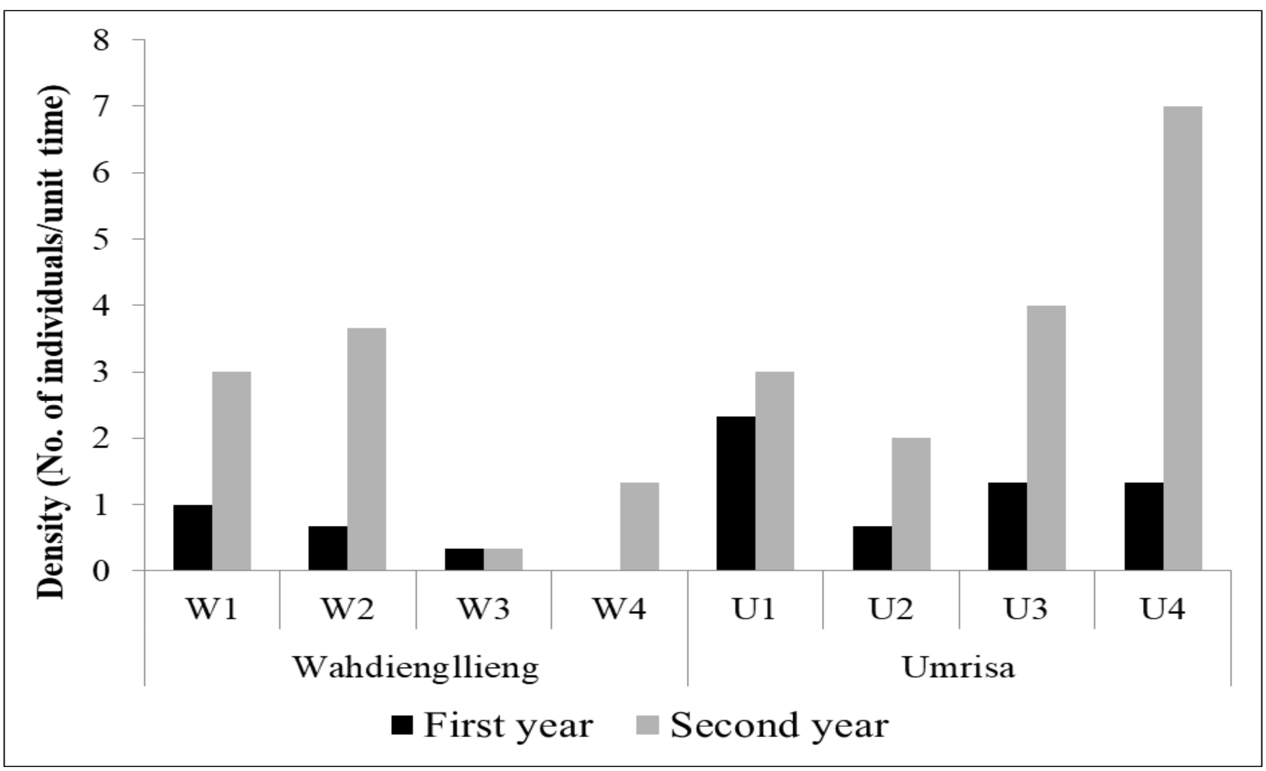

Figure 3. Spatial pattern in density of Plecoptera larvae collected from Wahdienglieng and Umrisa streams during 2014 and 2015

Table 2. Spatial distribution of Plecoptera larvae in different sites of two streams of Shillong during 2014 and 2015

Taxa	FFG	Wahdienglieng				Umrisa			
First year									
		W1	**W2**	**W3**	**W4**	**U1**	**U2**	**U3**	**U4**
Nemouroidae: Nemouridae									
Indonemoura spp Baumann,1975	Clinger/Crawler; Shredder	+(2)	-	-	-	+(3)	+(1)	-	+(4)
Amphinemura spp Ris, 1902	Clinger/Crawler; Shredder	-	-	-	-	+(2)	+(1)	+(1)	-
Nemouroidae: Leuctridae									
Paraleuctra spp Hanson, 1941	Clinger/Crawler; Shredder	-	-	-	-	-	-	+(1)	-
Perloidae: Perlidae									
Neoperla spp Needham, 1905	Clinger/ Crawler; Predator	-	+(1)	-	-	-	-	+(2)	-
Paragnetina spp Geoffroy, 1762	Clinger/ Crawler; Predator	-	-	-	-	+(2)	-	-	-
Kamimuria spp Klapalek, 1907	Clinger/ Crawler; Predator	+(1)	-	-	-	-	-	-	-
Tetropina spp Klapalek, 1909	Clinger/ Crawler; Predator	-	+(1)	+(1)	-	-	-	-	-
Second year									
Taxa	**FFG**	**Wahdienglieng**				**Umrisa**			
		W1	**W2**	**W3**	**W4**	**U1**	**U2**	**U3**	**U4**
Nemouroidae: Nemouridae									
Indonemoura spp Baumann,1975	Clinger/Crawler; Shredder	+(2)	+(6)	+(1)	+(3)	+(6)	+(3)	+(8)	+(20)
Amphinemura spp Ris, 1902	Clinger/Crawler; Shredder	-	+(3)	-	-	+(3)	-	-	-
Sphaeronemoura paraproctalis Aubert, 1967	Clinger/Crawler; Shredder	-	-	-	+(1)	-	-	-	-
Nemouroidae: Leuctridae									
Paraleuctra spp Hanson, 1941	Clinger/Crawler; Shredder	-	-	-	-	-	-	+(2)	-
Perloidae: Perlidae									
Neoperla spp Needham, 1905	Clinger/ Crawler; Predator	-	-	-	-	-	-	+(1)	-
Paragnetina spp Geoffroy, 1762	Clinger/ Crawler; Predator	+(1)	-	-	-	-	-	-	-
Kamimuria spp Klapalek, 1907	Clinger/ Crawler; Predator	+(6)	-	-	-	-	-	-	-
Tetropina spp Klapalek, 1909	Clinger/ Crawler; Predator	-	+(2)	-	-	-	+(3)	+(1)	+(1)

(- = absent, + = present, FFG = Functional Feeding Groups)

Table 3. Spatial variations in environmental variables (Mean±SD) of Wahdienglieng and Umrisa streams during 2014 and 2015

	Environmental variables	**Wahdienglieng**				**Umrisa**			
		W1	**W2**	**W3**	**W4**	**U1**	**U2**	**U3**	**U4**
First year	DO(mgl^{-1})	8.66±0.58	6.57±1.38	6.65±2.23	5.69±2.57	8.07±1.01	8.46±1.08	8.04±1.3	7.05±1.67
	FCO_2(mgl^{-1})	5.5±1	4.5±3.11	6.25±1.5	7.5±0.58	5.75±1.71	6.25±1.71	7.25±0.5	7.25±2.06
	TH(mgl^{-1})	82.63±35.72	51.3±51.57	82±23.15	87.25±26.85	79.8±26.36	80.05±25.91	81.6±22.42	81.9±24.52
	TA(mgl^{-1})	24.74±4.74	21.24±15.81	30.41±7.33	39.95±11.62	18.98±11.62	22.58±12.83	22.88±10	27.33±10.96
	pH	6.32±0.44	4.91±3.3	6.81±0.55	6.87±0.48	6.05±0.65	6.19±0.54	6.52±0.38	6.54±0.17
	EC(μScm^{-1})	13.31±1.61	8.26±6.03	24.95±14.89	42.19±28.87	11.09±2.5	24.13±5.79	31.3±5.65	32.58±5.81
	WT(◦C)	15±3.92	16.3±8.81	16.25±3.3	16.25±3.3	14.75±2.06	15.5±1.73	15.5±2.89	15.5±2.89
	RF(mm)	158.38±151.3	158.38±151.3	158.38±151.3	158.38±151.3	158.38±151.3	158.38±151.3	158.38±151.3	158.38±151.3
	SAND (%) (2mm)	92.94±2.94	91.58±4.18	91.69±1.55	92.49±1.6	92.79±1.06	93±1.41	91.65±1.85	91.75±1.78
	SILT (%) (0.05 mm)	3.53±3.4	5.01±3.82	4.81±3.2	3.8±1.94	3.38±2.81	3.39±2.03	4.34±2.51	4.21±2.16
	CLAY (%) (0.002 mm)	3.54±1.68	3.41±2.12	3.5±2.82	4.21±2.90	3.84±2.77	2.86±2.20	4.01±2.04	4.04±2.67
		Wahdienglieng				**Umrisa**			
		W1	**W2**	**W3**	**W4**	**U1**	**U2**	**U3**	**U4**
Second year	DO(mgl^{-1})	7.66±1	7.22±0.89	7.49±1.12	7.12±1.61	8.11±0.6	7.67±0.57	7.51±0.75	7.92±0.73
	FCO_2(mgl^{-1})	6.58±2.13	5.83±1.67	6.08±2.32	6.83±4.79	7.5±3.18	6.42±0.88	5.67±0.61	7.25±2.63
	TH(mgl^{-1})	62.67±3.13	63.25±5.76	65.17±9.85	63.67±25.86	62.08±1.85	63.92±4.06	66.92±4.52	72.83±10.84
	TA(mgl^{-1})	14.28±5.75	14.28±4.58	16.69±5.82	20.88±14.37	9.36±0.98	10.69±1.08	12.86±3.51	14.91±4.63
	pH	6.5±0.33	6.434±0.27	6.5±0.47	6.44±0.37	6.41±0.51	6.44±0.54	6.52±0.57	6.5±0.64
	EC(μScm^{-1})	22.98±14.59	23.09±17.45	30.74±17.91	33.18±21.22	19.36±17.65	31.37±5.84	39.18±11.55	36.48±9.38
	WT(◦C)	14.5±2.38	15.5±2.38	16±2.83	16±2.83	15.25±2.06	16±1.83	15.5±3	15.5±3
	RF (mm)	176.98±150.6	176.98±150.6	176.98±150.6	176.98±150.6	176.98±150.6	176.98±150.6	176.98±150.6	176.98±150.6
	SAND (%) (2 mm)	95.88±2.17	94.25±5.12	95.58±3.24	97.25±1.89	96.5±2.52	96.08±2.54	95±3.28	96±1.63
	SILT (%) (0.05 mm)	1.92±1.07	2.75±1.45	3.42±2.22	2.29±1.60	2.58±1.77	2.5±1.73	3.42±2.57	2.5±1
	CLAY (%) (0.002 mm)	2.21±	2.58±2.07	1±3.46	0.46±1.15	0.92±0.42	1.47±1.17	1.58±1.42	1.5±1

Table 4. PCA with Varimax rotation (Eigenvectors) of the environmental variables of the streams Wahdienglieng and Umrisa during 2014 and 2015

Variables	**Wahdienglieng**							**Umrisa**						
	(First year)			**(Second year)**				**(First year)**			**(Second year)**			
	VF1	**VF2**	**VF3**	**VF1**	**VF2**	**VF3**	**VF4**	**VF1**	**VF2**	**VF3**	**VF1**	**VF2**	**VF3**	**VF4**
DO(mgl^{-1})	0.36	-0.31	**0.78**	**-0.77**	-0.40	0.1	0.14	-0.57	**-0.76**	0.16	**-0.88**	0.04	-0.21	-0.14
FCO_2(mgl^{-1})	-0.06	-0.43	**-0.72**	**0.9**	-0.16	0.01	-0.13	0.25	0.28	**0.61**	-0.05	**0.72**	0.44	-0.02
TH(mgl^{-1})	0.46	**0.71**	0.26	0.04	**0.76**	0.27	0.42	**0.74**	0.5	-0.17	0.23	0.00	-0.05	**0.89**
TA(mgl^{-1})	**0.88**	0.01	-0.09	**0.60**	0.5	0.5	-0.12	-0.39	-0.28	**0.81**	0.17	0.26	0.33	**0.77**
pH	**0.82**	0.06	0.55	**0.75**	0.15	-0.10	0.11	**0.89**	0.09	-0.14	-0.02	0.04	**0.89**	0.08
EC(μscm^{-1})	**0.85**	0.24	0.16	**0.85**	-0.08	-0.18	0.11	**0.65**	-0.12	-0.04	-0.11	0.001	**0.65**	0.44
WT(◦C)	**0.82**	0.16	0.48	-0.02	**0.95**	0.13	-0.1	0.08	**0.88**	0.35	**0.92**	-0.01	-0.29	0.12
SAND (%) (2 mm)	**0.81**	-0.02	0.58	-0.12	0.16	**0.84**	-0.43	-0.59	-0.32	-0.35	0.07	**0.9**	-0.36	0.13
SILT (%) (0.05 mm)	0.41	**-0.78**	-0.06	-0.001	-0.11	-0.19	**0.93**	-0.07	-0.08	**0.94**	-0.17	**-0.86**	0.08	-0.11
CLAY (%) (0.002 mm)	0.19	**0.75**	0.14	0.18	-0.06	**-0.93**	-0.06	**0.65**	0.5	0.2	0.23	-0.4	**0.66**	-0.05
RF (mm)	0.15	**0.82**	-0.26	0.17	**0.86**	-0.07	-0.44	-0.01	**0.89**	-0.27	**0.91**	0.26	0.08	0.14
Eigen value	4.07	2.72	2.17	3.14	2.73	2.02	1.51	3.08	2.93	2.33	2.6	2.35	2.22	1.66
% of Variance	37.02	24.68	19.75	28.44	24.84	18.32	13.71	27.97	26.62	21.19	23.72	21.4	20.17	15.12
Cumulative %	37.02	61.7	81.45	28.44	53.28	71.6	85.31	27.97	54.59	75.78	23.72	45.12	65.29	80.41

*Extraction method: principal component analysis, rotation method: Varimax with Kaiser Normalization, Bold values indicate highly correlated variables in the PCs (> 0.6)

Spearman's rho correlation

Spearman's rho correlation, a non-paramatric analysis for non-normally distributed data was analyzed among the environmental variables, genera richness and density of Plecoptera larvae collected from Wahdienglieng and Umrisa streams (Table 5). Genera richness and density of Plecoptera larvae showed significant negative correlations with TA and WT in Wahdienglieng during the first year. PCA also showed high loading of these two variables in the Wahdienglieng which explained the less Plecoptera genera richness compared to stream Umrisa. In Umrisa, both genera richness and density of Plecoptera were negatively correlated with silt (SI) and clay (CL). The reason might be that Plecoptera larvae prefer higher particle size substrate such as pebbles and gravels (Oliveira & Nessimian, 2010). In the second year, genera richness and density had significant positive correlations with FCO_2 and EC in both the streams.

Canonical Correspondence Analysis

Triplot of Canonical Correspondence Analysis were determined using CANOCO for windows 4.5 which show association between different Plecoptera genera found at two streams and the environmental variables in both the years (Figure 4). In the first year at Wahdienglieng, *Kamimuria* spp, a Perlid and a predator has a flattened body and can find better refuges at any microhabitat that provides food resources (Hynes, 1970). *Paragnetina* spp. and *Kamimuria* spp were seen associated with the site W1, strongly influenced by pH and DO. In W1 pH was found slightly acidic favoured by Plecoptera larvae (Tierno de Figueroa & Lopez-Rodriguez, 2019). Similarly DO concentration at W1 indicated well oxygenated water conducive for high diversity and richness of the aquatic communities especially those who require clean and cold water like Plecoptera larvae, in which they act as indicator of water quality (Tixier *et al.*, 2012). The site W4 had strong association with *Sphaeronemoura paraproctalis* influenced by TA and EC indicating anthropogenic intervention.

CCA represent Umrisa as follows, in both the years U2 and U4 is placed in the same compartment indicating their similar characteristics. They are independent of environmental variables except WT in the second year. *Amphinemura* spp and DO were found positively correlated with each other in both the years and *Paraleuctra* spp and *Neoperla* spp which were recorded only at Umrisa was associated

Table 5. Significant Spearman's correlations of environmental variables with plecopteran genera richness (GR) and density (DEN) in Wahdienglieng and Umrisa streams

Spearman's rho correlation	Environmental variables	Wahdienglieng		Umrisa	
		GR	DEN	GR	DEN
First year	TA	-0.333*	-0.332*	NS	NS
	WT	-0.286*	-0.285*	NS	NS
	SI	NS	NS	-0.311*	-0.309*
	CL	NS	NS	-0.342*	-0.344*
Second year	FCO_2	0.436**	0.435**	0.384**	0.389**
	pH	NS	NS	0.419**	0.422**
	EC	0.439**	0.439**	0.324*	0.321*

Note : TA – Total Alkalinity, WT – Water temperature, SI – Silt, CL – Clay, FCO_2 – Free Carbon dioxide, EC – Electrical Conductivity, *= significant at 0.05 level, **= significant at 0.01 level and NS= not significant

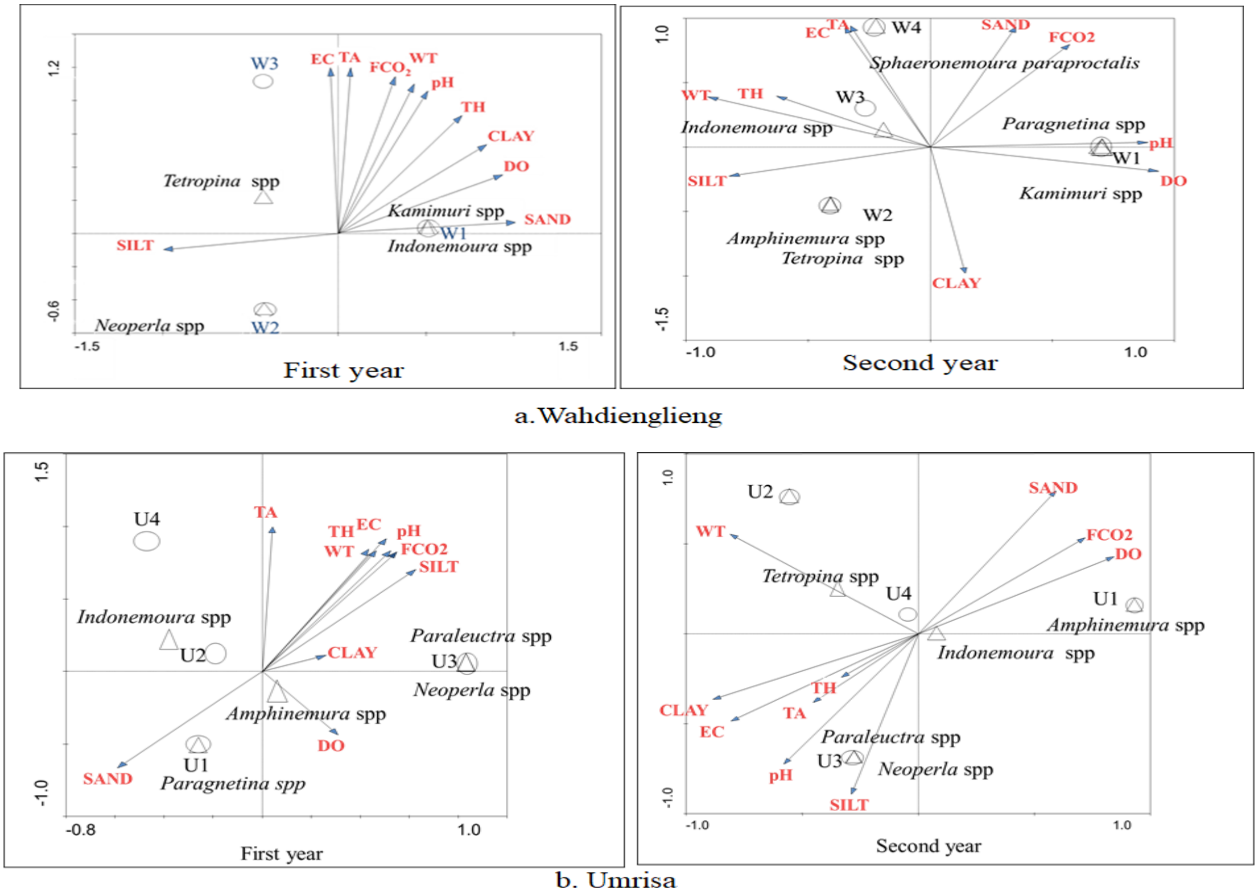

Figure 4. Triplots of Canonical Correspondence Analysis (CCA) showing associations of plecopteran larvae (triangles △) with environmental variables (arrows ↓) in four different sites (circles ○) during the first and second year of a. Wahdienglieng and b. Umrisa

with U3. *Paraleuctra* spp belonging to Leuctridae family is one of the aquatic insects that has 0 (zero) tolerance value with sensitivity grade 10 could be another reason for this larva to have affinity to this site (Mandaville, 2002) showing that the water quality of the site is unpolluted. They are also difficult to collect as the pre – emergent nymphs are hyporheic (Beaty, 2015).

Conservation of these aquatic ecosystems (streams, rivers, lakes, etc) and using such aquatic organisms (Plecoptera or other macroinvertebrates) as indicators is important for the survival of these resources and human race. Because, these organisms (Plecoptera) are the first to get eliminated from freshwater systems after relatively enrichment of nutrient, habitat deterioration or any other aquatic thermal regime change (Dewalt & Ower, 2019).

CONCLUSION

This study on the diversity and ecology of the two streams revealed that Plecoptera larvae are sensitive to slight changes in the ecosystem. Any unwanted alteration in either physical or chemical factors of water can cause hindrance to the occurrence and distribution of Plecopterans. It can be concluded that Plecoptera nymph has a strong affinity with the environmental factors such as substrate, anthropic action, dissolved oxygen, temperature and elevation. Therefore, their occurrence in most of the sites of these two water systems (Wahdienglieng and Umrisa) indicates that the water is still unpolluted and can be used as reference sites for those nearby urban streams. These two streams prevail at the city and from the two years study, it revealed that the study of diversity of pollution sensitive aquatic community like Plecoptera and the information gain from these streams can be used to refer for the future information for stakeholder and policy makers in relation to the quality of water and its conservation. These streams can be compared with other lotic systems which are in or around Shillong city to get a clear understanding as to how to restore, curb or manage any pollution related problems.

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