Land use influence on the aquatic insect communities on tropical forest streams of Liwagu River, Sabah, Malaysia

[1]Mohd S. I. Shafie, [1]Andrew B. H. Wong, [1,2]Sahana Harun, [1,2]Arman H. Fikri

[1] Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia; [2] Water Research Unit, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia. Corresponding author: A. H. Fikri, arman@ums.edu.my

Abstract. The diversity of aquatic insect communities from three types of land use (forest, agricultural and urban development) of Liwagu River, Sabah was investigated to study the relationships between aquatic insects with physico-chemical parameters and habitat quality parameters. Two stations of the forest area recorded highest species richness, abundance and proportion of sensitive aquatic insects taxa compared to the agricultural and urban development area. Cluster analysis illustrated the association of aquatic insect communities with the three types of land use. The functional feeding group of collector-gatherer and collector-filterer were dominant in all sampling stations. The results of the canonical correspondence analysis (CCA) shown the physico-chemical parameters (dissolved oxygen, temperature, phosphate, nitrate and conductivity) in addition to habitat quality assessment (canopy cover, epifaunal substrate, bank stability, vegetative protection, riparian vegetation zone and total habitat assessment) were the important factors that affecting the diversity of aquatic insect communities at Liwagu River, Sabah, Malaysia.
Key Words: biodiversity, feeding group, habitat quality assessment, physico-chemical parameters, land use, tropical forest stream.

Introduction. The ecological consequences of land use change can be severe, especially prevalent in lotic ecosystems, which integrate environmental impacts over large spatial scales (Palmer et al 2002). The agricultural activities such as tilling practices in crop fields can lead to soil erosion (Kang et al 2001) and runoff that cause large amounts of fine sediment deposition in nearby streams and rivers (Richter et al 1997). While sediment deposition has been described as the most extensive type of agricultural stream pollution (Cooper 1993), the drastically alteration of hydrology is another dominant problem affecting water quality in urbanizing watersheds (Paul & Meyer 2001). Specifically, increased impervious surface cover associated with development causes greater peak flood discharge volumes, leading to changes in stream geomorphology and channel erosion (Booth & Jackson 1997).

These anthropogenic disturbances in stream habitats can cause dramatic ecological transformations, including changes in ecosystem processes (Buffagni & Comin 2000; Gessner & Chauvet 2002) and community structure (Barbour et al 1996; Song et al 2009; Virbickas et al 2011). Alterations of aquatic insect communities have been the most extensively studied ecological responses to human impacts in freshwater ecosystem (Paul & Meyer 2001). Land use changes had been associated with changes of aquatic insects diversity (Egler et al 2012; Hepp et al 2013), overall abundance (Gimenez et al 2015), the proportion abundance of tolerant taxa (Hall et al 2001; Walsh et al 2001), and the distribution of ecological functional feeding groups (Brasil et al 2014; Saulino et al 2014). These changes in aquatic insect communities structure have been documented with the conversion of natural landscapes for both agricultural uses (Genito et al 2002;

Scherr & McNeely 2008; Bertaso et al 2015), as well as urban development (Lenat & Crawford 1994; Morley & Karr 2002; Stepenuck et al 2002).

Determining whether agricultural land preservation has a conservation value for lotic ecosystems requires an explicit examination of the ecological differences between stream communities in landscapes dominated by agriculture and development (Bertaso et al 2015). Recognizing changes in aquatic insect communities at urbanizing sites along this gradient could help establish management priorities for the conservation of biological diversity. Furthermore, changes in the diversity of particular invertebrate taxa (sensitive taxa and functional feeding groups) could indicate changes in consumer resources and identify which organisms are particularly susceptible to land use change (Saulino et al 2014). Understanding community patterns across the land use gradient is necessary to investigate specific factors within agricultural or developed areas that are affecting stream ecosystems. Therefore, this study aims to investigate the effects of different land use on the biological and ecological diversity of aquatic insects in respectively to the water quality and habitat quality in Liwagu River, Sabah Borneo, Malaysia.

Material and Method

Study site. The study was carried out in Liwagu River, northeast of the state of Sabah Borneo, Malaysia. The river is located between latitudes 5°43’ N and 5°05’ N and longitudes 116°51’ E and 116°85’ E. Most parts of Liwagu River are covered by primary and secondary forests. Kundasang area near the upstream of the river basin had intensive agricultural activities that create problems concerning water quality. In Ranau area, logging activities, mining activities and urban settlement further deteriorate water quality due to soil erosion and water pollution. Six sampling stations were selected along the Liwagu River: station LF1 and LF2 located at upstream (forest area), as reference sites; station LA3 and LA4 located at the midstream (agricultural area); station LU5 and LU6 located downstream (residential area) (Figure 1).

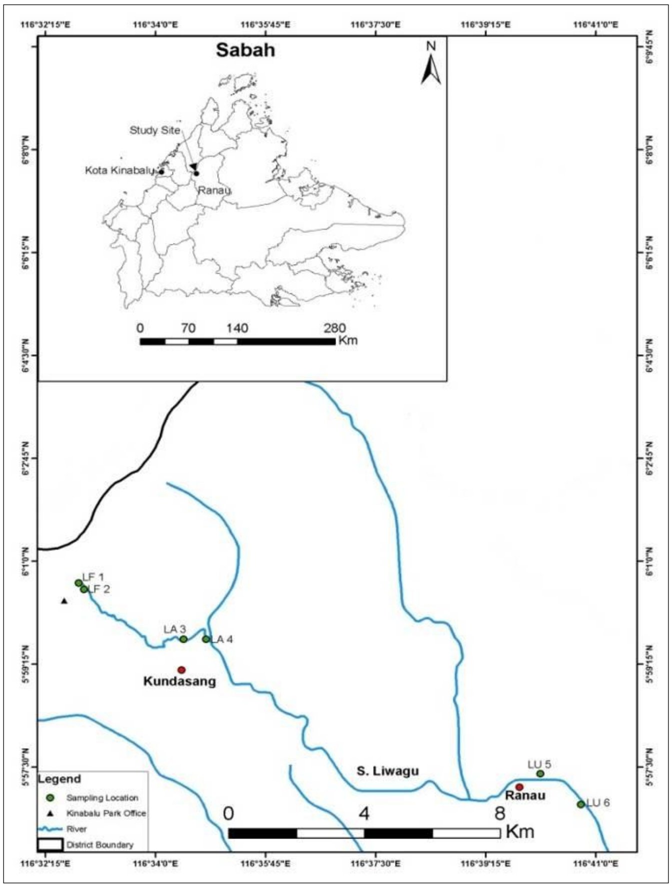

Figure 1. Location of study site at Liwagu River, Sabah, Malaysia.

Sampling of aquatic insect. Aquatic insects were collected from Liwagu River from April to October 2015 by sampling along an approximately 100 meter stretch of the river. Surber net (mesh size 125 µm, 900 cm^2 area) was used to collect the aquatic insects. At each sampling station, the aquatic insects were sampled in rivers influenced by agricultural, residential area and in the river with no anthropogenic disturbances (forest area). Three replicates of each of the six important habitats (run, riffle, pool, leaf litter, aquatic vegetation and stone substrate) were sampled. The Surber net was placed opposite with the flowing water. Big stones in swift-flowing water will be hand-lifted and wash by rubbing on the rock surface to remove the aquatic insects into the net (McGavin 2007). All aquatic insects were sorted and preserved in 95% ethanol. The aquatic insects were identified to the lowest possible taxonomical level with identification key available (Morse et al 1994; Yule & Yong 2004; Merritt et al 2008). The collected aquatic insects were categorized into five functional feeding groups on the basis of the earlier description of Merritt et al (2008) for aquatic insects. The functional feeding groups (FFGs) included collector-filterers (CF), collector-gatherers (CG), scrapers (SC), predators (P) and shredders (SH).

Physical and chemical parameters. At each station, pH, temperature, dissolved oxygen (DO), salinity and conductivity were measured *in situ* by using YSI multiparameter. Three replicates of water samples were collected along the stations into the 200 mL high density polyethylene (HDPA) bottles for analyses of ammonium nitrogen, nitrate, phosphate and total suspended solid (TSS). Ammonium nitrogen, nitrate and phosphate were analysed by using a colorimeter DR 900 while TSS was analysed by using the gravimetric method (APHA 1992).

Habitat assessment. For this study, visual-based habitat assessment of Rapid Bioassessment Protocols was employed (Barbour et al 1999). Meanwhile, riparian canopy cover was measured using a spherical densiometer (Hamid & Md Rawi 2014).

Data analysis. Several statistical methods were used to analyze data collected from sampling along the Liwagu River Basin, Sabah. Shannon-Weiner index (H') and Simpson index (1/D) was used to measure species diversity in order to understand the biotic community at every sampling station. Then, Bray-Curtis and UPGMA were computed for cluster analysis which is to analyze the similarities between sampling stations according to the number of individuals per species. Besides, Kruskal-Wallis test was used to investigate the significant differences of physico-chemical parameters and habitat score with different type of land use. PC-ORD version 5.0 was used to study the relationship among the diversity of aquatic insects with the physico-chemical parameters and habitat quality score by using canonical correspondence analysis (CCA). Meanwhile, the abundance data of aquatic insects were transformed using log (x+1).

Results

Physico-chemical parameters and habitat quality assessment. Table 1 shows the physico-chemical parameters and habitat quality score of the six sampling stations in Liwagu River, Sabah. Most of the parameters show significant differences (Kruskal-Wallis, $p < 0.05$) between the sampling stations except for pH level. The highest concentrations of dissolved oxygen (DO) were recorded at both station LF1 and LF2. Furthermore, the conductivity, suspended solid, ammonia-nitrogen, nitrate and phosphate on the urban development (LU5 and LU6) were higher than on the forest area (LF1 and LF2) of the Liwagu River. The total habitat score recorded was the highest at stations LF1 and LF2, while the lowest at the station LU6 (Table 1).

Table 1
Mean±SD and Kruskal-Wallis results of physico-chemical parameters and habitat quality assessment of Liwagu River, Sabah, Malaysia

	Forest		*Agricultural*		*Urban development*	
	LF1	*LF2*	*LA3*	*LA4*	*LU5*	*LU6*
*Elevation (a.s.l)**	*1516*	*1498*	*1220*	*1163*	*526*	*486*
Physico-chemical water quality parameters						
pH	7.43±0.17	7.47±0.21	7.47±0.17	7.35±0.51	7.88±0.21	7.60±0.41
Temperature (°C)*	16.43±0.58	16.92±0.96	18.97±1.32	20.01±0.76	22.62±1.29	24.28±1.56
DO (mg L^{-1})*	7.93±0.24	7.85±0.09	7.49±0.28	7.41±0.15	7.22±0.09	7.16±0.23
Salinity (%)*	0.01±0.00	0.01±0.00	0.02±0.01	0.02±0.01	0.09±0.02	0.09±0.02
Conductivity*	18.47±5.26	22.07±7.44	36.47±10.41	60.8±13.31	177.33±36.77	186.53±43.74
TSS (mg L^{-1})*	3.58±4.24	4.39±4.22	11.61±8.99	42.97±25.43	359.25±118.35	457.5±108.25
Ammonia-nitrogen (mg L^{-1})*	0.01±0.01	0.01±0.01	0.01±0.01	0.02±0.01	0.24±0.13	0.23±0.10
Nitrate (mg L^{-1})*	0.41±0.13	0.40±0.19	0.44±0.44	1.17±0.18	2.07±0.27	2.19±0.40
Phosphate (mg L^{-1})*	0.11±0.05	0.12±0.04	0.32±0.17	0.99±0.50	2.02±0.46	2.13±0.37
Habitat quality assessment						
Canopy cover (%)*	80.09±3.73	80.77±1.59	47.94±41.65	13.52±17.50	2.75±4.76	7.97±8.97
Epifaunal substrate*	18.33±1.00	18.00±0.58	17.33±1.00	12.00±2.65	12.33±2.08	5.33±4.04
Embeddedness*	17.67±0.58	18.33±0.58	17.33±1.15	13.67±1.53	13.33±3.06	11.00±2.65
Bank stability *	17.33±1.15	18.00±0.00	14.67±3.06	13.33±0.58	12.33±2.52	8.00±2.00
Vegetative protection*	17.33±1.15	18.00±0.00	12.67±5.03	9.67±1.53	12.00±2.00	8.00±2.00
Riparian vegetation zone width*	17.67±0.58	17.33±1.15	10.33±5.51	7.00±3.61	10.67±6.11	6.33±2.08
Total habitat score*	170±1.08	175±1.17	150.33±2.51	132±3.25	131±2.28	101±4.07

Note: *Kruskal-Wallis significant at $p < 0.05$.

Biodiversity of aquatic insect communities. A total of 7,501 individuals of aquatic insects representing 44 genera, 34 families and 8 orders were collected during the sampling period. Station LF1 and LF2 had the highest taxa richness of aquatic insects (42 and 40 genera, respectively) belonging to orders Trichoptera, Ephemeroptera, Plecoptera, Coleoptera, Odonata, Megaloptera, Diptera and Hemiptera. Meanwhile, stations LU5 and LU6 had the lowest taxa (14 and 10 respectively) represented by orders Ephemeroptera, Diptera, Coleoptera and Trichoptera and Hemiptera. The total number of individuals recorded at station LA3 was 2,172 individuals which is the highest, followed by station LF1 with 1,973 individuals, while the least total number of individuals were recorded at stations LU5 and LU6 with 209 and 230 individuals respectively (Table 2).

The diversity indices based on Shannon-Weiner Index and Simpson Index showed the same results comparing aquatic insects between the six sampling stations (Table 3). The value was highest in station LF-1 (1/D=19.54; H'=3.21) and LF-2 (1/D=19.92; H'=3.19) compared to station LU-6 (1/D=3.54; H'=1.58) and LU-5 (1/D=3.00; H'=1.52). The results were similar with taxa richness for both highest and lowest values.

Figure 2 showed the UPGMA clustering produced two cluster groups by using Bray-Curtis distance. The first cluster included stations LF1, LF2, LA3 and LA4, while the second cluster had stations LU5 and LU6 where each of the clusters had similarity in aquatic insect composition. The stations LA3 and LA4 had distinctive aquatic insect composition as compare to stations LF1 and LF2. Meanwhile, the second cluster showed the most dissimilar taxa composition from first cluster.

Table 2

Mean population of aquatic insects at station along Liwagu River, Sabah, Malaysia

Order	*Family*	*Genus*	*Forest*		*Agricultural*		*Urban development*	
			LF1	*LF2*	*LA3*	*LA4*	*LU5*	*LU6*
Trichoptera	Hydropsychidae	*Hydropsyche*	208	99	232	151	51	62
		Cheumatopsyche	24	23	33	25	4	5
	Lepidostomatidae	*Lepidostoma*	136	161	191	46	0	0
	Glossosomatidae	*Glossosoma*	47	43	0	0	0	0
	Limnocentropodidae	*Limnocentropus*	8	7	0	0	0	0
	Philopotamidae	*Warmaldia*	39	39	37	2	0	0
Plecoptera	Perlidae	*Tetropina*	45	24	0	0	0	0
		Neoperla	49	24	0	0	0	0
	Peltoperlidae	*Peltoperlopsis*	77	55	0	0	0	0
	Nemouridae	*Amphinemura*	40	32	0	0	0	0
Ephemeroptera	Heptageniidae	*Epeorus*	59	83	18	4	0	0
		Heptagenia	151	125	101	19	0	0
		Rhithrogena	13	2	17	8	0	0
	Baetidae	*Baetis*	89	60	127	234	14	20
		Pseudocloeon	84	101	181	398	0	0
	Potamanthidae	*Potamanthus*	23	53	0	0	0	0
	Tricorythidae	*Teloganella*	26	21	141	195	11	11
	Leptopheliibidae	*Habrophlebiodes*	5	2	226	81	1	0
Coleoptera	Elmidae	*Grouvellinus*	121	64	180	26	3	4
		Stenelmis	121	123	131	28	8	15
	Psephenidae	*Odontanax*	41	48	0	0	0	0
		Macroeubria	9	4	5	0	0	0
	Scirtidae	*Cyphon*	76	45	0	0	0	0
	Lampyridae	Unknown	8	3	0	0	0	0
	Hydrophilidae	*Berosus*	1	0	0	0	0	0
	Gyrinidae	*Gyrinus*	2	7	0	0	0	0
	Eulichadidae	*Stenocolus*	0	2	0	0	0	0
Hemiptera	Gerridae	*Metrocoris*	36	64	11	1	3	9
		Ptilomera	2	0	0	0	1	1
	Aphelocheiridae	*Aphelocheirus*	23	11	0	0	0	1
	Vellidae	*Rhagovelia*	119	77	0	0	1	0
Diptera	Chironomidae	*Chironomus*	0	8	3	0	108	102
	Simuliidae	*Simulium*	156	122	209	12	0	0
	Blephariceridae	*Philorus*	35	47	254	16	0	0
	Athericidae	*Atrichops*	14	11	4	0	1	0
	Tipulidae	*Tipula*	3	3	2	1	1	0
		Hexatoma	16	23	3	0	0	0
	Ceratopogonidae	*Bezzia*	17	2	0	16	2	0
Odonata	Coenagrionidae	*Ceriagrion*	1	0	0	0	0	0
		Pseudagrion	2	2	1	0	0	0
	Corduliidae	*Cordulia*	8	5	52	9	0	0
	Macromiidae	*Macromia*	5	3	0	0	0	0
	Calopterygidae	*Hetaerina*	2	0	2	2	0	0
Megaloptera	Corydalidae	*Protohermes*	32	15	11	0	0	0

Table 3

Shannon-Weiner Diversity Index and Simpson Index of aquatic insects at sampling stations along Liwagu River, Sabah, Malaysia

Land use	*Stations*	*Shannon–Weiner (H')*	*Simpson (1/D)*	*Genera*
Forest	LF1	3.21	19.54	42
	LF2	3.19	19.92	40
Agricultural	LA3	2.65	12.34	25
	LA4	2.08	5.70	20
Urban development	LU5	1.52	3.00	14
	LU6	1.58	3.54	10

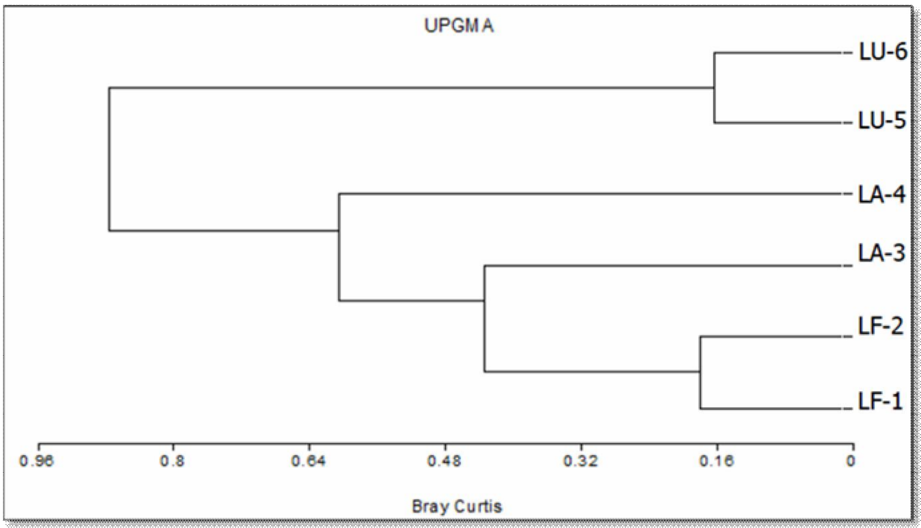

Figure 2. Cluster analysis (UPGMA method) based on Bray-Curtis distances.

Ecological functional feeding group of aquatic insect communities. The percentage of the FFGs is illustrated in Figure 3. The highest percentage of collector-gatherer (CG) and collector-filterer (CF) were both reported in LA3 and the lowest percentages were in urban development area (LU5 and LU6). The percentage of scraper (SC) and shredder (SH) were found highest in stations LF1, LF2 and LA3, but absent in stations LU5 and LU6, while predators (P) were found varied in percentage for every stations.

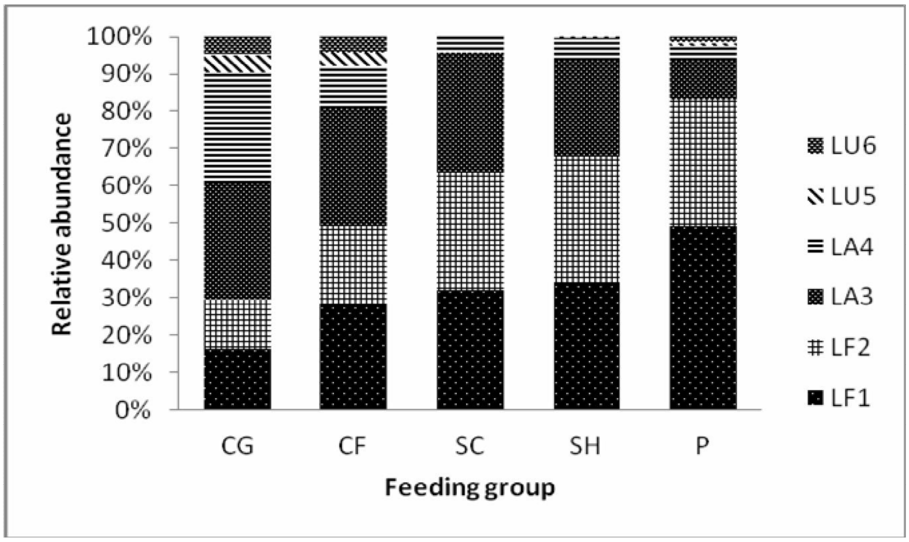

Figure 3. Composition of the ecological functions groups of aquatic insects at sampling stations along Liwagu River, Sabah, Malaysia.

The influence of the physico-chemical parameters and habitat assessment on the aquatic insect communities. The first and the second canonical axes explained 40.1% (eigenvalue of 0.368) and 18.4% (eigenvalue of 0.169) of the variation in the species data respectively. The species-environment correlation of the first axis was statistically significant in a Monte Carlo permutation test ($p < 0.05$). The first axis was correlated with temperature, DO, salinity, conductivity, nitrate, phosphate, canopy cover, embeddedness, bank stability, vegetation protection, riparian, total habitat score and epifaunal substrate.

As can be seen from the Figure 4, *Baetis* sp. and *Pseudocloeon* sp. (Ephemeroptera) were negatively associated with the concentration of phosphate, nitrate, and conductivity (group A). Although the high value of TSS was recorded in stations LU5 and LU6, the impact of the TSS on the diversity of the aquatic insect was weak as indicated by the CCA ordination (Figure 4). Another taxa of Ephemeroptera and Odonata (group B) correlated with stream temperature. The third genera assemblage (group C) showed a high preference for optimum epifaunal substrate and embeddedness. The last group of taxa (group D), which belongs to different taxa (Ephemeroptera, Plecoptera, Trichoptera, Odonata, Diptera, Coleoptera, Hemiptera and Megaloptera), are correlated with optimum habitat quality (epifaunal substrate, embeddedness, bank stability, vegetative protection, riparian vegetative zone width, canopy cover and total habitat score) as well as high dissolved oxygen.

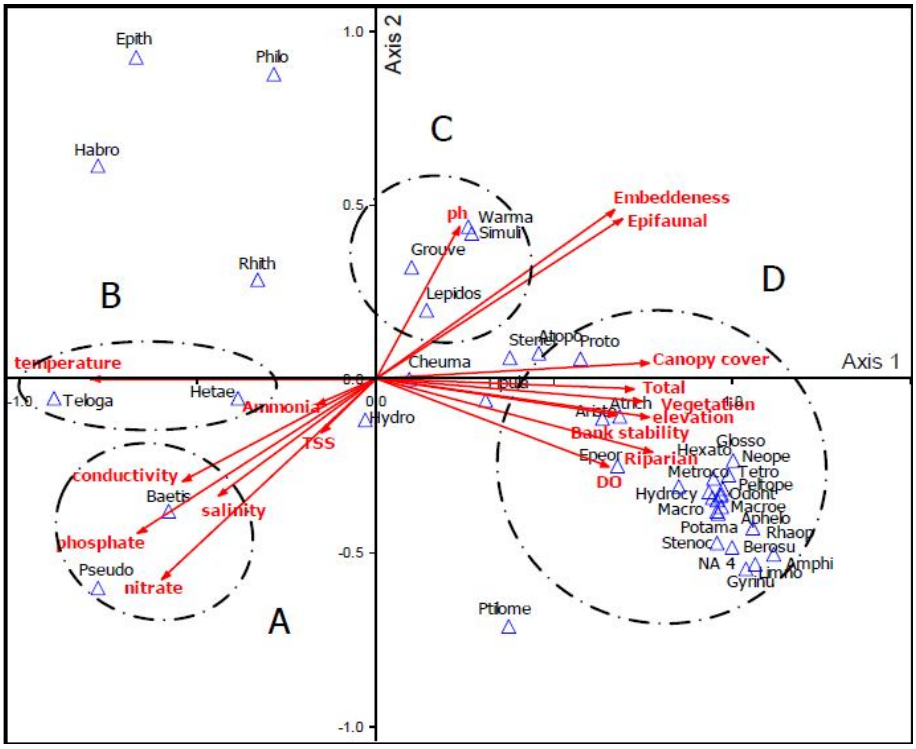

Figure 4. The canonical correspondence analysis (CCA) biplot of the aquatic insects in relation to the habitat assessment quality and physico-chemical parameters in Liwagu River, Sabah, Malaysia.

Discussion

Biodiversity of aquatic insect communities. In general, high abundance of aquatic insects (7,501 individuals) was recorded. Hence, taxa richness and abundance were much higher compared with aquatic insects in other Malaysia rivers with similar sampling design such as Tropical Forest Stream in Gunung Pulai, Johor, (1,584 individuals; Nor Zaiha et al 2015), Liwagu river, Tambunan (2,163 individuals; Fikri et al 2015) and Cameron Highlands, Pahang (27 taxa; Tan 2016). However, richer aquatic insect communities were recorded from other parts of Southeast Asian tropical streams. Maneechan & Prommi (2015) recorded a total of 11,153 individuals of aquatic insects representing 64 families in Streams of the Mae Klong Watershed, Western Thailand. In the East Kalimantan, Indonesian, Dolny et al (2012) collected 14 aquatic insect families of 88 species.

In this study, stations LF1 and LF2 showed with the highest diversity of aquatic insects where the natural habitat disturbances are minimal. Even though no apparent logging activity was recorded in these areas, they may be slightly affected by anthropogenic activity during frequent recreational activities. The reduction in the diversity of aquatic insect communities in stations LU5 and LU6 confirmed that deforestation and deterioration of natural habitat quality for urban development influenced the diversity of aquatic insects (Egler et al 2012; Che Salmah et al 2013).

Impacts of urban development often showed drastic changes in the river bank (Chin 2006). In this study, there was a sign of riverbank soil erosion in stations LU5 and LU6. In such conditions, increase inputs of sediment will occur in the river, and the available substrates will becomes more unstable and with less food resources (coarse organic particulate matter) for the aquatic insects. On the other hand, nutrient runoff from the urban development resulted in the decline of abundance and diversity of aquatic insects (Ortiz & Puig 2007; Minshall et al 2014; Gimenez et al 2015). Since species thrive optimally with a particular combination of physical and chemical attributes, disruption in water quality will lead to greater changes in river ability to offer goods and serves.

Despite the overall reduction in taxa richness, highest abundance of aquatic insects was found in the agricultural site (LA3). This might be due to increased input of organic nutrients from agricultural activities, which could have possibly given the aquatic insect communities to increase in number. A similar study was done by Deborde et al (2016) who observed that highest abundant of aquatic insects was found in the agricultural and mixed land uses.

The diversity of aquatic insect were more diverse in forest area (LF1 and LF2) and least diverse in the urban development area (LU5 and LU6). It might be due to the reduced food resources downstream, increase in environmental stress, fewer microhabitats and high levels of organic pollution. This is the trend of expected result in most of the riverine ecosystems as they reflect the changes in stream order and other factors that influence aquatic insect composition and structure (Osborne 2000; Che Salmah et al 2013).

***Ecological functional feeding group**.* In all stations, collector-gatherer was dominant and this is similar to the previous report by Silveira et al (2006) and Oliveira & Nessimian (2010). Collectors-filters utilize the filtration mechanism to feed on fine particulate organic matter (FPOM) present in water body (Oliveira & Nessimian 2010). This group had the highest percentage of collector-filterer in the forest area (LF1 and LF2). The domination of collectors in this study demonstrates the importance of their role in freshwater ecosystem. However the increase of predators in the forest area was attributed to the presence of other groups of invertebrates and not on the availability of particulate matter and environmental gradient.

No scraper was recorded in the urban development area. This might be due to the lacking of macrophyte as food resources at this area since scraper grazes the macrophyte that attached to the stones and vegetation (Oliveira & Nessimian 2010). Shredder was almost absent in human settlement area, but they comprised higher percentage in the forest area of Liwagu River. This could be due to the accumulation of coarse particular organic matter (CPOM) among the habitats in the forest area. Thus the amount of algal growth on rocks and leaf litters (food sources) in the river is corresponding to the percentage of scrapper and shredder in the forest area. It is also indicate that the river's riparian of the forest area was well preserved and minimal perturbation to its aquatic habitats (Hamid & Md Rawi 2014).

***Influence of physico-chemical parameters and habitat assessment on biodiversity of aquatic insect communities**.* The variety structures of aquatic insect communities that were observed were influenced by the location of the sampling site (upstream or downstream) and also by the distance from sources of anthropogenic activities (agricultural and urban development). The CCA ordination showed that variation in aquatic insect communities was related to temperature, conductivity, phosphate, nitrate, dissolved oxygen and habitat quality (Figure 4).

The significant positive relationships were observed between dissolved oxygen, habitat qualities (canopy cover, bank stability, vegetative protection, riparian zone width and total habitat score) and diversity of aquatic insect communities at upstream of Liwagu River. Dissolved oxygen plays a vital role in sustaining life in water bodies because aquatic organisms use it for respiration, to break organic compounds in water, and subsequently for nutrient cycles (Hirayama & Kasuya 2008). Similar results were reported in other Southeast Asian tropical streams (Jung et al 2008; Che Salmah et al 2013; Maneechan & Prommi 2015; Prommi & Payakka 2015).

According to result of CCA, taxa on axis one included *Baetis* sp. and *Pseudocloeon* sp. (Ephemeroptera), showed a negative correlation with decreasing nutrients (phosphate and nitrate). A similar result was observed by Maneechan & Prommi (2015) in Mae Klong Watershed, Thailand who observed that Baetidae negatively correlated with the concentration of phosphate. Thus these taxa can be proposed as indicators for bioassessment of water quality, as they were limited to clean, oxygenated water and are sensitive to pollutants.

Based on CCA analysis, temperature showed negative correlation with axis 1. Ephemeroptera (*Teloganella* sp.) and Odonata (*Hetaerina* sp.) correlated with this parameter and therefore can be proposed as taxa tolerate to temperature. Aquatic insects require varied optimal temperature to survive (Singh & Sharma 2014; Prommi & Payakka 2015). Meanwhile some of the aquatic insects taxa such as Trichoptera (*Lepidostoma* sp. and *Warmaldia* sp.), Diptera (*Simulium* sp.) and Coleoptera (*Grouvellinus* sp.) were associated with the pH. A similar study by Tripole et al (2008) in Grande river sub-basin, San Luis, Argentina observed that aquatic insects taxa were affected by water pH.

Conclusions. This study concluded that the diversity and abundance of aquatic insect communities were affected by the level of nutrient enrichment in the river and also by the human activities near the river such as agriculture and urban development which will leads to natural habitat quality deterioration and soil erosion. Further study need to carry out to establish or develop multimetric based on macroinvertebrate in order to access the ecological condition of the tropical forest stream of Liwagu River, Sabah, Malaysia.

Acknowledgements. Special thanks to the Stevson, Alvinus, Nashrul, Joumin and Jumardi for the assistances during the field works. We are grateful to the Kinabalu Park for permitting and providing the facilities to conduct this research. This project was supported by Universiti Malaysia Sabah under the grant SBK0184-STWN-2015.

References

APHA, 1992 Standard methods for the examination of water and wastewater. 18th ed. Washington: American Public Health Association, AWWA, MPCE.

Barbour M. T., Gerritsen J., Griffith G. E., Frydenborg R., McCarron E., White J. S., Bastian M. L., 1996 A framework for biological criteria for Florida streams using benthic macroinvertebrates. Journal of the North American Benthological Society 15(2):185-211.

Barbour M. T., Gerritsen J., Snyder B. D., Stribling J. B., 1999 Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2nd edn, EPA 841-B-99-002, USEPA: Washington D.C., pp. 5-31.

Bertaso T. R. N., Spies M. R., Kotzian C. B., Flores M. L. T., 2015 Effects of forest conversion on the assemblages' structure of aquatic insects in subtropical regions. Revista Brasileira de Entomologia 59(1):43-49.

Booth D. B., Jackson C. R., 1997 Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. Journal of the American Water Resources Association 33:1077-1090.

Brasil L. S., Juen L., Batista J. D., Pavan M. G., Cabette H. S. R., 2014 Longitudinal distribution of the functional feeding groups of aquatic insects in stream of the Brazilian Cerreado Savanna. Neotropical Entomology 43(5):421-428.

Buffagni A., Comin E., 2000 Secondary production of benthic communities at the habitat scale as a tool to assess integrity in mountain streams. Hydrobiologia 422:183-195.

Chin A., 2006 Urban transformation of river landscapes in a global context. Geomorphology 79:460-487.
Cooper C. M., 1993 Biological effects of agriculturally derived surface water pollutants on aquatic systems - a review. Journal of Environmental Quality 22:402-408.
Deborde D. D. D., Hernandez M. B. M., Magbanua F. S., 2016 Benthic macroinvertebrate community as an indicator of stream health: the effects of land use on stream benthic macroinvertebrates. Science Diliman 28(2):5-26.
Dolny A., Harabis F., Barta D., Lhota S., Drozd P., 2012 Aquatic insects indicate terrestrial habitat degradation: changes in taxonomical structure and functional diversity of drangonflies in tropical rainforest of East Kalimantan. Tropical Zoology 25(3):141-157.
Egler M., Buss D. F., Moreira J. C., Baptista D. F., 2012 Influence of agricultural land-use and pesticides on benthic macroinvertebrate assemblages in an agricultural river basin in southeast Brazil. Brazilian Journal Biology 72(3):437-443.
Fikri A. H., Wong A. B. H., Mazlan F. H., Abd Fatah E. H., Kamarudin S. J., 2015 Diversity composition and distribution of aquatic insects in Liwagu water catchment, Tambunan, Sabah. Journal of Tropical Biology and Conservation 12:13-24.
Genito D., Gburek W. J., Sharpley A. N., 2002 Response of stream macroinvertebrates to agricultural land cover in a small watershed. Journal of Freshwater Ecology 17(1):109-119.
Gessner M. O., Chauvet E., 2002 A case for using litter breakdown to assess functional stream integrity. Ecological Application 12:498-510.
Gimenez B. C. G., Lansac-Toha F. A., Higuti J., 2015 Effect of land use on the composition, diversity and abundance of insects drifting in neotropical streams. Brazilian Journal of Biology 75(4):52-59.
Hall M. J., Closs G. P., Riley R. H., 2001 Relationships between land use and stream invertebrate community structure in a South Island, New Zealand, coastal stream catchment. New Zealand Journal of Marine and Freshwater Research 35:591-603.
Hamid S. A., Md Rawi C. S., 2014 Ecology of Ephemeroptera, Plecoptera and Tricoptera (Insect) in rivers of the Gunung Jerai Forest Reserve: diversity and distribution of functional feeding group. Tropical Life Science Research 25(1):61-73.
Hepp L. U., Restello R. M., Milesi S. V., Biasi C., Molozzi J., 2013 Distribution of aquatic insects in urban headwaters streams. Acta Limnologica Brasiliensia 25(1):1-9.
Hirayama H., Kasuya E., 2008 Factors affecting submerged oviposition in a water strider: level of dissolved oxygen and male presence. Animal Behaviors 76:1919-1926.
Jung S. W., Nguyen V. V., Nguyen Q. H., Bae Y. J., 2008 Aquatic insect faunas and communities of a mountain stream in Sapa Highland, northern Vietnam. Limnology 9:219-229.
Kang S. Z., Zhang L., Song X. Y., Zhang S. H., Liu X. Z., Liang Y. L., Zheng S. Q., 2001 Runoff and sediment loss responses to rainfall and land use in two agricultural catchments on the Loess Plateau of China. Hydrological Processes 15(6):977-988.
Lenat D. R., Crawford J. K., 1994 Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia 294:185-199.
Maneechan W., Prommi T. O., 2015 Diversity and distribution of aquatic insects in stream of the Mae Klong watershed, western Thailand. Psyche 2015(2):1-7.
McGavin G. C., 2007 Expedition fields techniques. Insects and other terrestrial arthropods. Geography Outdoors, Royal Geographic Society with IBG, 283 pp.
Md Rawi C. S., Al-Shami S. A., Madrus M. R., Ahmad A. H., 2013 Biological and ecological diversity of aquatic macroinvertebrates in response to hydrological and physicochemical parameters in tropical forest streams of Gunung Tebu, Malaysia: implications for ecohydrological assessment. Ecohydrology 7:496-507.
Merritt R. W., Cummins K. W., Berg M. B., 2008 An introduction to the aquatic insects of North America. 4th edition, Dubuque, Kendall Hunt Publisher, 1158 pp.
Minshall G. W., Shafii B., Price W. J., Holderman C., Anders P. J., Lester G., Barrett P., 2014 Effects of nutrient replacement on benthic macroinvertebrates in an ultraoligotrophic reach of the Kootenai River, 2003–2010. Freshwater Science 33(4):1009-1023.

Morley S. A., Karr J. R., 2002 Assessing and restoring the health of urban streams in the Puget Sound basin. Conservation Biology 16(6):1498-1509.
Morse J. C., Yang L., Tian L., 1994 Aquatic insects of China useful for monitoring water quality. Hehai University Press, Nanjing, China, 570 pp.
Nor Zaiha A., Mohd Ismid M. S., Salmiati, 2015 Temporal distribution of benthic macroinvertebrate communities from tropical forest stream in Gunung Pulai recreational forest, Johor, Penisular Malaysia. Sains Malaysiana 44(9):1223-1228.
Oliveira A. L. H., Nessimian J. L., 2010 Spatial distribution and functional feeding groups of aquatic insect communities in Serra da Bocaina streams, southeastern Brazil. Acta Limnologica Brasiliensia 22(4):424-441.
Ortiz J. D., Puig M. A., 2007 Point source effects on density, biomass and diversity of benthic macroinvertebrates in a Mediterranean stream. River Research and Application 23:155-170.
Osborne P. L., 2000 Tropical ecosystem and ecological concepts. The Press Syndicate of the University of Cambridge, United Kingdom, 201 pp.
Palmer M. A., Moglen G. E., Bockstael N. E., Brooks S., Pizzuto J. E., Wiegand C., VanNess K., 2002 The ecological consequences of changing land use for running waters with a case study of urbanizing watersheds in Maryland. Yale Forestry and Environmental Sciences Bulletin 107:85-113.
Paul M. J., Meyer J. L., 2001 Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333-365.
Prommi T., Payakka A., 2015 Aquatic insect biodiversity and water quality parameters of streams in Northern Thailand. Sains Malaysiana 44(5):707-717.
Richter B. D., Braun D. P., Mendelson M. A., Master L. L., 1997 Threats to imperiled freshwater fauna. Conservation Biology 11(5):1081-1093.
Saulino H. H. L., Corbi J. J., Trivinho-Strixino S., 2014 Aquatic insect community structure under the influence of small dams in a stream of the Mogi-Guacu river basin, state of Sao Paulo. Brazilian Journal of Biology 74(1):79-88.
Scherr S. J., McNeely J. A., 2008 Biodiversity conservation and agricultural sustainability: towards a new paradigm of ‘ecoagriculture’ landscapes. Philosophical Transactions of the Royal Society B: Biological Sciences 363(1491):477-494.
Silveira M. P., Buss D. F., Nessimian J. L., Baptista D. F., 2006 Spatial and temporal distribution of benthic macroinvertebrates in a Southeastern Brazilian River. Brazilian Journal of Biology 66(2B):623-632.
Singh N., Sharma R. C., 2014 Some important attributes which regulates the life of macroinvertebrates: a review. International Journal of Recent Scientific Research 5(2):357-361.
Song M. Y, Leprieur F., Thomas A., Lek-Ang S., Chon T. S., Lek S., 2009 Impact of agricultural land use on aquatic insect assemblages in the Garonne river catchment (SW France). Aquatic Ecology 43(4):999-1009.
Stepenuck K. F., Crunkilton R. L., Wang L., 2002 Impacts of urban land use on macroinvertebrate communities in southeastern Wisconsin streams. Journal of the American Water Resources Association 38(4):1041-1051.
Tan K. W., 2016 Evaluation of water quality and benthic macroinvertebrates fauna relationship using principal component analysis (PCA): a case study of Cameron highlands, Malaysia. Environmental Management and Sustainable Development 5(1):187-208.
Tripole S., Vallania E. A., Corigliano M. C., 2008 Benthic macroinvertebrate tolerance to water acidity in the Grande river sub-basin (San Luis, Argentina). Limnetica 27(1):29-38.
Virbickas T., Pliuraite V., Kesminas V., 2011 Impact of agricultural land use on macroinvertebrate fauna in Lithuania. Polish Journal of Environmental Studies 20(5):1327-1334.
Walsh C. J., Sharpe A. K., Breen P. F., Sonneman J. A., 2001 Effects of urbanization on streams of the Melbourne region, Victoria, Australia: benthic macroinvertebrate communities. Freshwater Biology 46:535-551.

Yule C. M., Yong H. S. 2004 Freshwater invertebrates of the Malaysian Region. Kuala Lumpur, Akademi Sains Malaysia, 861 pp.

Received: 28 January 2017. Accepted: 10 March 2017. Published online: 10 April 2017.
Authors:
Mohd Syafiq Izzat Shafie, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia, e-mail: izzatshafie91@gmail.com
Andrew Bak Hui Wong, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia, e-mail: andrew88wbh@gmail.com
Sahana Harun, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia, e-mail: sahana@ums.edu.my
Arman Hadi Fikri, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia, e-mail: arman@ums.edu.my

How to cite this article:
Shafie M. S. I., Wong A. B. H., Harun S., Fikri A. H., 2017 Land use influence on the aquatic insect communities on tropical forest streams of Liwagu River, Sabah, Malaysia. AACL Bioflux 10(2):341-352.