Aquatic insect communities in and around the tropical streams of Kinabalu Park, Sabah, Malaysia

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Abstract. This study aimed to evaluate the effects of land use on aquatic insect communities in and around the streams of Kinabalu Park, Sabah, Malaysia. Five sampling stations were selected from pristine streams (S1 and S2) and streams in the vicinity of human activities (S3, S4, and S5). Aquatic insects were sampled using Surber net from June 2012 to January 2013. A total of 10360 individuals of aquatic insects from nine orders, 49 families, and 67 genera were collected. Order Coleoptera (27%), Ephemeroptera (26%), Trichoptera (24%) were the common orders found in the streams of Kinabalu Park. *Stenelmis* spp. (12%) was the dominant taxa, followed by *Psephenus* spp. (10%) and *Hydropsyche* spp. (8%). Pristine streams generally had higher total abundance, genera richness and diversity of aquatic insects. Based on the water parameters, all stations were classified as Class I. Biotic indices rated most stations were not impacted, but lower values were found in S3, S4, and S5. Canonical Correspondence Analysis (CCA) showed that water temperature, canopy cover, water velocity and stream width were the most influential environmental parameters on aquatic insect assemblages in the streams of Kinabalu Park.

Key Words: aquatic insects, anthropogenic activities, tropical streams, Kinabalu Park, Sabah.

Introduction. Freshwater ecosystems are critical for human survivability and development, as it provides vital resources and function such as water supplies, food resources, purification of human wastes, groundwater discharge, recreation and transportation (Baron et al 2002; Aylward et al 2005). Yet, the increasing demands on freshwater ecosystem due to the exponential human population growth and economic development had impaired the freshwater environments that included rivers, lake, and wetlands. These increase the needs to monitor and manage the freshwater environment.

Freshwater ecosystem in Malaysia constitutes with extreme habitats such as peat swamp forest, caves and alpine region (Morse et al 2007). Extreme rapid development has occurred in Malaysia since the 1970's. Urbanization, deforestation, construction, land conversion, and industrialization has been the main anthropogenic stressors that adversely impact the freshwater ecosystem in Malaysia. In 2014, 48% among the 473 rivers monitored were found to be polluted (Department of Environment 2015).

In Southeast Asia, established biomonitoring mostly used the guidelines and protocols from developed countries with slightly modification for the differences in habitats and aquatic insect diversity (Sudaryanti et al 2001; Morse et al 2007; Mekong River Commission 2010). In Malaysia, there is a lack of aquatic insect studies and mostly focus on biodiversity surveys (Morse et al 2007). The monitoring of water quality in Malaysia is relying on traditional physico-chemical and microbial measurements. The Water Quality Index (WQI) derived from standardized measurements is used to determine the freshwater water quality in Malaysia (Arsad et al 2012). Monitoring of the water quality in Malaysia is mostly done by monitoring stations of National Monitoring Network, established by Malaysia Department of Environment.

Kinabalu Park as one of the protected areas in Sabah has unique, diverse and endemic biota. Flora and fauna in the Kinabalu Park had been studied extensively

(Takashi 1991; Wong & Chan 1997), yet little was known of the aquatic insect communities in the park. In addition, the streams of Kinabalu Park are subjected to the impact from nearby agricultural activities of local villagers and tourism activities (Nais 1996; Juin et al 2000). Therefore, this study aimed to evaluate effects of land use on aquatic insect communities of the streams in and around the Kinabalu Park.

Material and Method

Study area. Five sampling stations with 100 m reach were selected from Sg. Liwagu (S1), Sg. Silau-Silau (S3) , Sg. Mesilau East (S2 and S4) and Sg. Mesilau West (S5) in the vicinity of Kinabalu Park (Figure 1). Stations in Sg. Liwagu and upstream of Sg. Mesilau East was located in pristine forest area; station in Sg. Silau-Silau located in Kinabalu Headquarters; another station in the downstream of the Sg. Mesilau East, near the Mesilau Nature Resort; and the last station at Sg. Mesilau West, where small-scale plantation was located. The five sampling stations were sampled monthly for six sampling occasions.

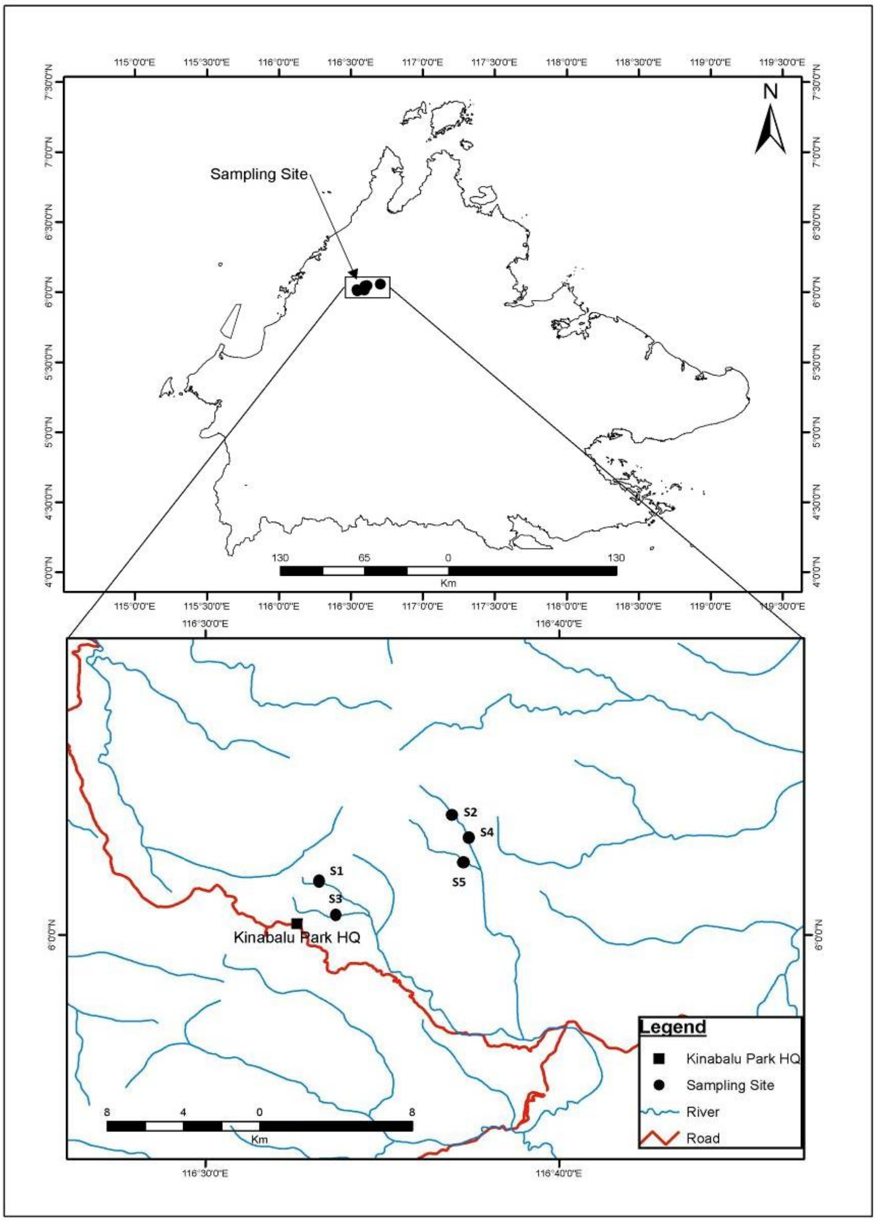

Figure 1. Map shows the five sampling stations (S1-S5) at Kinabalu Park.

Aquatic insects. Samplings were conducted from June 2012 until January 2013. Surber net (mesh size of 500 µm) was used to sample aquatic insects in the following in-stream habitats: riffle, run, and pool. Each of these habitats had five randomly selected replicates. Kick sampling technique was applied for collection in the riffle and run areas. One meter square area in front of the net was disturbed for two minutes. Meanwhile, insects in pool section were collected by continuous sweeping through the water when the bottom substrates were disturbed for two minutes. Specimens sorted in the field were identified and stored in 75% of ethanol. The taxonomic keys from Yule & Yong (2004), DeWalt et al (2009), Morse et al (1994), and Merritt et al (2008) were used to identify the specimens.

Physical and water quality parameters. Three transects were established for the measurement of the physical and water quality parameters before collecting the aquatic insects. Water temperatures, dissolved oxygen (DO), salinity, pH, and conductivity were measured *in situ* using the HANNA Multiparameter Meter (Model Hi 9828). Stream width and depth were measured with measuring tape and steel ruler. Canopy cover measured with a Spherical Densiometer. Water velocity was derived from the method described in Carter et al (2006). A buoyant object was used and the amount of time it flow through the length of the measuring tape lay along the edge of the stream were measured.

Data analysis. Shannon diversity index and evenness index were applied to determine the diversity of aquatic insects. Three biotic indices including Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness, Biological Monitoring Work Party (BMWP) and Average Score per Taxa (ASPT) were calculated to evaluate the biological quality of the streams. EPT index is simply the taxa richness of the Ephemeroptera, Plecoptera and Trichoptera in the sample (Mandeville 2002). BMWP index is the summarization of the tolerance scores of each aquatic macroinvertebrate family found in a sample, which higher values indicate better water quality (Armitage et al 1983). ASPT is the average tolerance score of the assemblage, which was the division of BMWP by the number of families in the sample.

Analysis of Variance (ANOVA) is performed to test the significant differences of variables between the stations using IBM SPSS Statistics Version 20. The tested variables included total abundance, genera richness, Simpson diversity index, Evenness index, EPT index, BMWP, ASPT, and the seven physical and water quality parameters measured for this study. Variables with non-normal distribution were log transformed. Welch ANOVA was performed for variables with heterogeneity of variances.

Cluster analysis classifies the data into groups or clusters based on similarities or distance among data (McGarigal et al 2000). This method was used in this study to explore the aquatic insect taxa composition and distribution among the sampling stations. Unweighted Pair-Groups with Arithmetic Averages (UPGMA) method of cluster analysis were used with two similarities or distance, which were the Bray-Curtis distance.

The aquatic insect composition and the physical water quality data were analyzed by Canonical Correspondence Analysis (CCA). CCA is a direct gradient analysis that elucidates the relationships between biological communities and their environment (Ter Braak and Verdonschot 1995). CCA was conducted using PC-ORD software Version 5 (Peck 2010). Rare taxa with less than 5% occurrence were excluded from the CCA (Bachelet et al 1996). After removal of the rare taxa, 52 of 67 taxa and seven environmental parameters (water temperature, pH, conductivity, water velocity, stream width, depth and percentage of canopy cover) were analyzed with CCA. Monte-Carlo simulations with 999 permutations were used to verify the statistical significance of the relationships between aquatic insect assemblage and environmental parameters.

Results and Discussion

Water and biological quality. Table 1 summarizes the mean of the water quality and physical parameters at the streams of Kinabalu Park. In regard to the range of pH, conductivity, and DO recorded, all stations were classified as Class I, based on National

Water Quality Standards for Malaysia (Department of Environment 2015). Results of ANOVA illustrated that there was no significant difference ($p > 0.05$) of the water quality and physical parameters among the sampling stations (Table 1).

Table 1

Summary of mean (standard deviation) of water quality and physical parameters at the streams of Kinabalu Park. P values indicate statistical significance based on ANOVA test

Parameters	*S1*	*S2*	*S3*	*S4*	*S5*	*P*
Temperature (°C)	14.79±1.6	16.14±0.93	16.90±0.18	14.49±0.85	16.29±0.52	0.78
pH	8.26±0.79	8.04±0.58	7.69±0.64	8.07±0.31	7.63±1.34	0.03
Conductivity (μS cm^{-1})	21.50±4.64	18.00±6.13	16.17±3.13	27.17±7.49	30.61±14.1	0.09
*DO (mg L^{-1})	4.68	4.15	4.68	5.01	4.62	-
Velocity(m s^{-1})	0.50±0.13	0.46±0.11	0.34±0.10	0.38±0.08	0.39±0.06	0.18
Width (m)	5.61±1.20	6.19±1.66	5.36±3.95	10.49±3.10	15.77±2.53	0.36
Depth (cm)	30.01±2.49	18.88±8.73	13.53±2.41	26.81±6.84	22.51±8.19	0.56
Canopy (%)	63.25±11.64	83.83±2.65	83.83±5.11	20.33±4.90	26.78±10.00	0.98

*Data only available for the first sampling occasion due to equipment problem.

The scores of the three biotic indices were summarized in Table 2. EPT, BMWP, and ASPT rated the most of the stations with very good water quality. S1 and S2 stations had the higher score compared to other three stations that located near to the human activities. Within the three disturbed stations, S3 produced the lowest scores for all three indices. Among all three indices, showed significant differences ($p < 0.05$), tested with ANOVA and Welch ANOVA.

Based on the stream classification of water quality parameters, the streams of Kinabalu Park generally had good water quality and are fall within Class I. However, the difference can be detected through the biotic indices results. Consistent results from the three biotic indices indicate and ANOVA showed that both pristine streams (S1 and S2) had better water quality. The only exception was station S3 that had significantly lower water quality as indicated by both EPT index and BMWP index. This clearly demonstrates the usability of the biological indices to detect degradation in freshwater ecosystems. BMWP and ASPT indices had been implemented and shown to be suitable tools for stream quality assessment (Azrina et al 2006; Al-Shami et al 2011; Fikri et al 2013; Tan & Beh 2015).

Table 2

Biotic indices scores in the five sampling stations. P-values for the statistical significance based on ANOVA and Welch ANOVA test

Biotic indices	*S1*	*S2*	*S3*	*S4*	*S5*	*P*
EPT	21	17	7	15	15	0.000
Rating	Non impacted	Non impacted	Slightly impacted	Non impacted	Non impacted	
BMWP	151	153	72	120	123	0.000
Rating	Very good	Very good	Good	Very good	Very good	
ASPT	7.19	7.29	6.55	7.06	6.83	0.039
Rating	Rather clean	Rather clean	Rather clean	Rather clean	Rather clean	

Aquatic insect communities. A total of 10360 individuals of aquatic insects, constituted by 49 families and 67 genera were collected for this study (Table 3). Order Coleoptera (27%), Ephemeroptera (26%), Trichoptera (24%) were the common orders in the streams of Kinabalu Park. In addition, the *Stenelmis* spp. (12%) was the most abundant taxa, followed by *Psephenus* spp. (10%) and *Hydropsyche* spp. (8%). However, the dominant taxa for each station were different: S1 dominated by *Micrasema* spp.;

Psephenus spp. (14%) in S2; Chironomidae (42%) in S3; *Pseudocloeon* spp. (11%) in S4; and *Hydropsyche* spp. (18%) in S5.

Table 3

Aquatic insect abundance among the five sampling stations. Code was used in CCA biplot

Taxa	*Code*	*S1*	*S2*	*S3*	*S4*	*S5*	*Total*
EPHEMEROPTERA							
Baetidae							
Baetis spp.	T1	41	64	11	27	55	198
Platybaetis spp.	T2	155	33	4	43	63	298
Pseudocloeon spp.	T3	245	76	17	339	194	871
Caenidae							
Caenis spp.	T4	2	0	0	0	0	2
Ephemerellidae							
Caudatella spp.	T5	29	22	0	270	62	383
Ephemerella spp.	T6	15	5	2	113	3	138
Heptageniidae							
Cinygma spp.	T7	1	1	0	0	10	12
Heptagenia spp.	T8	86	36	1	17	37	177
Epeorus spp.	T9	48	147	0	60	90	345
Leptophlebiidae							
Paraleptophlebia spp.	T10	1	0	0	37	1	39
Neophemeridae							
Neoephemeropsis spp.	T11	0	3	0	0	0	3
Potamanthidae							
Potamanthus spp.	T12	16	160	0	0	0	176
Rhoenanthus spp.	T13	0	2	0	0	0	2
Prosopistomatidae							
Prosopistoma spp.	T14	2	0	0	0	0	2
Tricorythidae							
Tricorythus spp.	T15	0	5	0	0	3	8
PLECOPTERA							
Perlidae							
Etrocorema spp.	T16	65	23	0	1	0	89
Neoperla spp.	T17	3	18	0	5	1	27
Phanoperla spp.	T18	4	10	0	0	1	15
Tetropina spp.	T19	58	152	0	69	9	288
Peltoperlidae							
Cryptoperla spp.	T20	9	0	0	0	0	9
Peltoperlopsis spp.	T21	22	31	0	33	0	86
Neumoridae							
Amphinemura spp.	T22	1	0	0	5	4	10
TRICHOPTERA							
Brachycentridae							
Micrasema spp.	T23	406	8	0	83	0	497
Ecnomidae							
Ecnomus spp.	T24	0	2	0	0	7	9
Glossosomatidae							
Glossosoma spp.	T25	50	31	0	2	1	84
Goeridae							
Goera spp.	T26	9	4	0	18	0	31
Hydropsychidae							
Aethalopsyche spp.	T27	8	0	0	129	0	137
Ceratopsyche spp.	T28	27	61	14	38	18	158
Cheumatopsyche spp.	T29	23	45	3	19	4	94
Hydropsyche spp.	T30	77	122	1	284	388	872
Hydroptilidae							
Ugandatrichia spp.	T31	6	0	0	0	0	6
Lepidostomatidae							
Lepidostoma spp.	T32	45	54	4	266	19	388
Limnocentropodidae							
Limnocentropus spp.	T33	39	70	7	44	9	169

Philopotamidae							
Warmaldia spp.	T34	2	31	1	0	1	35
Polycentropodidae							
Cyrnellus spp.	T35	2	0	0	4	2	8
Psychomyiidae							
Tinodes spp.	T36	1	0	0	0	0	1
Rhyacophilidae							
Rhyacophilia spp.	T37	5	6	0	15	11	37
ODONATA							
Calopterygidae							
Matrona spp.	T38	0	1	0	0	0	1
Coenagrionidae							
Argia spp.	T39	1	2	0	0	0	3
Cordulegastridae							
Anotogaster spp.	T40	0	0	2	0	0	2
Corduliidae							
Cordulla spp.	T41	0	1	0	0	0	1
Euphaeidae							
Anisopleura spp.	T42	0	0	0	0	1	1
Gomphidae							
Leptogomphus spp.	T43	0	1	0	0	0	1
Micromiidae							
Micromidia spp.	T44	0	0	1	0	1	2
MEGALOPTERA							
Corydalidae							
Protohermes spp.	T45	7	61	8	40	68	184
HEMIPTERA							
Aphelocheiridae							
Aphelocheirus spp.	T46	0	42	0	0	2	44
Gerridae							
Naboandelus spp.	T47	1	2	0	0	0	3
Metrocoris spp.	T48	9	8	5	7	9	38
Naucoridae							
Hyocoris spp.	T49	5	8	0	0	8	21
Pleidae							
Paraplea spp.	T50	0	0	0	2	1	3
Vellidae							
Rhagovelia spp.	T51	6	5	2	0	0	13
LEPIDOPTERA							
Pyralidae							
Eoophyla spp.	T52	2	13	0	0	2	17
Elophila spp.	T53	0	0	1	0	0	1
Paracymoriza spp.	T54	0	0	0	0	1	1
COLEOPTERA							
Elmidae							
Grouvellinus spp.	T55	77	108	0	196	110	491
Stenelmis spp.	T56	341	274	0	278	325	1218
Gyrinidae							
Gyrinus spp.	T57	0	2	0	0	0	2
Lampyridae							
-	T58	14	24	0	5	0	43
Ptilodactylidae							
Stenocolus spp.	T59	1	4	0	0	1	6
Psephenidae							
Psephenus spp.	T60	231	358	4	184	243	1020
Scirtidae							
Cyphon spp.	T61	9	28	0	13	11	61
DIPTERA							
Athericidae							
Atherix spp.	T62	3	19	2	4	1	29
Blephariceridae							
Blepharicera spp.	T63	48	34	1	54	208	345

Chironomidae							
-	T64	65	30	105	106	15	321
Simuliidae							
Simulium spp.	T65	97	241	53	141	105	637
Tipulidae							
Antocha spp.	T66	2	3	0	53	0	58
Hexatoma spp.	T67	25	50	1	7	6	89
TOTAL		2447	2541	250	3011	2111	10360

Note: "-" identified until family level.

Among the five sampling stations (Table 4), station S4 yield highest total abundance of aquatic insects (29.1%), followed by S2 (24.5%) and S1 (23.6%). Meanwhile, lowest total abundance recorded in station S3 covered only 2.4% of the total sample collected. In term of taxa richness, highest genera recorded in both S1 and S2, while stations S3 had lower taxa richness. For Shannon's diversity index, S4 station had the highest diversity. This is contributed by it more evenly distributed abundance among their taxa. As showed in Table 4, except evenness index, other three metrics were significantly different among the stations ($p < 0.05$).

Table 4

Total abundance, genera richness, Shannon's diversity index and Evenness index of the five sampling stations. P-values for the statistical significance based on ANOVA and Welch ANOVA test

Metrics	*S1*	*S2*	*S3*	*S4*	*S5*	*P*
Total abundance	2447	2541	250	3011	2111	0.000
Genera richness	52	52	23	38	43	0.000
Shannon's diversity index (H')	2.97	3.17	2.02	3.01	2.64	0.001
Evenness index (E)	0.38	0.46	0.33	0.53	0.33	0.399

UPGMA cluster analysis using Bray-Curtis distance (Figure 2) classified the five sampling stations into two groups. The station S3 had the most distinctive aquatic insect composition comparing to other four stations. Another cluster grouped stations S1, S2, S4, and S5 together, where the two disturbed stations S4 and S5 with higher similarity in aquatic insect composition.

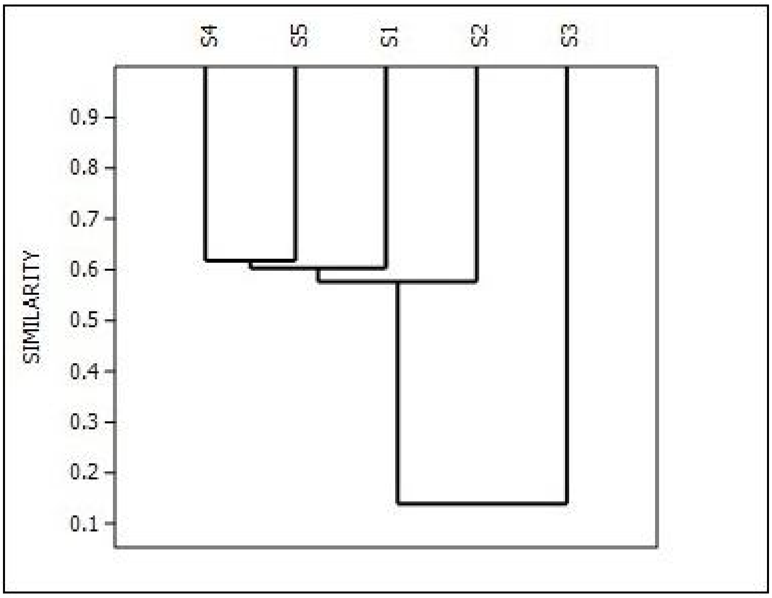

Figure 2. Dendrogram derived from UPGMA method of clustering with Bray-Curtis distance.

Cluster analysis showed that station S3 had the most distinctive composition among the stations. This was expected as this station had the low taxa richness (23 genera) and taxa abundance (range from one to 105). This station also recorded the lowest diversity

(2.02) as illustrated by Shannon's diversity index. Fai (2006) found an increase of Chironomidae abundance in Sg. Silau-Silau, which generally as a sign indicates perturbation. Another study on periphyton in the same stream (Ghazali 2006) reported an increase of periphyton diversity, which reflects the impairment of water quality. Small stream width and slow flow in this stream might limit the diversification of aquatic insects due to fewer habitats available. Besides, potential soil erosion areas were observed and fine sediment was spotted in the streambed. Sediment blocks light penetration through turbid water, and consequently reduced the oxygen produced by submerged macrophytes through photosynthesis (Dunlop et al 2005). Plecoptera taxa (Perlidae, Peltoperlidae, and Neumoridae) that relied heavily on high oxygenated habitats was not found in this station. Increasing sediments in running water inhibit their gills for respiration, while decreasing the stream turbidity prevent the vision of Perlidae to locate prey (Relyea et al 2000; Dunlop et al 2005; Dunlop et al 2008). Chironomidae that dominating in S3 is generally being used to indicate the presence of perturbation. As Chironomidae larvae contain hemoglobin-like pigments that retain oxygen (Hershey et al 2009). This feature makes them to tolerate and capable of surviving in low dissolved oxygen polluted streams (Al-Shami et al 2010).

Aquatic insects and environmental parameters. Based on Monte-Carlo analysis, the axes produced from CCA were statistical significant between the aquatic insect communities and their environmental parameters (p = 0.001). In particular, the first two CCA axes explain 22.6% of the variance of aquatic insect abundance and environmental parameters (eigenvalue of 0.238 for axis-1 and 0.147 for axis-2) (Table 5).

Table 5

First two axes of the CCA ordination for aquatic insect abundance and environmental parameters in the streams of Kinabalu Park

Environmental parameters	*Axis 1*	*Axis 2*
Temperature	-0.697	0.554
Conductivity	0.259	0.548
pH	-0.017	-0.102
Water velocity	-0.303	-0.802
Stream width	0.312	0.703
Stream depth	0.176	-0.494
Canopy cover	-0.865	-0.205
Eigenvalue	0.238	0.147
Variance in species data		
% of variance explained	14.0	8.6
Cumulative % explained	14.0	22.6

CCA axis-1 showed that water temperature (r = -0.697) and canopy cover (r = -0.865) had the highest influence on the aquatic insect abundance (Table 5). Stream width and water velocity had high negative (r = -0.802) and positive correlation (r = 0.703) respectively to CCA axis-2.

CCA analysis reveals that water temperature, canopy cover, stream width and water velocity influenced the distribution of aquatic insects in the streams of Kinabalu Park (Figure 3). Water temperature significantly affects abundance, diversity, and distribution of aquatic insects (Lessard & Hayes 2003; Burgmer et al 2007; Li et al 2012), as it influencing their embryonic development, growth, emergence, metabolism and survivability (Hauer & Hill 2006). Decreasing in temperature also increase the water capability to saturated dissolved oxygen, which highly influence the occurrence and distribution of pollution-sensitive taxa (Hauer & Hill 2006).

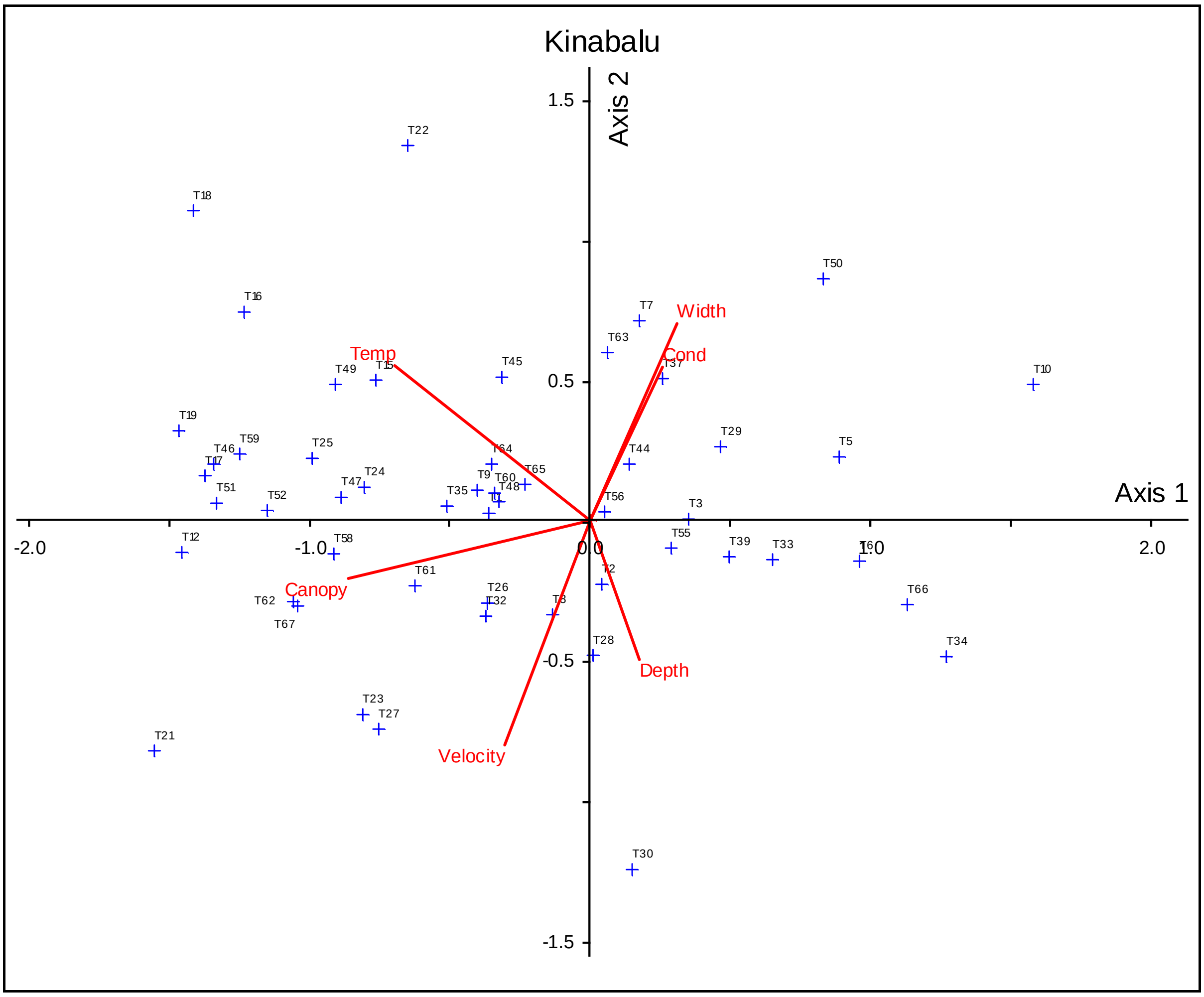

Figure 3. CCA ordination biplot between the aquatic insect abundance (+ mark) and the environmental parameters (lines). Taxa codes refer to Table 3.

Small-scale human activities had less impact on aquatic insect communities, as the alteration of riparian structures were minimal. Lorion & Kennedy (2009) reported pasture land with at least 15 m riparian buffer zone significantly reduced the effects of deforestation on stream communities and resembled those found at forested reference sites. Removal of riparian buffer zone caused sedimentation that increase turbidity and narrow the stream width (Hawes & Smith 2005). In addition, riparian buffer area capable in filters, transforms, and sinks harmful nutrients and pollutants (Hawes & Smith 2005). This will slow the flow from directly entering nearby water bodies and deteriorate the water quality. This might explain why S4 and S5 similar assemblage as illustrated by cluster analysis, as the riparian buffer area observed in those stations remain almost untouched.

Stream width showed weak positive relationships (R = 0.331, $p < 0.05$) with abundance while stream depth showed positive relationships with abundance and genera richness. Stream width and depth both related to stream size, as the both measurement increase from headwater streams to large rivers. Stream size had been reported to influence aquatic insect communities (Heino et al 2005; Dinakaran & Anbalagan 2007). Wahizatul et al (2011) also reported the positive relationship between aquatic insect abundance with stream width. Species richness of macroinvertebrates changes with stream size, which increases from headwater towards mid-sized streams (Minshall et al 1985; Hershey et al 2009). These changes increase the in-stream environmental heterogeneity or availability of various microhabitats that promotes the coexist of taxa with different niche (Heino et al 2005).

The current velocity is generally related to the flow of the water bodies. In this study, majority taxa collected were fast-flowing dwellers or insects that adapted to running water. The most dominant taxa in this study, *Stenelmis* spp. (Elmidae) preferred substrate types of boulders and cobbles (Crips & Crips 1974), which could be found throughout each sampling station. Other taxa such as Heptageniidae, *Psephenus* spp., *Platybaetis* spp., *Baetis* spp. were adapted to fast flowing water through their dorsoventrally flattened and hydrodynamically streamlined body shape that provides resistance towards fast current (Giller & Malmqvist 1998).

Conclusions. The streams of Kinabalu Park remain in good condition as indicated by Class I classification and biotic indices rating. Although there were slightly decrease of aquatic insect diversity occurred in stations near to human activities. Water temperature, canopy cover, stream width and water velocity shown to be influencing the aquatic insects communities in the tropical streams of Kinabalu Park.

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