



Faculty of Resource Science and Technology

**Drift and Benthic Densities of Aquatic Insects and the Evaluation of Water
Quality in Selected Streams in Sarawak**

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Drift and Benthic Densities of Aquatic Insects and the Evaluation of Water Quality in Selected Streams in Sarawak

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The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

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ABSTRACT

The presence and composition of aquatic insects are important bioindicators of the level of pollution and quality of freshwater systems such as rivers and streams. In this regard, the abundance and diversity of drift and benthic aquatic insects in streams can provide important indicators on the health of the streams. The results obtained from this study can be used as a baseline data to monitor the level of pollution and health of the streams in Sarawak. The objective of this study aims to (i) document the diversity and abundance of aquatic insects in the drift and composition of benthic aquatic insects during sunrise and sunset at five selected streams in Sarawak, (ii) identify the relationship between the compositions of aquatic insects in the drift and composition of benthic aquatic insects during sunrise and sunset with its physicochemical parameters of the streams, (iii) evaluate the status of the water quality and organic pollution of the streams. The five streams involved in the study were the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. Drift samplings of aquatic insects in the streams were carried out using the Surber Sampler while benthic samplings were conducted using Kick net between March - June 2016. The aquatic insects in the drift were collected every three hours for 24 hours while the benthic aquatic insects were collected during sunrise and sunset. A total of 15 samplings were conducted. The samplings data were then subjected to Pearson's correlation analysis to analyse the relationships among diversity of the streams and water quality while Analysis of Variance (ANOVA) was used to compare the variations in water quality between sampling locations and sampling periods and Canonical Correspondence Analysis (CCA) was conducted to examine the relationship between the aquatic insect community structure and stream physicochemical parameters. A total of 462.29 aquatic insect individuals per 100m³ belonging to 39 taxa, 25 families and 7 orders were recorded in the drift in five streams. The *Baetis* sp.

from the family Baetidae was the common taxa which dominated the drift in the Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream, while the drift in Sabong Stream was dominated by *Simulium* sp. The drift density of the aquatic insects increases just after sunset in every sampling in the streams. Irregular patterns of aquatic insects drifting throughout night time were observed in the streams and the drift density of aquatic insects fluctuated just after sunrise in the streams. The community structure of the aquatic insects in the drift in the Sabong Stream was significantly influenced by pH and dissolved oxygen. On the other hand, the drift of aquatic insects in the Cina Stream was significantly influenced by temperature and water discharge. The aquatic insect density in the Serin Stream was influenced by pH, temperature, turbidity and water current. Whereas, drift in the Bak Muan Sadir Stream was affected by water discharge and total suspended solid (TSS). In terms of diversity of the benthic aquatic insects, the results of the study showed that a total of 36 taxa belonging to 19 families and 5 orders of aquatic insects were recorded during sunrise while 30 taxa, 18 families and 5 orders of aquatic insects were recorded in the five streams during sunset. The order Ephemeroptera was most diverse in terms of number of individuals followed by Dipterans and Trichopterans, while other orders of aquatic insects were less abundant in the streams. The richness of the EPT (Ephemeroptera, Plecoptera and Trichoptera) taxa indicated that the streams have good water quality. Based on the analysis of the biotic indices (BMWP, ASPT, BMWP_{THAI} and ASPT_{THAI}), it is indicate that the water quality of each stream in this study was clean and experiences low level of pollution.

Keywords: Aquatic insect, drift, water quality, *Baetis* sp., drift pattern.

Kajian Kelimpahan Serangga Akuatik Hanyutan dan Bentik serta Penilaian Kualiti Air di Anak Sungai Terpilih di Sarawak

ABSTRAK

Kehadiran dan komposisi serangga akuatik merupakan penunjuk bio tahap pencemaran yang penting dan kualiti sistem air tawar seperti sungai dan anak sungai. Dalam hal ini, kelimpahan dan kepelbagaian serangga hanyutan akuatik dan bentik di anak sungai boleh memberikan petunjuk yang penting terhadap kesihatan anak sungai. Keputusan yang diperoleh daripada kajian ini boleh digunakan sebagai data asas untuk memantau tahap pencemaran dan kesihatan di anak sungai di Sarawak. Objektif kajian ini bertujuan untuk (i) mendokumenkan kepelbagaian dan kuantiti serangga akuatik dalam hanyutan dan komposisi serangga akuatik bentik semasa matahari terbit and matahari terbenam di lima anak sungai terpilih di Sarawak, (ii) mengenalpasti hubungan antara komposisi serangga akuatik hanyutan dan komposisi serangga bentik semasa matahari terbit dan matahari terbenam dengan ukuran fizikokimia di anak sungai, (iii) menilai status kualiti air dan pencemaran organik di anak sungai. Lima anak sungai yang dipilih dalam kajian ini adalah: Sungai Sabong, Sungai Duyoh, Sungai Cina, Sungai Serin dan Sungai Bak Muan Sadir. Pensampelan serangga akuatik hanyutan di anak sungai telah dijalankan menggunakan Surber Sampler manakala pensampelan serangga akuatik bentik telah dijalankan menggunakan Kick net pada Mac - Jun 2016. Serangga akuatik hanyutan telah dikumpul setiap tiga jam untuk 24 jam manakala serangga akuatik bentik pula telah dikumpul semasa matahari terbit dan matahari terbenam. Sebanyak 15 pensampelan telah dijalankan. Sampel kemudiannya telah dianalisis menggunakan analisis kolerasi Pearson untuk menganalisis hubungan antara pembolehubah di anak sungai dan kualiti air manakala, analisis Varians (ANOVA) digunakan untuk membandingkan variasi kualiti air di antara lokasi persampelan dan tempoh pensampelan

dan analisis Canonical Correspondence (CCA) telah dijalankan untuk mengkaji hubungan antara struktur komuniti serangga akuatik dan ukuran fizikokimia. Sejumlah 462.29 serangga akuatik setiap 100m³ air ditapis tergolong daripada 39 taksa, 25 famili dan 7 order serangga akuatik hanyutan telah dicatatkan di lima anak sungai. Baetis sp. yang tergolong dalam famili Baetidae merupakan serangga akuatik hanyutan yang dominan di Sungai Duyoh, Sungai Cina, Sungai Serin dan Sungai Bak Muan Sadir, tetapi hanyutan di Sungai Sabong didominasi oleh Simulium sp. Pola serangga akuatik hanyutan didapati tidak teratur pada waktu malam dan bilangan serangga akuatik hanyutan berkurang selepas matahari terbit di setiap anak sungai. Struktur komuniti serangga akuatik hanyutan di Sungai Sabong sangat dipengaruhi oleh pH dan oksigen terlarut. Sebaliknya, hanyutan serangga akuatik di Sungai Cina sangat dipengaruhi oleh suhu air dan aliran air. Kepadatan serangga akuatik di Sungai Serin dipengaruhi oleh pH, suhu, kekeruhan dan arus air. Manakala, hanyutan serangga akuatik di Sungai Bak Muan Sadir dipengaruhi oleh aliran air dan pepejal terampai (TSS). Dari segi kepelbagaian serangga akuatik benthik, hasil kajian menunjukkan bahawa sejumlah 36 taksa serangga akuatik yang tergolong dalam 19 famili dan 5 order dicatatkan semasa matahari terbit manakala 30 taksa, 18 famili dan 5 order serangga akuatik dicatatkan di lima anak sungai semasa matahari terbenam. Order Ephemeroptera adalah yang paling tinggi dari segi bilangan individu diikuti oleh Diptera dan Trichoptera, manakala serangga akuatik dari order lain adalah sedikit di anak sungai. Kekayaan EPT (Ephemeroptera, Plecoptera dan Trichoptera) menunjukkan bahawa anak sungai mempunyai kualiti air yang baik. Analisis indeks biotik (BMWP, ASPT, BMWP_{THAI} dan ASPT_{THAI}) menunjukkan bahawa kualiti air di setiap anak sungai dalam kajian ini adalah bersih dan mengalami tahap pencemaran yang rendah.

Kata kunci: Serangga akuatik, hanyutan, kualiti air, Baetis sp., pola penghanyutan.

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LIST OF ABBREVIATIONS

cm	Centimeter
m	Meter
mm	millimeter
km	Kilometer
mg	Miligram
ml	Milimeter
L	Litre
°C	Degree Celcius
%	Percentage
DO	Dissolved Oxygen
TSS	Total Suspended Solids
TEM	Temperature
TBY	Turbidity
WCN	Water Current
Q	Water Discharge
DPH	Stream Depth
WDH	Stream Width
<i>H</i>	Shannon-Wiener's diversity index
<i>d</i>	Margalef's species richness index
ANOVA	Analysis of variance
CCA	Canonical correspondence analysis
N	Number of individuals
S	Number of taxa

r^2	Pearson's correlation coefficient	
m/s	Meter per second	
m ³ /s	Meter cube per second	
m ²	Meter square	
V	Water Velocity	
A	Cross-sectional area	
t	Time	
H	Height of water column	
PAST	Paleontological Statistics	
DD	Day drift	
ND	Night	drift

CHAPTER 1

INTRODUCTION

1.1 General Introduction

This study aims to study the relationship between the compositions of aquatic insects as a form of bioindicator on the health of a particular type of freshwater system, namely streams. In this chapter, the information and variables involved in the study will be discussed along with the problem statement, research objectives and significance of the study.

Freshwater environments can be divided into two main groups, which are still water systems such as ponds and lakes, and running water systems such as streams and rivers (Leopold *et al.*, 1964; Allan and Castillo, 2007; Mazzucco *et al.*, 2015). Streams are unique ecosystems that sustain a rich biodiversity. The stream environment provides substantial benefits in sustaining urban society and also the dependent environments.

Although freshwater makes up only 0.01% of the total water body on earth, it comprises nearly 100,000 species of aquatic insects or 8.0% of the 1.3 million species of insects that have been defined scientifically (Dudgeon, 1999). Aquatic insects, which are the focus of this study, are invertebrates that belong to the category of animals without backbones (Budin *et al.*, 2007). They can be divided into two types, namely aquatic microinvertebrates and aquatic macroinvertebrates. Aquatic microinvertebrates are small microscopic life forms that reside in water columns while aquatic macroinvertebrates are aquatic insects that spend most of their life-cycle in the water (Kannoje *et al.*, 2012). Benthic macroinvertebrates are a

distinct type of macroinvertebrates that inhabit the bottom substrates of freshwater systems (Rosenberg and Resh, 1993).

There are many different types of aquatic insects and nearly every type of freshwater environment will have some type of aquatic insects. Aquatic insects play important roles in the freshwater aquatic habitat as a source of food for fish and other invertebrates in the water system. They can be commonly found in all types of freshwater aquatic habitat throughout the world including rivers, ponds and streams, especially around vegetation and also along with sediment in the bed of water bodies. Aquatic insects can be found on rocks, logs, sediment, debris and aquatic plants (Aweng *et al.*, 2012; Kannoje *et al.*, 2012).

Macroinvertebrates, especially aquatic insects, play an important role in freshwater lotic habitats or freshwater systems characterised by rapidly moving water (Merritt and Cummins, 1996; Mazzucco *et al.*, 2015). The compositions of aquatic insects are important components in the aquatic environment as they control the food web in the ecosystems. Studies shows that the collection of aquatic insects, particularly macroinvertebrates in most streams, is highly diverse and many of the individual species may be absent in the sense that ecosystem functions can continue if they are absent (Derleth, 2003). They are critical part of the food web in streams and are easy to sample and identify. The composition of aquatic insects is the result of interactions between their ecological and physical conditions that characterise the habitat and food availability in the aquatic habitat.

Most river and stream environments have aquatic insects of various compositions with species from numerous orders such as Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies), Coleoptera (aquatic beetles) and Diptera (midges). Macroinvertebrates

including aquatic insects are very essential in ecological environments as they are one of the main bioindicators or measurement of the quality or health of the freshwater environment (Majumder *et al.*, 2013). Each species of aquatic insect has different tolerance towards changes in the environmental conditions. Aquatic insects are the most widely used organisms in freshwater biomonitoring on the impact of human activities such as pollution. Diversity and biotic indices of aquatic insects such as benthic macroinvertebrate samples are often used to measure pollution in rivers (Giller and Malmqvist, 1998; Selvanayagam, 2016). The orders of Ephemeroptera, Plecoptera and Trichoptera are generally known as good bioindicators in stream environments (Rosenberg and Resh, 1993; Menbohan, F. 2012; Menbohan *et al.*, 2014). Aquatic insects belong to these orders are very sensitive to pollution and live in streams and rivers which have good quality of water. However, aquatic insects of the orders Coleoptera (moths) and Hemiptera (water bugs) are usually not used in biomonitoring studies since they can be found in both polluted and unpolluted freshwater system.

Bacteria, algae, microfauna, fish and macrophytes in freshwater environments are often used as biological indicators. However, the most commonly used indicator wmacroinvertebrate, and particularly aquatic insect. Macroinvertebrates are used to define the quality of the stream based on their biological reliability, which is the assessment tool that produces stable and consistent results (Norris and Morris, 1995; Takhelmayum and Gupta, 2015; Selvanayagam, 2016). The presence or absence of the indicator species or indicator community reflects environmental conditions (Plafkin *et al.*, 1989). The indicator species are assigned scores for their tolerance level. There are a large number of species and different stresses produce different macroinvertebrate communities. Plafkin *et al.* 1989 also reported that small order streams often do not support fish but do support extensive macroinvertebrate communities while the macroinvertebrates are generally have limited mobility. Thus,

macroinvertebrates are indicators of localized environmental conditions. Benthic macroinvertebrates are small enough to be easily collected and identified besides they are the primary food source for recreationally and commercially important fish. An impact on macroinvertebrates impacts the food web and designated uses of the water resource.

1.2 Problem Statement

At present, in Sarawak, government agencies such as the Department of Environment (DOE) and the Sarawak Forestry Department (SFD) are responsible for monitoring the biological component of streams and rivers. There have been several studies on aquatic insects and their relationship with water quality conducted by these agencies. However, data on aquatic insects for many streams and rivers in Sarawak are still inadequate to make any conclusion on aquatic insect composition and variation status in the state. For example, there is a study on the macrofauna of the Rajang River in Sarawak, but to date there is no study that focuses on aquatic insects in the streams in Sarawak (Shabdin, 2010).

In addition, studies on assessment of water quality have also given more attention to physicochemical parameters such as temperature, pH and dissolved oxygen. Moreover, ecological studies in Malaysia that have emphasised the relationship between water quality and aquatic insects have focused on freshwater systems in Peninsular Malaysia and Sabah (Wahizatul *et al.*, 2011; Yap and Ismail, 2011; Ismail *et al.*, 2012; Harun *et al.*, 2015). Even these studies have not investigated the importance of aquatic insects as biological indicator of the health of streams. Hence, more research is required to provide detailed information on the role of aquatic insects in streams and specifically the relationship between aquatic insects and water quality and how they can be used as biological indicators of the health of streams.

Based on these considerations, this study focuses on the composition of aquatic insects in selected streams in Sarawak, and their relationship to the water quality of streams. It is hoped that the study will show the important role played by aquatic insects as bioindicators of the health of the streams, and thus provide useful results for relevant agencies to take remedial measures to maintain the health of streams and quality of freshwater aquatic systems in general.

1.3 Research Objectives

This study was guided by four main objectives:

- (i) to document the diversity and abundance of aquatic insects in the drift or the movement of aquatic insects in flowing waters and composition of benthic aquatic insects during sunrise and sunset at five selected streams in Sarawak.
- (ii) to identify the relationship between the compositions of aquatic insects in the drift with the physicochemical parameters of the streams and relationship between the composition of benthic aquatic insects during sunrise and sunset with physicochemical parameters of the streams.
- (iii) to evaluate the status of the water quality and organic pollution of the streams as revealed by the bioindicators provided by the aquatic insects.

The five streams identified for this study are the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. The aquatic insects were collected during sunrise and sunset to document the diel variation and distribution of aquatic insects present in the stream during sunrise and sunrise. The physicochemical parameters in this study refer to dissolved oxygen, temperature, pH, turbidity, water current and water depth. These

physicochemical parameters are considered as the important environmental parameters which affect the aquatic insect composition in the stream.

1.4 Hypothesis

The main hypothesis tested in present research were (i) more taxa obtained in this study compared to previous aquatic insect survey in Malaysia, especially Sarawak, (ii) aquatic insect abundance more at night than during the daytime, (iii) abiotic factors influence the aquatic insect assemblages in streams at Sarawak.

1.5 Significance of study

Although a number of studies on aquatic insect have been conducted in the rivers of Sarawak, there is a lack of published data on the evaluation of water quality and organic pollution in streams in the state. Therefore, accurate information and data on the diversity and composition of aquatic insects, water quality status and organic pollution of the streams are required to assess the health of the streams. Correlation between the community structure of aquatic insects in streams and stream physicochemical characteristics are important. It is hoped that the results obtained from this study can be used as a baseline data to monitor the level of pollution and health of the streams in Sarawak.

It is hoped that the results will enable relevant government agencies to obtain accurate measurement of the level of pollution in the streams and take remedial actions. It is also hoped that the results of the study will assist relevant government agencies to monitor adverse human or anthropogenic activities that cause pollution in streams and adopt necessary preventive measures. Further, the study could provide ways to monitor the health of

freshwater systems in general, including rivers and lakes which serve as valuable components of Sarawak's rich biodiversity and act as valuable sources of fish, food and medicine.

CHAPTER 2

LITERATURE REVIEW

2.1 River Water Quality and Status

The Department of Environment (DOE) uses Water Quality and Interim National Water Quality Standard for Malaysia (INWQS) to evaluate the status of the river water quality (DOE, 2016). The Water Quality Index (WQI) introduced by DOE is being practised in Malaysia for about 30 years and serves as the basis for the assessment of environment water quality, while NWQS classifies the beneficial uses of the watercourse based on WQI (Table 2.1). Class I - III of the INWQS specifies the water quality level necessary to sustain macroaquatic life, with varying degree of sensitivity. Fish is used as an indicator due to its economic value. The same is true for potable water supply, where conventional treatment systems should be able to treat Class II designated water source efficiently, whereas, more advanced treatment systems are required for a Class III designated water source. Class IV and below can still be used for irrigation, whereas Class V water sources are considered to have minimal beneficial usage (Zainudin, 2010).

Table 2.1: National Water Quality Standards for Malaysia (INWQS).

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity*	µS/cm	1000	1000	-	-	6000	-
Floatables	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	%	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
Total Dissolved Solid	mg/l	500	1000	-	-	4000	-
Total Suspended Solid	mg/l	25	50	50	150	300	300
Temperature	°C	-	Normal + 2 °C	-	Normal + 2 °C	-	-
Turbidity	NTU	5	50	50	-	-	-

Table 2.2: Interim Bational Water Quality Standard (INWQS) Class Definitions.

Class	Uses
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species
Class IIA Class IIB	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species. Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III – Common of economic value and tolerant species; livestock drinking.
Class IV	Irrigation.
Class V	None of the above.

2.2 Ecology of Aquatic Insects

Aquatic insects can be found almost in every type of habitat in the world including lakes, torrential streams, highly saline pools, coastal waters and estuaries, groundwater, acid peat swamps, hot springs and also in pools of crude oil seeping from the ground. Studies of aquatic insects of freshwater river and stream ecosystems have commonly examined the species-habitat relationship with respect to the water quality of the habitat (Wahizatul *et al.*, 2011; Ismail *et al.*, 2012). Aquatic insects usually live on rocks, sediment, debris and aquatic plants in some parts of their life cycle. As these organisms live in the water, they are highly dependent on the water quality for their survival. Hence, the presence and composition of aquatic insects serve as valuable indicators of the health of freshwater systems (Wahizatul *et al.*, 2011; Aweng *et al.*, 2012).

Most studies on freshwater river and stream ecosystems usually examine the species in the river or stream with their habitat relationship rather than on the water quality of the river or stream. According to research done by Ismail in 2012, the warm and wet climate of Malaysia in particular provides an ideal environment for the life cycle of aquatic insects as they are commonly reliant on humid habitat.

In Malaysia, aquatic insects are not only abundant but also represented in a huge variety of taxonomic classification. They consist of the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), Odonata (and dragonflies and damselflies), Blattodea (cockroaches), Hemiptera (water bugs), Megaloptera (alderflies), Neuroptera (spongiflies), Coleoptera (aquatic beetles), Trichoptera (caddisflies), Lepidoptera (moths) and Diptera (midges). Eggs, larvae, pupae and adults of these insects spend most of their life cycle in water. All immature

stages of Ephemeroptera, Odonata, Plecoptera, Trichoptera, Lepidoptera and Diptera usually live in water throughout their life cycle, while only the larva of Megaloptera and Neuroptera live in water. In addition, the adults of Hemiptera and Coleoptera are found in water and on the surface of water (Yong and Yule, 2004).

Ephemeroptera (mayflies) occur widely in both lotic or flowing water habitats and lentic or still water habitats. Odonata (dragonflies and damselflies) are extensively distributed and abundant in nearly all fresh and brackish water. They are essentially rich in warmer waters, for example the warmer waters in lowlands of tropical and subtropical regions. Whereas, stoneflies are distributed globally, mainly in cold mountain streams. Foottit and Adler (2009) have reported that Coleoptera (beetles) can be found in a varied range of lotic and lentic habitats but some species are found only in marine intertidal habitat. All Trichoptera (caddisflies) are aquatic insects with eggs, larvae and pupae taking place in a wide variety of freshwater habitats and adults flying nearby terrestrial habitats. All Diptera (midges) require moist environment to live, such as brackish waters, coastal marine and brine pools (Foottit and Adler, 2009).

Aquatic environments provide highly beneficial conditions for aquatic insect such as providing the food, water, shelter, and space essential for the survival and enable them to perform functions such as feeding, respiration and osmoregulation. However, adverse anthropogenic activity can greatly disrupt the beneficial conditions that allow aquatic insects to live in aquatic systems. The temperature, turbidity and total suspended solid (TSS) in rivers and streams can be greatly affected by human activities such as agriculture, irrigation, deforestation, wastewater discharge, construction of hydropower facilities and the use of water for cooling (Chapman, 1996).

In rivers and streams in particular, the biological conditions are strongly influenced by water chemistry and habitat quality. Standing and slow-flowing streams and muddy or sandy areas with high fine-sediment particles, for example, are known to support higher diversity and abundance of Diptera (Wahizatul *et al.*, 2011; Payakka and Prommi, 2014). The combination of water analysis, diversity indices and water quality indices can thus be reasonably applied to investigate the health of rivers and streams.

In aquatic ecosystems, the study on aquatic insects is mainly important because light limitation normally exists especially during sunrise and sunset. Therefore, activity of aquatic organisms which is influenced by light and dark cycles are relevant since they are the herbivores which eaten by fishes (Flecker, 1992). The study of darkness effect on macroinvertebrate activity has been done in different way. In flowing waters, existence of a nocturnal peak in drift rates has been recognised in earlier studies (Elliott, 1967; Brittain and Eikeland, 1988). Macroinvertebrate movement at night are associated with their behavioural changes particularly described by the differences in light intensity (Bishop, 1969; Scheuerelle and Schindler, 2003). Some studies have reported that macroinvertebrate movement was affected by oxygen driven in flowing waters (Fereiro, 2014).

2.3 Classification of Drift

Drift or downstream transport of living organisms in flowing waters can act as a primary source of recolonizing organisms, including aquatic insects in aquatic habitat. Williams and Hynes (1976) define colonisation as the invasion of species that results in disturbed and newly created habitats. Drift loss can happen when the stream flow is directed

into a lake or large pool. Number of aquatic insect drift shows the amount of aquatic insect that have drifted with the water discharge in the stream.

Drift has been found to be affected and influenced by abiotic and biotic factors (Nowinszky *et al.*, 2012). Large areas of water with low velocity of current can act as catching basins for drifting organisms. Drifting insects or movement of aquatic insect in the flowing waters is often a very important source of food supply for certain fish taxa such as Salmonids (Gray, 2003). Study by Mustafa *et al.*, (2012) on feeding habits of fishes in Kenyir Lake Terengganu, Malaysia found that hampala barb (*Hampala macrolepidota*) consumed mainly aquatic insects. Aquatic insects show different compositions that vary in accordance with the environmental conditions. Drift is important to stream systems in recolonisation, mainly as a food source for visual predators (Merritt and Cummins, 1996).

2.3.1 Catastrophic Drift

Catastrophic drift occurs due to unusual physical disturbance to the environment such as flooding. It is considered as a form of passive drift which results from sudden increases in velocity of the water current and water discharge of the stream (Pearson and Franklin, 1968). Catastrophic drift is usually influenced by abiotic factors. These factors create an unfavourable habitat for some order of insects and may result in the involuntary drifting of the aquatic insects. The insects must move simply as it may affect their survival. Among the abiotic factors that cause catastrophic drift are human activities like high discharge or drought, ice, pesticides, oil spills and poor water quality. Discharge arising from human activity including waste water or industrial pollution is one of the main factors which affect the degree of catastrophic drift. These factors can be an unfavourable habitat for the insects and it may

even contribute to the death of the organisms. Human activities can therefore change the composition of aquatic insects in the ecosystem (Wahizatul *et al.*, 2011). According to Rak *et al.* (2010), even small changes in the aquatic conditions will have significant effect on the community of aquatic insects. Hence, the presence and composition of aquatic insects and the adverse effects of catastrophic drift on their habitat can be a useful measure of the degree of pollution in rivers and streams.

2.3.2 Behavioural Drift

Unlike catastrophic drift, behavioural drift is considered as an active and voluntary drift initiated by aquatic insects. The active and voluntary entry into the water current by the insects is seen to be a mechanism for them to avoid predators, competitors or overloaded aquatic conditions that pose a risk to the insects whereby they are moving into a better habitat that will sustain their source of food and survival (Saltveit *et al.*, 2001). Behavioural drift has received most attention in ecological studies as it is thought to be the result of some diel behavioural pattern of the organisms in streams. Diel behavioural pattern refers to the behaviour of aquatic insects over a 24-hour period of time (Schreiber, 1995). Behavioural drift is also influenced by light intensity in several organisms. Some of the order of insects that occur in behavioural drift are Ephemeroptera, Plecoptera, Trichoptera, Diptera and Amphipoda (Pearson and Franklin, 1968; Gray, 2003).

2.3.3 Constant Drift

Constant drift is natural drift that occurs due to ordinary, accidental dislodgement of organisms that lose contact with the substrate and enter the drift. There are several biotic factors which influence constant drift of aquatic insects such as competition for food

resources; piscine predator avoidance, invertebrate predator avoidance and dispersal affect constant drift. This type of drift is not specific to any order of insects (Gray, 2003).

2.4 Diel Periodicity in Drift Patterns of Aquatic Insects

Diel periodicity is defined as a recurrent temporal pattern within a period of 24 hour (Waters, 1972). Studies by McLay (1968) on drift in the Kakanui river, New Zealand has shown that the drift rate was irregular at low level during daylight hours. The drift was found to be composed of Chironomidae larvae, oligochaetes, Parnidae larvae and adults while Trichoptera were also found in the drift occasionally. There was a steady decrease in the drift rate throughout the night after the initial increase before it reached normal daytime rates by sunrise. The total drift collection in the study on diel aquatic insects' activity of mayfly nymphs and its variation with behavioural drift showed nocturnal increase in drift density for both Baetis and Cinygmula. The typical drift pattern was low and constant drift density during the day and much higher values at night while the maximum drift density was observed during the first night time collection (Allan *et al.*, 1986).

In Malaysia, study by Bishop (1973) in Sungai Gombak also showed the number of drifting aquatic organisms taken at night were greater than during the day and the nocturnal increase in drift not in particular pattern which has no consistent peak during darkness. The overall pattern was probably considered light at the primary factor which controls the drift activity in many taxa (Bishop and Hynes 1969, Bishop 1973). Another study on aquatic insect drift was carried out by Fazimah *et al.* (2005) on drift pattern of aquatic insects in the Selai River in the Endau-Rompin National Park, Johor. The drift was found to increase after dusk until midnight and remained high until dawn. The drift of the aquatic insects decreased and

remained low throughout the day. It however increased at night as insectivorous fish that prey on the insects are usually active during the day.

Cadwallader (1975) has reported that the larvae of *Deleatidium* spp., *Zephlebia scita*, *Coloburiscus humeralis*, *Hydro psyche colonica*, *Olinga jeredayi*, *Pycnocentria evecta* and Rhyacophilidae were found mostly in the drift at night in the Glentui river in New Zealand, in some cases with a peak just after sunset. Ephemeroptera adults occurred mainly at sunset in the Glentui River. The occurrence in the drift of the aquatic day-active forms was correlated with water temperature, with the increased in the drift associated with higher temperatures. According to Bailey (1981) who has done a study on diel patterns in nymphs of an Australian Mayfly *Atalophlebioide* sp. from Condor Creek, Australia, the nocturnal activity of aquatic insects in his study was clearly greater than the diurnal activity in all three experiments with the change of activity level occurring during the night compared with mean hourly activity for the night. This means that aquatic insects choose to drift at night than during daytime.

2.5 Relationship between Aquatic Insects and Environment

Most studies on aquatic insects and drift patterns have focused on the underlying biotic and abiotic factors regulating stream drift. Abiotic factors mainly involve the physical parameters of the water such as temperature, turbidity and water depth while biotic factors are composed of the effects of predators and ecological interactions such as plants, animals, bacteria and fungi (Svendsen *et al.*, 2004).

2.5.1 Abiotic Factors

The abiotic factors that affect the population of aquatic insects especially macroinvertebrates include the speed of the water current, temperature, substratum, level of oxygen, salinity, hardness and general water chemistry. Many macroinvertebrates need current as they rely on it for feeding purposes and for respiration. Temperature tolerance for aquatic insects varies among different order. For instance, Ephemeroptera, Plecoptera and Trichoptera have narrow tolerance toward high temperature while Odonata have high tolerance towards temperature. Substratum is a main contribution of abiotic factor as certain species live in different types of substratum as species richness and abundance are higher in sand substrate (Baptista *et al.*, 2001). The level of oxygen can also become a factor in polluted rivers and streams and affect the population of aquatic insects (Chapman, 1996). Indeed, oxygen is one of the most important factors for water quality and aquatic life. It is required by all aerobic organisms for respiration. In addition to oxygen, water temperature also influences the rate of physiological processes of aquatic insects (Chapman, 1996). The effect of temperature on the biota or effect of temperature on the habitats indirectly influences the metabolic rates and the oxygen concentration of the river.

The role of light in the composition and diversity of aquatic insects, on the other hand, is complicated. Light influences primary production in the river and controls the life history patterns of aquatic insects (Giller and Malmqvist, 1998). Light and darkness are major environmental influences in the lives of aquatic insects. The presence or absence of moonlight provides a trigger for the beginning or end of each lifecycle of the insect (Bruce-White and Shardlow, 2011). Light at night could reduce effective population sizes of the insects through the direct loss of individuals, reproductive failure and changes to sex ratios (Perkin, 2013).

2.5.2 Biotic Factors

Biotic factors like predation, competition and parasitism are more challenging to be measured because they rely mainly on the interaction between the organisms in the aquatic system. Predators such as fish can alter and change the species composition and species abundance of aquatic insects' especially benthic macroinvertebrates. Studies on predation interaction show that predators are the causes of instability in freshwater environments (Holomuzki *et al.*, 2010). Statzner (1984) has reported that the abundance of food, predators, and especially benthic density is regarded as the most important biotic factors affecting the drift of certain orders of aquatic insects like Ephemeroptera. The amount of food availability will also indicate where an aquatic insect will live. For example, it has been found that Ephemeroptera (mayfly) nymphs experience increased susceptibility to drift due to behavioural regulation of oxygen consumption. As the oxygen level decreases, the nymphs increase their exposure and thus the susceptibility to accidental drift increases. The nymphs drift significantly during dark than the day time (Svendsen *et al.*, 2004).

2.6 Aquatic Insects as Biological Indicators

Pollution has been defined as the changes that occur in the physical, chemical and biological characteristics of water, air or soil that can affect the health and activities of living organisms (Ismail *et al.*, 2012). Traditionally, chemical analyses have been used to monitor water pollution where water samples were taken at certain points and analysed for suspected chemical pollutants. Pollution is best recognised in living organisms. According to Ismail *et al.* (2012), scientist in many countries especially developed countries, have been using aquatic insects and particularly macroinvertebrates communities in freshwater including insects as an

alternative method to monitor the water biologically. Freshwater seems to respond more meaningfully to the effect of biologically relevant substances.

Biomonitoring which is also known as biological monitoring can be defined as the systematic use of biological responses to evaluate the changes that happen due to anthropogenic activity in the environment including pollution with the intention to use water quality information in a quality control program (Rosenberg and Resh, 1993; Bae *et al.*, 2005). The diversity, abundance and composition of aquatic insects such as Ephemeroptera, Plecoptera and Trichoptera in relation to the physical and chemical conditions of the aquatic habitat have been used as part of biomonitoring (Wahizatul *et al.*, 2011). The baseline data provided by the aquatic insects (indicator organisms) can be used to estimate the level of environmental impact and its risk for the organisms (Wahizatul *et al.*, 2011).

The level of environment impact can be evaluated using the tolerance value of the aquatic insects towards organic pollutions at family level. The tolerance values provided for Hilsenhoff Biotic Index (Hilsenhoff, 1982) and the scores of Biological Monitoring Working Party (Mandaville, 2002; Nasirian, 2014). The tolerance values for Hilsenhoff Biotic Index ranged from 0 to 10. The values nearly to 0 shows that the family is very intolerant to pollution while values closely to 10 were given to the family which have high tolerance level to pollution (Table 2.1). Scores of Biological Monitoring Working Party show the level of tolerance for any given species to the pollution in aquatic habitat. Each family is assigned a score between 1 to 10. The family with lower scores are tolerant to pollution while the family with tolerance value numbers closer to 10 is extremely sensitive to pollution in their habitats (Table 2.3).

Table 2.3: Family-level pollution tolerance scores of aquatic fauna for the Hilsenhoff Biotic Index.

Plecoptera	Capniidae 1, Chloroperlidae 1, Leuctridae 0, Nemouridae 2, Perlidae 1, Perlodidae 2, Pteronarcyidae 0, Taeniopterygidae 2
Ephemeroptera	Baetidae 4, Baetiscidae 3, Caenidae 7, Ephemerellidae 1, Ephemeridae 4, Heptageniidae 4, Leptophlebiidae 2, Metretopodidae 2, Oligoneuriidae 2, Polymitarcyidae 2, Potomanthidae 4, Siphonuridae 7, Tricorythidae 4
Odonata	Aeshnidae 3, Calopterygidae 5, Coenagrionidae 9, Cordulegastridae 3, Corduliidae 5, Gomphidae 1, Lestidae 9, Libellulidae 9, Macromiidae 3
Trichoptera	Brachycentridae 1, Glososomatidae 0, Helicopsychidae 3, Hydropsychidae 4, Hydroptilidae 4, Lepidostomatidae 1, Leptoceridae 4, Limnephilidae 4, Molannidae 6, Odontoceridae 0, Philopotamidae 3, Phryganeidae 4, Polycentropodidae 6, Psychomyiidae 2, Rhyacophilidae 0, Sericostomatidae 3
Megaloptera	Corydalidae 0, Sialidae 4
Lepidoptera	Pyralidae 5
Coleoptera	Dryopidae 5, Elmidae 4, Psephenidae 4
Diptera	Athericidae 2, Blephariceridae 0, Ceratopogonidae 6, Blood-red Chironomidae (Chironomini) 8, Other (including pink) Chironomidae 6, Dolichopodidae 4, Empididae 6, Ephydriidae 6, Psychodidae 10, Simuliidae 6, Muscidae 6, Syrphidae 10, Tabanidae 6, Tipulidae 3
Amphipoda	Gammaridae 4, Talitridae 8
Isopoda	Asellidae 8
Acariformes	4
Decapoda	6
Gastropoda	Amnicola 8 Bithynia 8, Ferrissia 6, Gyraulus 8, Helisoma 6, Lymnaea 6, Physa 8, Sphaeriidae 8
Oligochaeta	Chaetogaster 6, Dero 10, Nais barbata 8, Nais behningi 6, Nais bretscheri 6, Nais communis 8, Nais elinguis 10, Nais pardalis 8, Nais simplex 6, Nais variabilis 10, Pristina 8, Stylaria 8, Tubificidae: Aulodrilus 8, Limnodrilus 10
Hirudinea	Helobdella 10
Turbellaria	4

Table 2.4: Scores for Biological Monitoring Working Party (BMWP) for benthic macroinvertebrate family.

Taxa	BMWP	Taxa	BMWP
Coleoptera		Odonata	
Chrysomelidae	5	Aeshnidae	8
Clambidae	5	Agriidae	8
Curculionidae	5	Chlorocyphidae	-
Dryopidae	5	Coengrionidae	6
Dytiscidae	5	Coenagriidae	-
Elmidae	5	Cordulegastridae	8
Gyrinidae	5	Corduliidae	8
Haliplidae	5	Gomphidae	8
Helodidae	5	Lestidae	8
Hydrophilidae	5	Libellulidae	8
Hygrobiidae	5	Macromiidae	-
Psephenidae	-	Platyenemididae	6
Diptera		Protoneuridae	-
Athericidae	-	Plecoptera	
Ceratopogonidae	-	Capniidae	10
Chaoboridae	-	Chloroperlidae	10
Chironomidae	2	Leuctridae	10
Simuliidae	5	Nemouridae	7
Tipulidae	5	Perlidae	10
Ephemeroptera		Perlodidae	10
Baetidae	4	Planariidae	5
Caenidae	7	Taeniopterygidae	10
Ephemerellidae	10	Trichoptera	10
Ephemeridae	10	Beraeidae	10
Heptageniidae	10	Brachycentridae	-
Leptophlebiidae	10	Calamoceratidae	-
Nemouridae	7	Dipseudopsidae	-
Potamanthidae	10	Ecnomidae	10
Siphonuridae	10	Goeridae	-
Hemiptera		Helicosychidae	5
Belostomatidae	-	Hydropsychidae	6
Corixidae	5	Hydroptilidae	10
Gerridae	5	Lepidostomatidae	10
Hydrometridae	5	Leptoceridae	10

Table 2.4 continued

Mesovelidae	5	Limnephilidae	10
Naucoridae	5	Molannidae	10
Nepidae	5	Odontoceridae	10
Notonectidae	5	Philopotamidae	8
Pleidae	5	Phryganeidae	10
Megaloptera		Polycentropodidae	7
Corydalidae	-	Psychomyiidae	8
Neuroptera		Rhyacophilidae	7
Sialidae	4	Sericostomatidae	10
Lepidoptera			
Pyralidae	-		

Notes: "-" indicates "unknown"

Biomonitoring efforts that use aquatic insects and other macroinvertebrates have a number of benefits and they are useful indicators of localised conditions unlike fish which do not migrate significantly. Some species of aquatic insects such as Ephemeroptera, Plecoptera and Trichoptera are very sensitive to pollution and live in high quality environment with good water quality and thus they are used as bioindicators (Ismail *et al.*, 2012). Insects belonging to the order Odonata and Diptera, on the other hand, are generally considered as tolerant to pollution but some groups of taxa from both these orders can only breed in clean and unpolluted water. For example, the order Diptera consists of family Chironomidae which can tolerate with pollution while family Simuliidae is intolerant to pollution.

Indicator species such as Ephemeroptera, Plecoptera and Trichoptera have been found to be particularly sensitive to specific environmental factors. Changes in their abundance will reflect the environmental changes that occur. The existence of some organisms in the water indicates the quality of the water and provides an overall assessment about the physical and chemical properties of the water (Wahizatul *et al.*, 2011; Ismail *et al.*, 2012). Aquatic insects

are often used as indicators on the effect of human activity on water systems and also provide useful information on the habitat and water quality (Payakka and Prommi, 2014).

2.7 Anthropogenic Activities Affecting Aquatic Insect Composition

Anthropogenic activities or human activities that cause environmental degradation to the ecosystem including pollution in streams can influence the composition and diversity of aquatic insects in aquatic ecosystem. Fertiliser run-off, domestic sewage, mining activities and deforestation are examples of anthropogenic activities which can affect the water quality of an environment (Edegbene *et al.*, 2015; El Hussein *et al.*, 2015). Research has shown that disturbance resulting from anthropogenic activities has changed the water quality and community structure of aquatic insect (El Hussein *et al.*, 2015). Further, anthropogenic activities can lower the concentration of dissolved oxygen (DO). According to Wahizatul *et al.* (2011), the concentration of dissolved oxygen is one of the most vital water parameters to study the composition of aquatic insect communities. Other than DO concentration, anthropogenic activities also change other water parameter such as pH, temperature, alkalinity, nutrients and concentration of metal (Payakka and Prommi, 2014). Moreover, activities such as effluents from oil palm plantation and processing can lead to an increase in nutrient level and suspended solid. Studies (Yong and Yule, 2004; Comte *et al.*, 2012; Rawi *et al.*, 2013; Harun *et al.*, 2015) have reported that high concentration of suspended solid may decrease the abundance of aquatic insects.

It is evident that anthropogenic activities can significantly lower the abundance and diversity of aquatic insects (Wahizatul *et al.*, 2011; Kyerematen and Gordon, 2012). Anthropogenic activities which result in pollution in rivers and streams can lead to intolerance

among certain species of aquatic insect species which may be replaced by other species that are more tolerant to pollution (Robb, 1980). Tolerant insects such as Chironomidae can be found dominant in polluted rivers and streams. As reported by Yakub (2004), the domination of Chironomidae indicates that the water quality is being severely polluted by anthropogenic activities. In addition, human activities such as the loading of sediment also increase the abundance of Chironomidae. Loading of sediment could cause low concentration of oxygen, and thereby change the substrate and reduce food value for the insects.

Majumder *et al.* (2013) have conducted a study on aquatic insects in urban freshwater lakes of Tripura in Northeast India which has revealed that none of the orders of Ephemeroptera, Plecoptera and Trichoptera were recorded in the aquatic sites that were polluted. The study has reported that insects of the order of Hemiptera, Diptera, Odonata and Coleoptera appeared to be more dominant in urban areas than the orders of Ephemeroptera, Plecoptera and Trichoptera. This could be due to greater anthropogenic activities in the aquatic systems in urban habitats (Majumder *et al.*, 2013).

Thus, variations in anthropogenic activities greatly influence the composition pattern of aquatic insects since some of them are highly sensitive to pollution, while some others are more tolerant or completely tolerant to pollution and human disturbance (Hepp *et al.*, 2013). High level of anthropogenic activity can lead to relatively low composition, composition and abundance of aquatic insects (Edegbene *et al.*, 2015). Changes in the composition of stream communities as a result of anthropogenic activities caused by human have frequently been indicated in groups of aquatic insects since they are the most sensitive indicators for long-term environmental changes in water and habitat quality (Johnson *et al.*, 1993).

CHAPTER 3

DRIFT OF AQUATIC INSECTS AT SELECTED STREAMS

3.1 Introduction

Drift is the downstream transport of aquatic species in flowing waters. Among species of aquatic insects, studies by Watson (1971) on the drift of stream invertebrates in particular have been carried out over the years due to their significant presence in running water, including streams. These studies however have been carried out mostly in temperate regions and have concentrated mainly on the overall effect of the invertebrates on the constancy of stream communities (Watson, 1971). Studies also showed that the drift of benthic invertebrates plays important role in the spatial composition of stream invertebrates (Grzybkowska *et al.*, 2004). The realisation that drift plays a significant role in population dynamics and life histories of aquatic invertebrate species has led to measurement of the composition and variation of the drift to other forms of sampling in lotic ecological studies (Bishop, 1973).

Drift can be classified into three types, namely catastrophic drift, behavioural drift and constant drift. “Catastrophic” drift is more common in small lotic streams than in large lotic rivers while “behavioural” drift comprises animal behaviour in the river and “constant” drift is described as drift in small quantities due to accidental dislodgement movement of the substrate nevertheless of any diurnal periodicity (Matzinger and Bass, 1995).

Early studies defining nocturnal periodicity in invertebrate drift have focused on different extrinsic factors such as light intensity, water discharge, water velocity, quality of

water and presence of fish (Kennedy *et al.*, 2013). Whereas, intrinsic factors that have been studied include life stages of invertebrate and benthic density which causes invertebrate drift in streams (Kennedy *et al.*, 2013). In particular, water discharge has been found to be a significant extrinsic factor that causes invertebrate drift in streams and rivers that affects behavioural and constant drift of invertebrates (Kennedy *et al.*, 2013).

Assessing the quality of habitat in streams and rivers including availability of food for fish can be done by investigating the abundance and diversity of invertebrate species in the aquatic system. This can be done by carrying out sampling study on the invertebrate drift in the stream or river. The aquatic invertebrate drift samples can be used to create water quality indices which will provide a reliable assessment of the indices comparable to the more generally used benthic-invertebrate indices (Vadas Jr and Orth, 1997).

Periodic patterns in invertebrate drift are the result of alterations in benthic density, species life cycles and periodic changes in water flow and water temperature. Diel periodicity of drift is generally associated with the occurrence of predators and the diurnal pattern of invertebrates (Castro *et al.*, 2013). In flowing aquatic systems, invertebrate drift can describe the significant movements of organisms which may disturb the pattern of benthic sampling (O'Hop and Wallace, 1983).

The obvious diel pattern in the invertebrate drift movement of crustaceans and immature insects has received some attention with reports of low numbers in daytime activity, a drastic rise in numbers invertebrate drifting just after sunset, and a high but various levels of invertebrates drifting throughout the night (Allan *et al.*, 1986). Fazimah *et al.* (2005) have stated that the drift in the Selai River in Johor, Malaysia starts to increase after dusk and

remain increasing until midnight and stay high until dawn and the drift of aquatic insects reduced after sunrise and remain low throughout the day.

Invertebrate drift in tropical regions has not received much attention, although available information describes the drift dynamics in tropical streams as similar to those described for temperate regions. Ramírez and Pringle (1998) have described that strong nocturnal diel periodicity such as peaks in nocturnal drift is found in streams where diurnal predators are present, while in temperate regions drift related to seasonal temperature changes and drifting of organisms are found throughout the entire year. However, in some cases, drift fluctuations is more seasonal in tropical streams related to dry and wet seasons than temperate streams (Ramírez and Pringle, 1998).

While there are generally limited studies on invertebrate drift in tropical streams, there are no studies on drift of aquatic insects in small rivers or streams in Sarawak. Hence the present study has been undertaken to identify the abundance of aquatic insects drifting at rivers. The purpose of the present study was to study the abundance and diversity of aquatic insects in the drift of five streams in Sarawak, namely the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. In addition, the study aims to identify the drift pattern of the aquatic insects occurring in the streams and to investigate the composition of aquatic insects in the drift and its relationship with the water quality of the streams.

3.2 Methodology

3.2.1 Sampling Locations

Researches on aquatic insects and also the water quality studies in five types of streams of Sarawak were conducted in this study: Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream (Figure 3.1). The selection of each stream was based on the substrate of the stream. At every sampling location, the coordinates were recorded by using GARMIN GPSmap (Table 3.1).

Table 3.1: The coordinates, width and description of the streams.

Location	Stream	Coordinate	Width (m)	Description of sampling site
1	Sabong Stream	N 01° 44' 39.4" E 110° 19' 08.2"	5.1m	Water: fast flowing and clear. Substrate: sand + boulder + rock.
2	Duyoh Stream	N 01° 20' 39.0" E 110° 02' 37.4"	4.2m	Water: fast flowing and turbid. Substrate: sand + cobble + boulder.
3	Cina Stream	N 01° 36' 50.4" E 110° 11' 58.3"	5.5m	Water: moderate flowing and clear. Substrate: sand + boulder.
4	Serin Stream	N 01° 12' 23.4" E 110° 21' 52.2"	5.9m	Water: fast flowing and clear. Substrate: sand + cobble + boulder
5	Bak Muan Sadir Stream	N 01° 06' 26.0" E 110° 16' 28.1"	3.1m	Water: moderate flowing and clear. Substrate: sand + gravel.

The aquatic insects and water quality samplings were carried out for 24 hours at the selected streams from March 2016 to June 2016. Both aquatic insect drift and water quality samples were collected every three hours once in 24 hours period. The samplings were repeated for three times at each sampling area throughout the sampling periods.

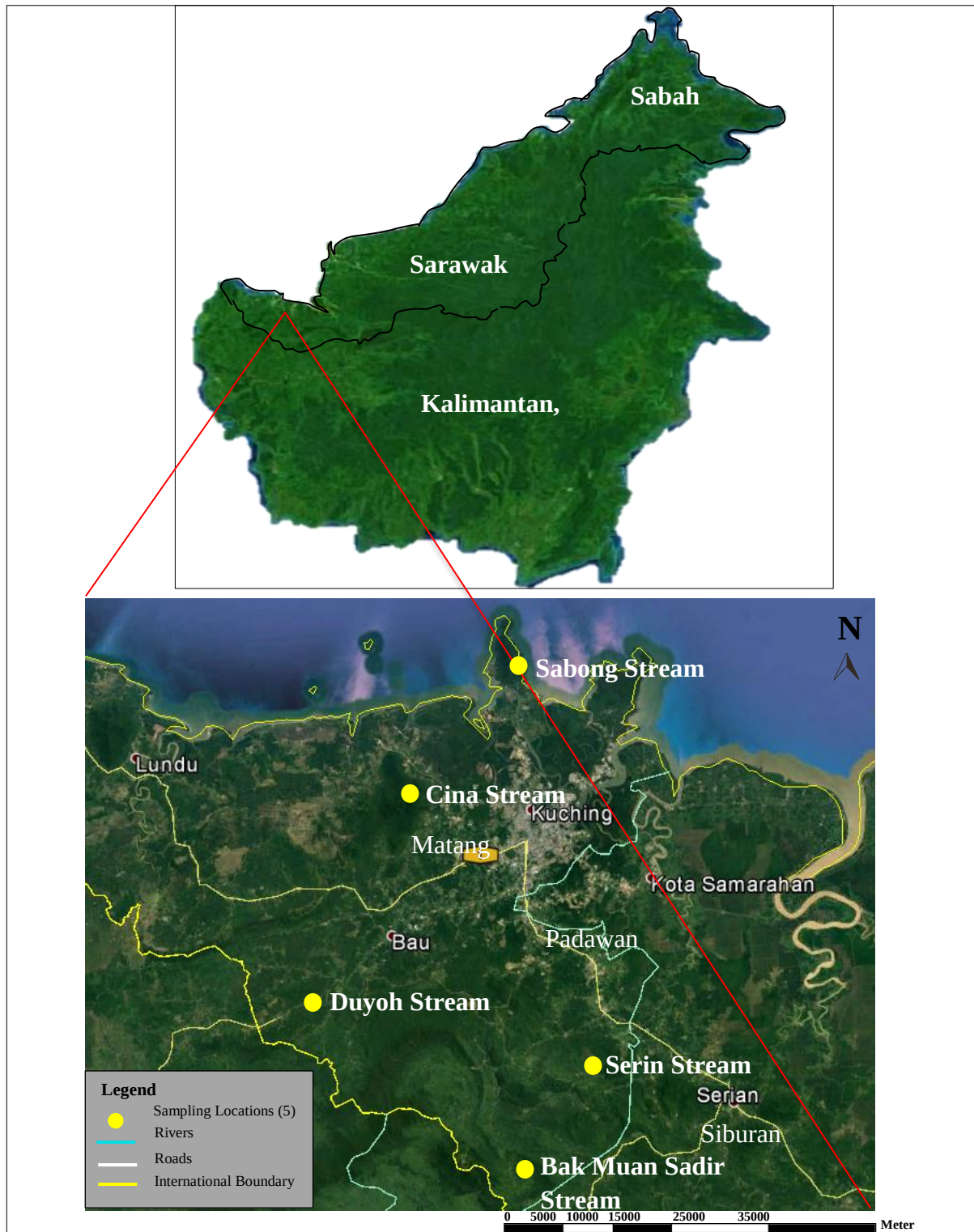


Figure 3.1: Map showing five sampling locations of streams at Sarawak.

The Sabong Stream is located at Kuching area near Mount Santubong, while the Duyoh Stream is located at Bau area. On the other hand, the Cina Stream is located at Matang

which is in the Matang Family Park, while the Serin Stream is located in Padawan and the Bak Muan Sadir Stream is located at Siburan.

3.2.2 Stream Physicochemical Parameters

The water quality or physicochemical parameters selected for this study were pH, water temperature (TEM), dissolved oxygen (DO), river depth (DPH), river width (WDH), turbidity (TBY), total suspended solid (TSS), water current (WCN) and water discharge (Q). Water quality parameters namely pH, TEM, DO, DPH, WDH, TBY, and WCN, Q were measured *in-situ*. TSS parameter was analysed *ex-situ*.

3.2.2.1 In-situ Physicochemical Parameters

pH and water temperature (TEM) were measured *in-situ* using a EXTECH SDL100 pH meter. Dissolved oxygen was measured *in-situ* using EXTECH SDL150 Dissolved Oxygen meter. Turbidity of water was measured using a MARTINI Mi 415 turbidity meter. The river depth (DPH) of the sampling location was measured using a ruler while width (WDH) of the river was measured using measuring tape. The water current (WCN) and water discharge (Q) was determined by measuring the velocity of the water with Geopacks (The Geography Specialist Flow Rate Meter). Water Discharge (Q) is defined as the volume of water flowing in the river per unit time past a specific point of the stream.

Water discharge (Q) was calculated to determine the discharge of water through the Surber sampler during sampling. The formula used for calculating water discharge is:

$$Q = V \times A$$

where, Q = discharge (m³/s), V = water velocity (m/s) and A = cross-sectional area (depth of water x width of the river) (m²).

3.2.2.2 *Ex-situ* Physicochemical Parameters

3.2.2.2.1 Total Suspended Solids

The procedure for determining total suspended solids (TSS) follows the standard method (2540-D) used by APHA (2000). Glass microfiber filter disc with 47 mm size were used to filter water samples. Filter papers were dried and weighed to a constant weight using analytical balance and recorded before being placed using forceps on the funnel base which attached to the vacuum pump. Then, the funnel cup was placed before water samples were poured. A 500 ml of water sample was shaken vigorously and transferred for filtration. A vacuum pump was connected to let the water sample to pass through the flask quickly. The filter papers were then removed from the base carefully using forceps and wrapped in aluminium foil. The wet filter paper was then dried in oven for an hour at 100°C to 105°C. Later, the dried filter paper was left to be cooled and then weighed to a constant weighed. TSS was determined by using the formula below:

$$\text{TSS (mg/L)} = \frac{(A-B) \times 1000}{C}$$

where, A = initial weight of filter paper, B = final weight of filter paper and volume of water samples filtered (mL).

3.2.3 Sampling and Identification of Aquatic Insects

At each sampling stations, a Wildco® Surber stream bottom sampler of 363-micron mesh size was used to collect the insect samples. The frame size of the sampler was 30 cm height x 30 cm width. The coordinates of the station was recorded using GPSMAP® GPS 62 Series. The sampler was placed at the river bed. The samples of the aquatic insects in the drift were collected every three hours by clearing the Surber sampler. The collected samples were transferred into a bucket filled with water. A 250 micron sieve was used to sort the large materials such as leaves from the insect samples. The aquatic insect samples were preserved in 80% ethanol before being taken to the laboratory for identification. In the laboratory, aquatic insects were sorted accordingly to their morphological characteristics and identified under Olympus SN: 3LO9174 stereo microscope. Aquatic insects was carried out to the lowest possible taxa using keys available in McCafferty (1981); Yule and Yong (2004); Thorp and Rogers (2011); Pravin (2012). After identification, aquatic insects were placed in vials with 95% ethanol for preservation.

3.2.4 Data Analysis

3.2.4.1 Analysis of Indices

Drift density was calculated using the number of invertebrates captured by the nets per volume of water passing through the nets during the sampling period. The comparisons of the species, drift densities and average size of invertebrates were performed between day and night and every three hours.

Calculation to standardise the drift samples to 100m³ of volume filtered was done using the following formula,

$$\text{Drift Density} = \frac{[(N)(100)]}{[(t)(W)(H)(V)(3600/h)]}$$

where, N represents the number of invertebrates in a sample, t represents the time that the net was set (h), W is the net width (m), H is the mean height of water column in the net mouth (m), and V is the velocity (ms⁻¹).

The community structure of aquatic insect drift in this study was examined based on their diversity indices. These include the Shannon-Wiener's diversity index (*H*) and Margalef's species richness index (*d*). Data analysis of diversity indices for species diversity and richness was calculated using the formulae below:

i. Shannon-Wiener's diversity index (*H*) (Shannon and Weaver, 1963),

$$H = -\sum \frac{N_i}{N} \ln \frac{N_i}{N}$$

where, N is the number of individual, S represents total number of taxa and *ln* represents the natural logarithm. Shannon-Wiener's diversity index (*H*) was used to calculate the species diversity of the aquatic insects in drift. It provides important information about variety and commonness of the species in a community. Biologists used this diversity index as an important tool to understand community structure. This index accounts for both abundance and evenness of the species present. It is one of the basic concepts of ecology that has been used to characterise communities and ecosystems.

- ii. Margalef's species richness index (d) (Margalef, 1968),

$$d = \frac{(S - 1)}{\ln N}$$

where, N is the number of individual, S represents total number of taxa and $\ln$ represents the natural logarithm. Margalef's species richness index (d) is the simplest measure of biodiversity and simply a count of the number of different species in a given area. It does not take into account the proportion and within the local aquatic community. The PAST (Paleontological Statistics) version 2.04 Software was used to re-check and analyse the species diversity indices and species abundance of the aquatic insects in the samples.

3.2.4.2 Statistical Analysis

Correlation analysis was conducted to examine the relationship between the aquatic insect community structure and stream physicochemical parameters. The correlation analyses applied in this study were Pearson's correlation analysis and Canonical Correspondence Analysis (CCA). Pearson's correlation analysis was carried out using Minitab Statistics 17 and CCA was performed using PAST 3.14. CCA was performed to identify and describe pattern in community structure of aquatic insects in drift with stream physicochemical parameters by summarising the structure of a species by sample data matrix. Analysis of variance (ANOVA) was used to compare the variations in water quality between sampling locations and sampling periods with significant set at $p < 0.05$. These statistical analyses were performed using IBM SPSS Statistics 21 for windows. Paired t -test was used to find the significant differences between day and night drift of aquatic insects in the streams. Paired t -test was performed using Minitab Statistics 17 software for Windows.

3.3 Results

3.3.1 Composition of Aquatic Insects in Drift

A total of 462.29 individuals of aquatic insects per 100m³ of volume filtered which belongs to 39 species, 25 families and 7 orders of aquatic insects was recorded from the five streams, namely Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. Figure 3.2 shows the abundance of the aquatic insects in the five streams. The order Ephemeroptera was the highest in the number of families represented by families Baetidae, Heptageniidae, Leptophlebiidae, Caenidae, Potamanthidae, Ameletidae, Ephemeridae and Ephemerellidae. Whereas, the order Diptera was represented by six families and recorded as second highest in number of families namely Simuliidae, Chironomidae, Tipulidae, Phoridae, Culicidae and Ceratopogonidae. The order Trichoptera was featured by family Philopotamanthidae, Psychomyiidae, Hydropsychidae and Ecnomidae while the order Coleoptera included Elmidae, Scirtidae, Psephenidae and Pyralidae. The Order Plecoptera, Odonata and Collembola were represented by one family each namely Perlidae, Calopterygidae and Isotomidae respectively.

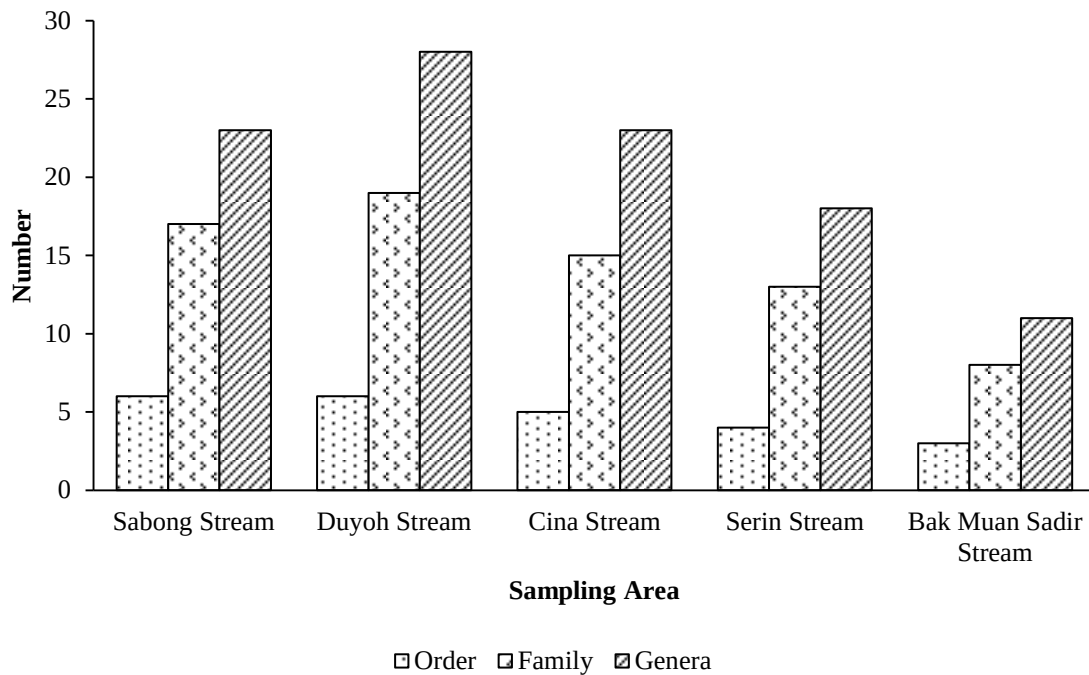


Figure 3.2: Number of orders, families and genera from five sampling areas in Sarawak.

3.3.1.1 Sabong Stream

There were 22 genera from 17 families which belonged to 6 orders with 48.4 individuals per 100m³ of volume filtered that were recorded in Sabong Stream. The composition of aquatic insects consisted of 22.2 individuals per 100m³ of Diptera (45.9%), 17.3 individuals per 100m³ of Ephemeroptera (35.5%), 5.9 individuals per 100m³ of Trichoptera (12.3%), 2.0 individuals per 100m³ of Plecoptera (4.1%), 1.1 individuals per 100m³ of Coleoptera (2.0%) and 0.1 individuals per 100m³ of Odonata (0.2%). There were five genera from order Diptera that represented the family Simuliidae (*Simulium* sp.), Chironomidae (*Cricotopus* sp., *Chironomus* sp., and *Clinotanypus* sp.) and Tipulidae (*Tipula* sp.). The order Ephemeroptera was represented by six families, namely Baetidae, Heptageniidae, Leptophlebiidae, Caenidae, Potamanthidae and Ephemerellidae while the Trichopteran was represented by families Philopotamidae, Psychomyiidae and

Hydropsychidae whereas *Phanoperla* sp. and *Neoperla* sp. belonged to family Perlidae from order Plecoptera. the families Elmidae, Scirtidae and Tipulidae belonging to the order Coleoptera that were collected from Sabong Stream where the least number of aquatic insects that were found drifting in this stream were from the order Odonata which were represented by the family Calopterygidae (0.1 individuals per 100m³). *Simulium* sp. was recorded as the most dominant number of aquatic insects that was found drifting in the Sabong Stream with 18.2 individuals per 100m³. The aquatic insects inhabiting in the Sabong Stream are listed in Table 3.2.

Table 3.2: List of aquatic insect order, family, taxa and drift density of aquatic insect species at the streams (aquatic insect individuals per 100m³ of volume of water filtered).

Species	Sampling Site				
	Sabong Stream	Duyoh Stream	Cina Stream	Serin Stream	Bak Muan Sadir Stream
Ephemeroptera					
Baetidae					
<i>Baetis</i> spp.	13.8	19.6	37.6	43.1	64.1
<i>Platybaetis</i> spp.	2.0	5.4	6.7	9.6	0.6*
Ameletidae					
<i>Ameletus</i> spp.	0.0	12.9	8.3	1.8	0.6*
Heptageniidae					
<i>Thalerosphyrus</i> sp.	0.3*	0.4*	2.0	0.4*	0.0
<i>Camponeuria</i> spp.	0.2*	1.4	0.2*	4.0	9.8
<i>Epeorus</i> sp.	0.0	1.5	0.6*	3.9	5.0
Leptophlebiidae					
<i>Choroterpes</i> sp.	0.4*	2.1	2.1	5.1	18.3
<i>Habrophlebiodes</i> sp.	0.0	1.7*	0.0	1.4	0.0
<i>Thraulius</i> sp.	0.0	0.1*	0.0	0.0	0.0
Caenidae					
<i>Caenis</i> spp.	0.2*	6.7	1.3*	5.0	14.5
Potamanthidae					
<i>Potamanthus</i> sp.	0.2*	0.0	0.0	0.0	0.0
Ephemerellidae					
<i>Drunella</i> sp.	0.2*	0.3*	0.0	0.0	0.0
Ephemeridae					
<i>Ephemera</i> sp.	0.0	0.0	0.2*	0.1*	0.0
Plecoptera					
Perlidae					
<i>Phanoperla</i> spp.	1.7	0.0	0.3*	0.0	0.0
<i>Neoperla</i> sp.	0.3*	0.0	0.0	0.0	0.0
<i>Kamimuria</i> sp.	0.0	0.4*	0.0	0.0	0.0
Trichoptera					
Philopotamidae					
<i>Doloclanes</i> spp.	3.1	1.0	0.8*	1.3	0.0

Table 3.2 continued

Species	Sampling Site				
	Sabong Stream	Duyoh Stream	Cina Stream	Serin Stream	Bak Muan Sadir Stream
Psychomyiidae					
<i>Tinodes</i> sp.	0.0	0.0	0.7*	0.0	0.0
<i>Psychomyia</i> sp.	0.9*	0.0	0.0	0.0	0.0
Hydropsychidae					
<i>Cheumatopsyche</i> sp.	0.0	0.0	1.6	2.0	0.0
<i>Hydropsyche</i> sp.	1.9	1.0	0.0	0.0	0.0
Ecnomidae					
<i>Ecnomus</i> sp.	0.0	0.3*	0.0	0.0	0.0
Diptera					
Simuliidae					
<i>Simulium</i> spp.	18.2	5.1	24.6	9.7	15.9
Chironomidae					
<i>Cricotopus</i> spp.	1.5	1.9	0.3*	0.0	0.0
<i>Chironomus</i> spp.	1.4	3.7	2.5	0.2*	0.3*
<i>Polypedium</i> spp.	0.0	1.4	4.2	0.0	17.8
<i>Clinotanytus</i> spp.	1.0*	1.2	1.1*	0.0	0.0
Tipulidae					
<i>Tipula</i> sp.	0.1*	0.1*	0.0	0.0	0.0
<i>Megaselia deningi</i>	0.0	0.5*	0.0	0.0	0.0
Culicidae					
<i>Culex</i> sp.	0.0	0.2*	0.3*	0.0	0.0
Ceratopogonidae					
<i>Dasyhelea</i> sp.	0.0	0.2*	0.0	0.0	0.0
Coleoptera					
Elmidae					
<i>Stenelmis</i> sp.	0.3*	0.5*	2.2	0.5*	2.7
Scirtidae					
<i>Scirtes</i> sp.	0.4*	5.9	0.0	0.7	0.0
Psephenidae					
<i>Psephenus</i> sp.	0.0	0.0	0.3*	0.0	0.0
<i>Eubrianax</i> sp.	0.0	0.0	1.7	0.4*	0.0
Pyralidae					
<i>Petrophila</i> sp.	0.4*	0.0	0.0	0.0	0.0

Table 3.2 continued

Species	Sampling site				
	Sabong Stream	Duyoh Stream	Cina Stream	Serin Stream	Bak Muan Sadir Stream
Odonata					
Calopterygidae					
<i>Neurobasis</i> sp.	0.1*	0.0	0.0	0.0	0.0
Collembola					
Isotomidae					
<i>Isotomurus</i> sp.	0.0	0.1*	0.0	0.0	0.0
Total	48.4	75.5	99.7	89.2	149.5

*Note: * represents the number of aquatic insects < 10.0 individuals drifted in the streams.

3.3.1.2 Duyoh Stream

A total of 75.5 individuals per 100m³ with 27 species belonging to 19 families from 6 orders of aquatic insects were found in the Duyoh Stream, namely Ephemeroptera with 52.1 individuals per 100m³ (68.8%), 14.3 individuals per 100m³ of Diptera (19.1%), 6.4 individuals per 100m³ of Coleoptera (8.4%), 2.3 individuals per 100m³ of Trichoptera (3.0%), 0.4 individuals per 100m³ of Plecoptera (0.6%), and 0.1 individuals per 100m³ of Collembola (0.1%). There were six families (Baetidae, Ameletidae, Heptageniidae, Leptophlebiidae, Caenidae and Ephemerellidae) belonging to the order Ephemeroptera. The order Diptera was represented by 10 species belonging to families Simuliidae, Chironomidae, Tipulidae, Phoridae, Culicidae and Ceratopogonidae. Two genera were identified from the order Coleoptera which represented the family Elmidae (*Stenelmis* sp.) and Scirtidae (*Scirtes* sp.). The Trichopteran was represented by the families Philopotamidae, Hydropsychidae and Ecnomidae while one genus belonged to family Perlidae (*Kamimuria* sp.) from order Plecoptera and genus *Isotomurus* sp. belonged to the family Isotomidae from the order

Collembola. *Baetis* sp. was the dominant genus (19.6 individuals per 100m³) recorded in this stream (see Table 3.2).

3.3.1.3 Cina Stream

About 15 families representing 22 genera from 5 orders with 99.7 individuals per 100m³ were recorded in this study area. They included the order Ephemeroptera with 59.0 individuals per 100m³ amounting to 59.2% of the total individuals, Diptera with 33.0 individuals per 100m³ (33.2%), Coleoptera with 4.2 individuals per 100m³ (4.2%), Trichoptera with 3.1 individuals per 100m³ (3.1%) and Plecoptera with 0.3 individuals per 100m³ (0.3%). The order Ephemeroptera comprised six families (Baetidae, Ameletidae, Heptageniidae, Leptophlebiidae, Caenidae and Ephemeridae) which represented the dominant genus found in the Cina Stream, *Baetis* sp. (37.6 individuals per 100m³). There were six genera from the order Diptera belonging to families Simuliidae (*Simulium* sp.), Chironomidae (*Cricotopus* sp., *Chironomus* sp., *Polypedium* sp. and *Clinotanypus* sp.) and Culicidae (*Culex* sp.). The order Coleoptera was represented by the family Elmidae and Psephenidae while the families Philopotamidae, Psychomyidae and Hydropsychidae belonged to the order Trichoptera. One genus was identified from the order Plecoptera which belonged to the family Perlidae, namely *Phanoperla* sp. (see Table 3.2).

3.3.1.4 Serin Stream

In the Serin Stream, 89.16 individuals per 100m³ with 17 genera belonging to 13 families representing 4 orders of aquatic insects were recorded. They were represented by 83.5% of the order Ephemeroptera (74.4 individuals per 100m³), 11.1% of Diptera (9.9 individuals per 100m³), 3.7% of Trichoptera (3.3 individuals per 100m³) and 1.7% of

Coleoptera (1.6 individuals per 100m³). The dominant genus was *Baetis* sp. belonging to the order Ephemeroptera with 43.1 individuals per 100m³ followed by *Platybaetis* sp. with 9.6 individuals per 100m³. The Trichopteran was represented by two families, namely Philopotamidae and Hydropsychidae, and Dipteran was represented by the families Simuliidae and Chironomidae. Whereas *Stenelmis* sp., *Scirtes* sp. and *Eubrianax* sp. belonging to the families Elmidae, Scirtidae and Psephenidae respectively from order Coleoptera were recorded. The least number of individuals that were found drifting in the Serin Stream was the genus *Ephemer* sp. with 0.1 individuals per 100m³ belonging to the family Ephemeridae from the order Ephemeroptera (see Table 3.2).

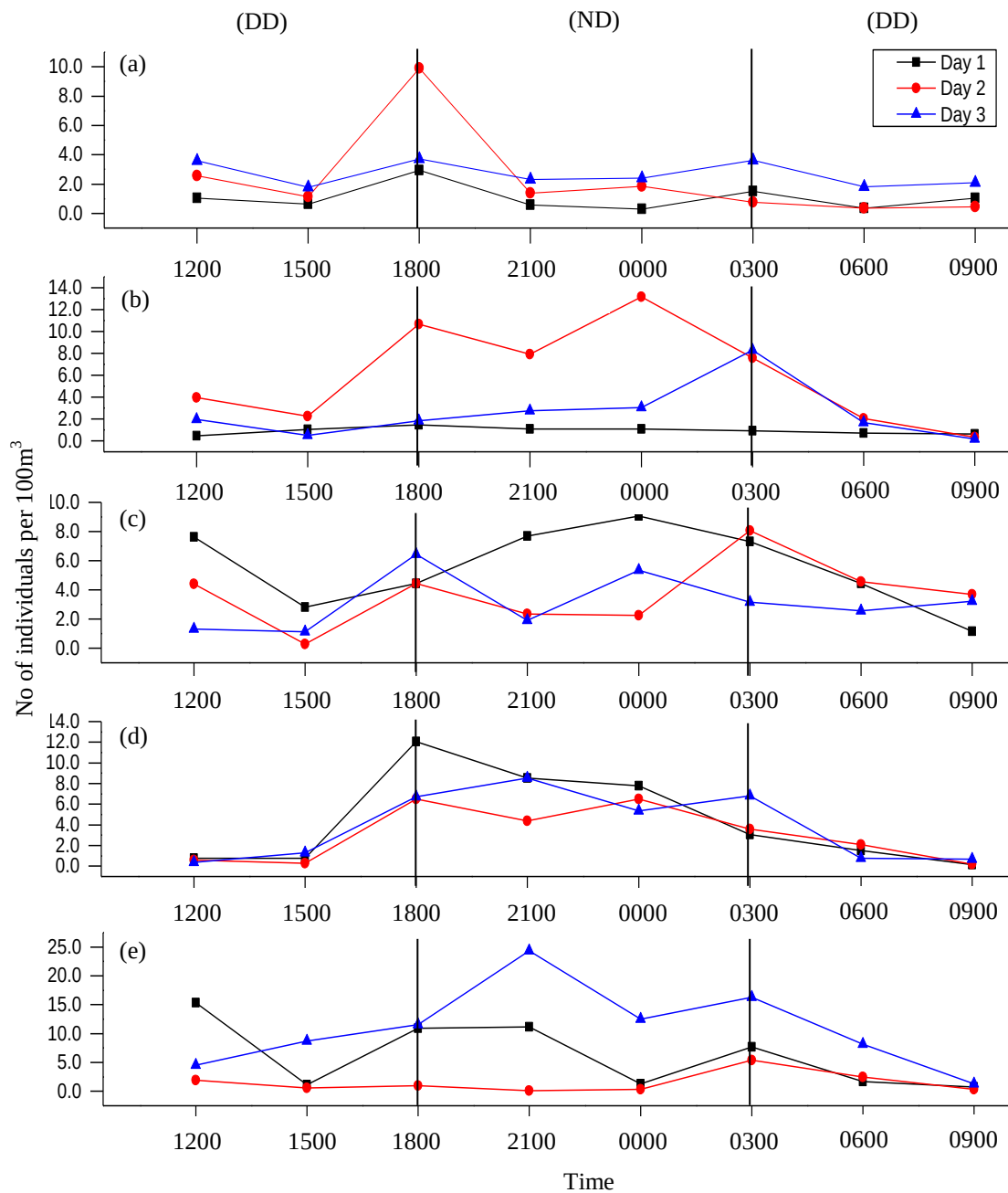
3.3.1.5 Bak Muan Sadir Stream

There were 149.5 individuals per 100m³ volume of water filtered in the Bak Muan Sadir Stream, with 11 genera belonging to eight families represented by three orders that were recorded. They included the order Ephemeroptera with 112.9 individuals per 100m³ or 75.5% of total individuals, Diptera with 34.0 individuals per 100m³ or 22.7% and Coleoptera with 2.7 individuals per 100m³ or 1.8%. The order Ephemeroptera comprised five families (Baetidae, Ameletidae, Heptageniidae, Leptophlebiidae and Caenidae) which were represented by the dominant genera in Sabong Stream, *Baetis* sp. with 64.1 individuals per 100m³ amounting to 42.9% followed by *Choroterpes* sp. with 18.3 individuals per 100m³ (12.2%). There were two genera from the order Diptera belonging to the families Simuliidae (*Simulium* sp.) and Chironomidae (*Chironomus* sp. and *Polypedium* sp.). Only one genus was identified from the order Coleoptera and belongs to family Elmidae, namely *Stenelmis* sp (see Table 3.2).

3.3.2 Diel Periodicity Drift Pattern

The number of aquatic insects occurring in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream were standardised to the number of aquatic insect per 100m^3 of volume of water filtered by the sampler in order to obtain the drift densities of aquatic insects in the drift. The total aquatic insects found drifting in the Sabong Stream was 48.4 individuals per 100m^3 of volume of water filtered by the sampler. The aquatic insects drifted the most at 1800 hour on every sampling days conducted in the Sabong Stream with maximum number of 2.96 individuals per 100m^3 on day 1, 9.9 individuals per 100m^3 on day 2 and 3.7 individuals per 100m^3 on day 3 were reached while the least aquatic insects were found drifting at 0000 hour on day 1, 0600 hour on day 2 and 1500 hour on day 3 as in Figure 3.3.

In the Duyoh Stream, 75.5 individuals per 100m^3 of aquatic insects were found drifting in the stream whereby the highest aquatic insects that drifted were observed at 1800 hour on day 1 (1.5 individuals), 0000 hour on day 2 (10.7 individuals) and 0300 hour on day 3 (8.3 individuals) while the lowest was at 1200 hour on day 1 and 0900 hour on day 2 and 3 (Figure 3.3). Drift density of the Cina Stream was 89.2 individuals per 100m^3 and the minimal drift density were found at 0900 hour on day 1 with 1.2 individuals, 1500 hour on day 2 and day 3 with 0.3 individuals and 1.1 individuals respectively while the highest drift density was observed at 0000 hour on day 1, 0300 hour on day 2 and 1800 hour on day 3.



*Note: (a) = Sabong Stream, (b) = Duyoh Stream, (c) = Cina Stream, (d) = Serin Stream, (e) = Bak Muan Sadir Stream, DD = Day Drift, ND = Night Drift

Figure 3.3: Drift pattern of aquatic insects in the streams.

A total of 89.2 individuals per 100 m³ of aquatic insects were found drifting in the Serin Stream with peak at 1800 hour on day 1 and day 2 and 2100 hour on day 3 while the

least number of aquatic insects found drifting in the Serin Stream was observed at 0900 hour on day 1 and day 2 and at 1200 hour on day 3. The Bak Muan Sadir Stream recorded a drift density of 149.5 individuals per 100m³ with the maximum drift density of 15.3 individuals per 100m³ on day 1 at 1200 hour, 5.4 individuals per 100m³ at 0300 hour on day 2 and 24.4 individuals per 100m³ at 2100 hour on day 3 of sampling conducted in the Bak Muan Sadir Stream. The lowest drift density rates of aquatic insects drifting in the Bak Muan Sadir Stream was found at 0900 hour on day 1 and day 3 and 2100 hour on day 2 (see Figure 3.3).

In all days sampled in every stream, some degree of nocturnal periodicity was exhibited. An increase in drift density occurred just after sunset for every sampling day in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. Although the peak of the drift density for the sampling days in every stream was different, the increase in drift density just after sunset shows that aquatic insects choose to drift after evening and during darkness. Irregular pattern of aquatic insects drifting throughout night time was observed on every sampling days in all the streams and fluctuation in drift density for all the sampling days in every stream was observed at 0600 hour which is just after sunrise.

The drift density of aquatic insects is about 60.0% more higher at night than during the daytime on every sampling carried out in the five streams where 64.8% of aquatic insects drifted at night in the Sabong Stream while 79.2% of aquatic insects in Duyoh Stream drift at night, 62.7% in Cina Stream, 89.48% in Serin Stream and 68.6% of aquatic insects drifted at night in Bak Muan Sadir Stream as in Figure 3.4 but there was no significant differences between day drift and night drift at the streams except in Serin Stream as shown in Table 3.3.

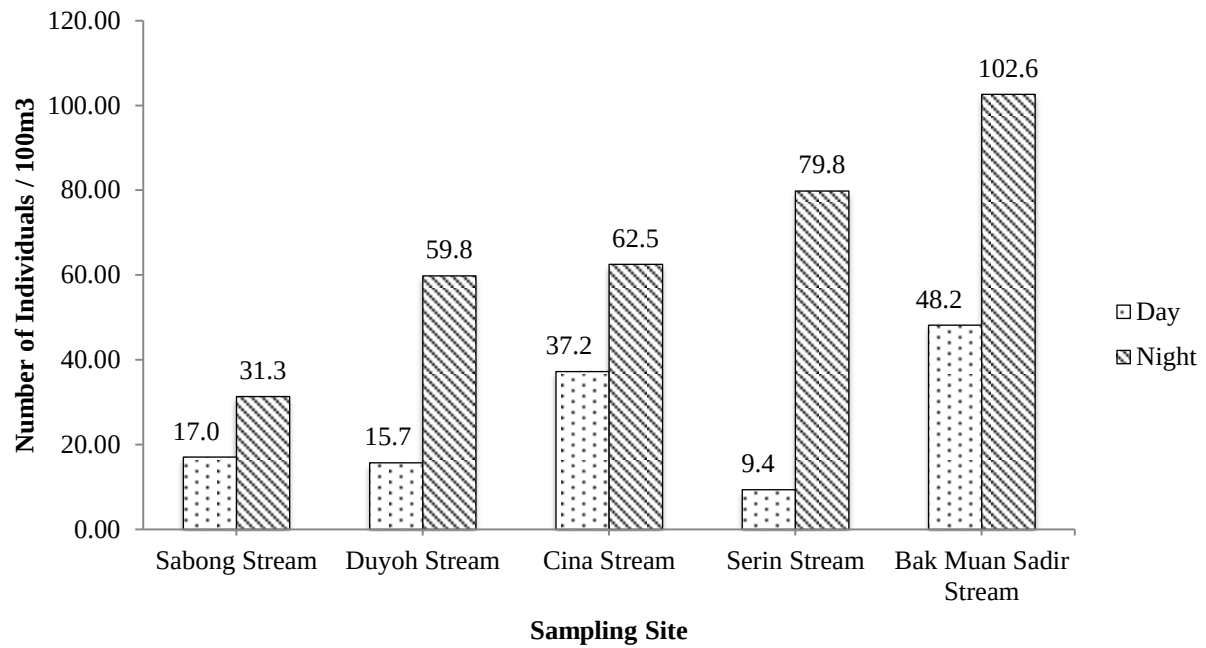


Figure 3.4: Drift density of aquatic insects at daytime and nighttime according to streams.

Table 3.3: Paired t-test of day drift and night drift according to the stream.

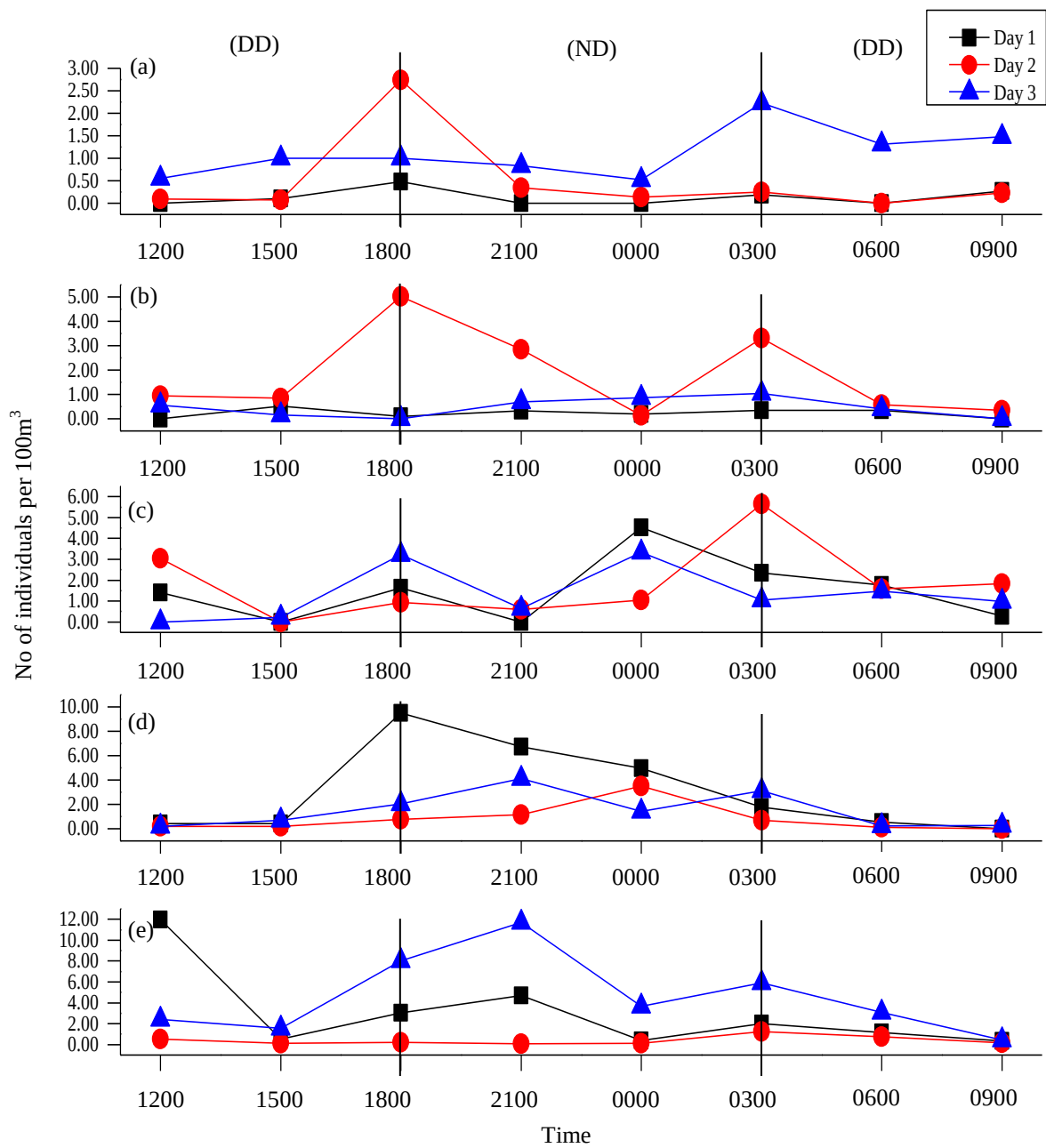
Location	Day and Night (<i>p</i> value)
Sabong Stream	0.638
Duyoh Stream	0.225
Cina Stream	0.074
Serin Stream	0.016*
Bak Muan Sadir Stream	0.261

3.3.2.1 Drift Pattern of *Baetis* sp.

The drift pattern of *Baetis* sp. was observed in this study as it is the common species which has the high number of individuals found in every stream. A total drift density for *Baetis* sp. of 13.8 individuals per 100m³ occurred in the Sabong Stream, 19.6 individuals per 100m³ in Duyoh Stream, 37.6 individuals per 100m³ in Cina Stream, 43.1 individuals per 100m³ in Serin Stream and 64.1 individuals per 100m³ of *Baetis* sp. were recorded in Bak Muan Sadir Stream.

In general, the drifting of *Baetis* sp. reduced just after sunrise and it was encountered in greatest numbers in late evening until early morning hours in all the streams. Nocturnal peaks were encountered for *Baetis* sp. throughout the sampling days in every stream. The minor peak was encountered just after sunset in all the streams which showed that the number of *Baetis* sp. drifting in the water current increases after sunset. The minor peak was observed on almost all the sampling days in every stream except day 3 in the Sabong Stream, day 1 and day 3 in the Duyoh Stream and day 2 in the Bak Muan Sadir Stream as in Figure 3.5. The minor peak may be a result of a late evening emergence of *Baetis* sp. It was found to be the greatest of the total drift of the aquatic insects found in every stream. The *Baetis* sp. was the dominant taxon which was recorded in every stream except the Sabong Stream where *Simulium* sp. was the main species of aquatic insects collected from the Sabong Stream.

Comparison between day and night drift of *Baetis* sp. was also done to show that the *Baetis* sp. drifted more frequently and in large number during night time than the day time whereby about 41.2% of *Baetis* sp. found in the Sabong Stream drifted at night, 14.9 individuals per 100m³ of *Baetis* sp. drifted at night in the Duyoh Stream while only 4.7 individuals per 100m³ of *Baetis* sp. found during day time, 49.5% of *Baetis* sp. drifted more at night than day time, 92.3% of total *Baetis* sp. found in the Serin Stream drifted at night time and only 36.0% of *Baetis* sp. found in the Bak Muan Sadir Stream drifted during day time and the balance drifted at night time (Figure 3.6). There are no significant differences between day drift and night drift of *Baetis* sp. in all the streams as stated in Table 3.4.



*Note: (a) = Sabong Stream, (b) = Duyoh Stream, (c) = Cina Stream, (d) = Serin Stream, (e) = Bak Muan Sadir Stream, DD = Day Drift, ND= Night Drift

Figure 3.5: Drift pattern of *Baetis* sp. in the streams.

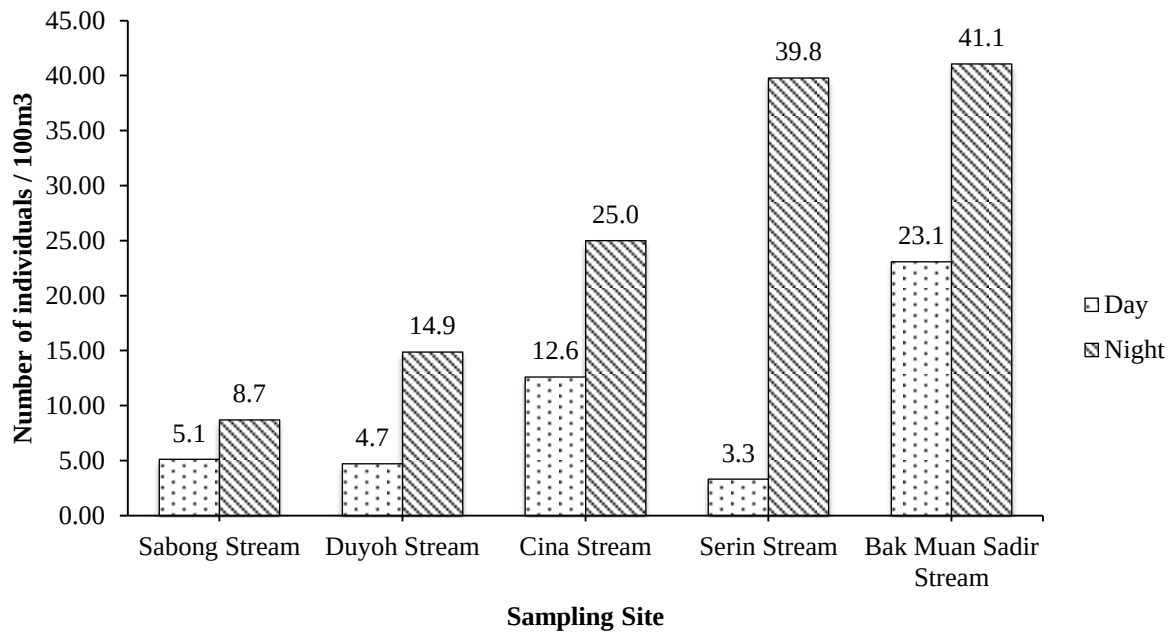


Figure 3.6: Drift density of *Baetis* sp. at daytime and nighttime according to streams.

Table 3.4: Paired t-test of day drift and night drift of *Baetis* sp. according to the stream.

Location	Day and Night (<i>p</i> value)
Sabong Stream	0.334
Duyoh Stream	0.325
Cina Stream	0.077
Serin Stream	0.128
Bak Muan Sadir Stream	0.530

3.3.3 Community Structure of Aquatic Insects in Drift

In general, the Shannon diversity index (H) of aquatic insects in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream ranged from 1.777 to 2.490 (Table 3.5). The H of the Duyoh Stream recorded the highest (2.490) which comprised 28 species of aquatic insects than the other four streams. The Bak Muan Sadir Stream recorded the lowest H with 1.777 which comprised 11 species. The Margalef species richness

(*d*) index was the highest in the Duyoh Stream (4.256), followed by the Sabong Stream (3.824), Cina Stream (3.651), Serin Stream (2.519) and Bak Muan Sadir Stream (1.581).

Table 3.5: Diversity and richness of aquatic insects in the streams.

Sampling Site	Sabong Stream	Duyoh Stream	Cina Stream	Serin Stream	Bak Muan Sadir Stream
Species (S)	23	28	23	18	11
Individuals (N)	315	569	414	853	559
Shannon species diversity (<i>H</i>)	2.127	2.490	2.026	1.927	1.777
Margalef's species richness (<i>d</i>)	3.824	4.256	3.651	2.519	1.581

3.3.4 Correlations between Community Structure and Physicochemical Parameters in the Streams

The Pearson correlation analysis shows that the Shannon diversity index (*H*) of aquatic insects in the drift of the Sabong Stream is negatively and strongly correlated ($p < 0.01$) with dissolved oxygen (DO) ($r^2 = 1.000$). Whereas, the Margalef species richness index (*d*) of aquatic insects in the Sabong Stream is negatively and strongly correlated ($p < 0.01$) with pH ($r^2 = 0.998$) as in Table 3.6. There is no strong significant correlation between the community structure of aquatic insects and physicochemical parameters in the Duyoh Stream as shown in Table 3.7. *H* of aquatic insects in the Cina Stream has positive and significant relationship ($p < 0.01$) with water temperature (TEM) ($r^2 = 0.998$) as in Table 3.8.

H of aquatic insects in the Serin Stream is inversely and significantly correlated ($p < 0.01$) with turbidity (TBY). The *d* of aquatic insects in the Serin Stream is significantly correlated ($p < 0.05$) with TEM ($r^2 = 1.000$) while negatively and strongly correlated ($p < 0.01$) with water current (WCN) ($r^2 = 0.998$) as well (Table 3.9). The *Q* ($r^2 = 1.000$) and total suspended solid (TSS) ($r^2 = 0.996$) of the Bak Muan Sadir Stream has high correlation

($p < 0.01$) with H of aquatic insects present in the Bak Muan Sadir Stream as indicated in Table 3.10.

Table 3.6: The Pearson's correlation coefficient (*r* value) among assemblages of aquatic insects and water parameters in Sabong Stream.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-1.000^b	-0.868	-	-0.982	0.383	0.953	0.908	0.516
Margalef's species richness (<i>d</i>)	-0.851	-0.999^b	-	-0.928	0.822	0.637	0.990	-0.029

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 3.7: The Pearson's correlation coefficient (*r* value) among assemblages of aquatic insects and water parameters in Duyoh Stream.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	0.953	-0.312	0.151	-0.352	-0.268	-0.312	-0.254	-0.702
Margalef's species richness (<i>d</i>)	-0.978	0.401	-0.244	0.261	0.358	0.401	0.345	0.631

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 3.8: The Pearson's correlation coefficient (*r* value) among assemblages of aquatic insects and water parameters in Cina Stream.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-0.991	0.423	-0.059	0.999^b	-0.384	-0.986	-0.813	0.827
Margalef's species richness (<i>d</i>)	0.049	-0.968	0.992	-0.134	0.978	0.014	0.720	0.402

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 3.9: The Pearson's correlation coefficient (*r* value) among assemblages of aquatic insects and water parameters in Serin Stream.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	0.790	-0.982	-0.998^b	-0.984	0.974	-0.904	0.923	0.693
Margalef's species richness (<i>d</i>)	-0.671	0.934	0.994	1.000^a	-0.999^b	0.815	-0.976	-0.557

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 3.10: The Pearson's correlation coefficient (*r* value) among assemblages of aquatic insects and water parameters in Bak Muan Sadir Stream.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	0.781	0.767	0.570	-0.484	0.991	0.946	1.000^b	0.998^b
Margalef's species richness (<i>d</i>)	0.798	-0.433	0.937	0.729	0.116	0.548	0.222	0.187

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

3.3.5 Correlations between Aquatic Insects and Physicochemical Parameters of the Streams

From the CCA diagram, the two axes accounted for 38.31% and 72.37% of the total variance respectively. Seven *in-situ* physicochemical parameters were subsequently used with five sampling sites and 39 species of aquatic insects' presence in the drift. The CCA indicated that the total extent variation or total inertia (TI) in the abundance of aquatic insects had an eigenvalue of 0.590 where the eigenvalue of the seven physicochemical parameters accounted for 38.31% of the total variance (TVE) as in Table 3.11.

Table 3.11: Summary of canonical correspondence analysis (CCA) for aquatic insects with determined eigenvalue and value of axis 1 and axis 2.

Axes	1	2
Eigenvalues	0.226	0.201
Species-environment correlations	0.657	0.342
Cumulative percentage variance:		
of aquatic insects data	19.69	17.51
of aquatic insects-environment relation	38.31	72.37
Sum of all unconstrained eigenvalues		0.558
Sum of all canonical eigenvalues		0.590

The relative magnitudes of these eigenvalue indicate that the first CCA and second CCA axes express the major pattern in the community structure of the aquatic insects. The biplot of the matrices corresponding to the sampling sites achieved by the two axes generated by the CCA (Figure 3.7), suggests that temperature (TEM), pH, water discharge (Q) and turbidity (TBY) were the important variables for the first axis.

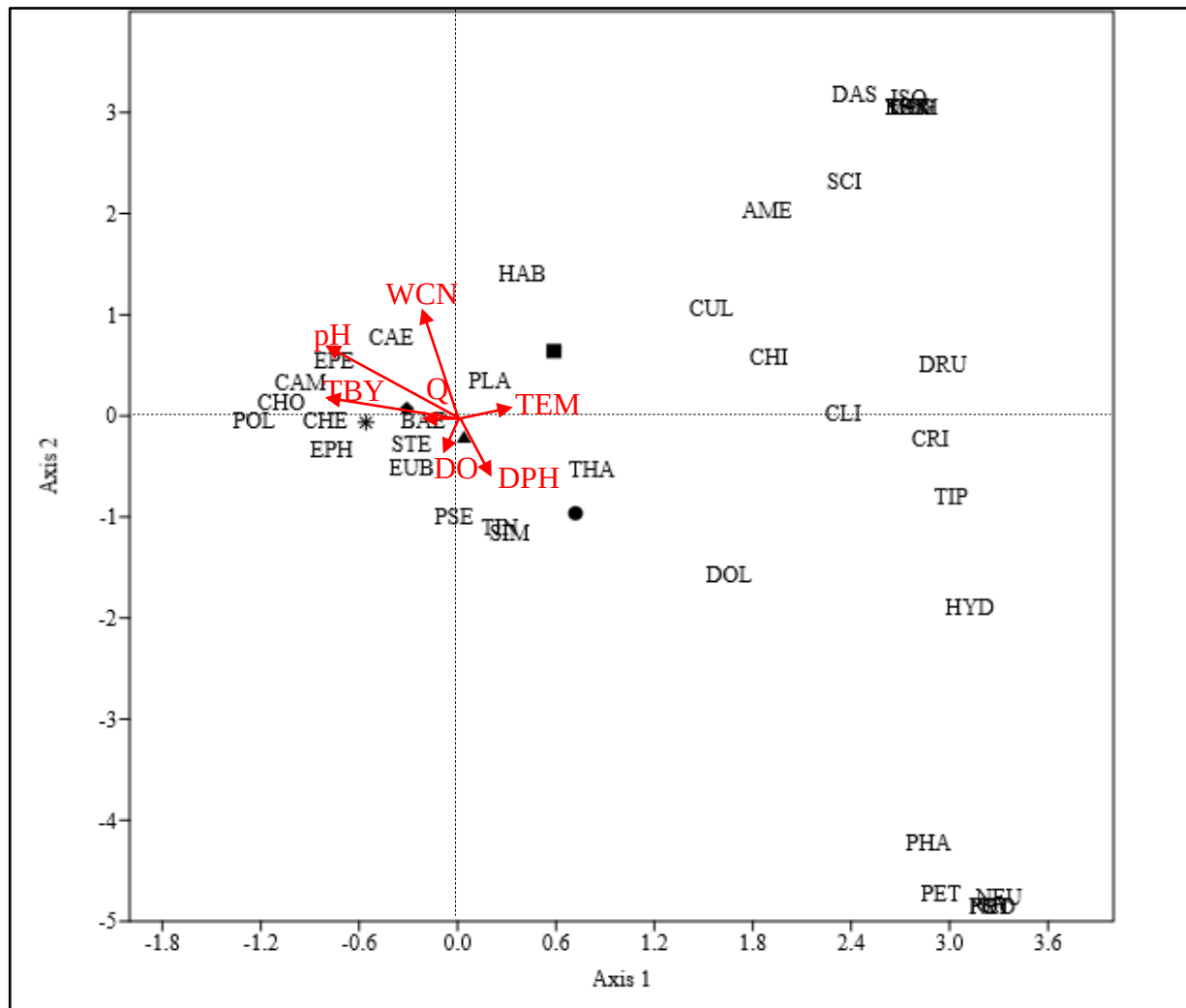


Figure 3.7: Canonical Correspondence analysis (CCA) ordination diagrams showing community structure of aquatic insect drift with water quality parameters in Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. Symbols: Circle (Sabong Stream), Square (Duyoh Stream), Triangle (Cina Stream), Diamond (Serin Stream), Star (Bak Muan Sadir Stream); Red Arrow: Environmental parameters (DO: Dissolved Oxygen, TEM: Temperature, pH, TBY: Turbidity, DPH: Depth, Q: Water Discharge, WCN: Water Current).

For axis 2, water current (WCN), depth (DPH) and dissolved oxygen (DO) were the most influential variables. The presence of high drift density of *Simulium* sp. was more closely associated with the Sabong Stream and it has high tolerance of dissolved oxygen and the drift density of *Simulium* sp. increases with water depth. The pH of the water recorded in the Serin and Bak Muan Sadir Stream were within the range of 7.68 (Serin Stream) and 7.11

(Bak Muan Sadir stream). Thus, it is suggested that *Caenis* sp. and *Epeorus* sp. chooses neutral pH of stream water.

The drift density of *Ephemera* sp. chooses temperature within the range of 25.95°C (Cina Stream) to 26.16°C (Serin Stream) which means it choose to live in moderate water temperature as the temperature in both these streams are higher compared to other streams. The species of aquatic insects present in the Sabong Stream such as *Cricotopus* sp., *Tipula* sp., *Hydropsyche* sp., *Phanoperla* sp., *Neurobasis* sp., *Petrophila* sp., *Doloclanes* sp., *Simulium* sp., *Thalerosphyrus* sp. and *Tinodes* sp. were intolerant to high pH of water and choose clean and unpolluted environment of habitat. The *Tinodes* sp. has remarkable dependence on depth and dissolved oxygen (DO) where it chooses to drift in shallow water and lower DO which only present in the Cina Stream.

Besides, higher drift densities of *Polypedium* sp., *Choroterpes* sp., *Stenelmis* sp., were recorded in the Bak Muan Sadir Stream. They are the only species which are intolerant to high water temperature as the Bak Muan Sadir Stream recorded a temperature of 24.86°C. The Duyoh Stream has high diversity of aquatic insect species while Bak Muan Sadir has the lowest diversity of aquatic insects. CCA result supports that Duyoh Stream, Serin Stream and Bak Muan Sadir Stream are associated with high water discharge (Q), TEM, pH and TBY. In addition, *Ephemera* sp., *Eubrianax* sp., *Phanoperla* sp. and *Chematopsyche* sp. choose warmer temperature. The abbreviations of the species of the aquatic insects in the study and used in the CCA ordination are shown in Table 3.12.

Table 3.12: Aquatic insect species abbreviations used in CCA ordination.

Abbreviation	Species Name	Abbreviation	Species Name
BAE	<i>Baetis</i> sp.	CHE	<i>Cheumatopsyche</i> sp.
PLA	<i>Platybaetis</i> sp.	HYD	<i>Hydropsyche</i> sp.
AME	<i>Ameletus</i> sp.	ECN	<i>Ecnomus</i> sp.
THA	<i>Thalerosphyrus</i> sp.	SIM	<i>Simulium</i> sp.
CAM	<i>Campsoneuria</i> sp.	CRI	<i>Cricotopus</i> sp.
EPE	<i>Epeorus</i> sp.	CHI	<i>Chironomus</i> sp.
CHO	<i>Choroterpes</i> sp.	POL	<i>Polypedium</i> sp.
HAB	<i>Habrophlebiodes</i> sp.	CLI	<i>Clinotanypus</i> sp.
THR	<i>Thraulius</i> sp.	TIP	<i>Tipula</i> sp.
CAE	<i>Caenis</i> sp.	MEG	<i>Megaselia deningi</i>
POT	<i>Potamanthus</i> sp.	CUL	<i>Culex</i> sp.
DRU	<i>Drunella</i> sp.	DAS	<i>Dasyhelea</i> sp.
EPH	<i>Ephemera</i> sp.	STE	<i>Stenelmis</i> sp.
PHA	<i>Phanoperla</i> sp.	SCI	<i>Scirtes</i> sp.
NEO	<i>Neoperla</i> sp.	PSE	<i>Psephenus</i> sp.
KAM	<i>Kamimuria</i> sp.	EUB	<i>Eubrianax</i> sp.
DOL	<i>Doloclanes</i> sp.	PET	<i>Petrophila</i> sp.
TIN	<i>Tinodes</i> sp.	NEU	<i>Neurobasis</i> sp.
PSY	<i>Psychomyia</i> sp.	ISO	<i>Isotomurus</i> sp.

3.4 Discussion

In this study, a total of 462.3 individuals per 100m³ volume of water filtered in five streams which belonged to 38 species, 25 families and 7 orders. Aquatic insects found drifting in the Sabong Stream were 48.4 individuals per 100m³, 75.5 individuals per 100m³, 99.7 individuals per 100m³ from the Cina Stream, Serin Stream (89.2 individuals per 100m³) and Bak Muan Sadir Stream (149.5 individuals per 100m³). The number of aquatic insects found drifting in the Sabong Stream recorded a much lower value than the 49.9 individuals per 100m³ in the drift recorded for the Selai River in Johor in the study by Fazimah *et al.* (2005). The total number of individuals in the drift for the Bak Muan Sadir Stream was found to be

149.5 individuals per 100m³ where this is much higher than 134.4 individuals per 100m³ recorded by in Gombak River (Bishop, 1963). The variation in aquatic insects drifts between the streams and rivers reflecting the greater stability of the physical habitats of the lotic environment. Lower pH in Sabong Stream may cause fewer organisms present in the drift. Aquatic insect drift in Bak Muan Sadir stream can relate to catastrophic drift which results from the physical disturbance such as raining by increasing the turbidity and water velocity in the streams which caused an increase in aquatic insect drift. Waters (1972) stated that higher water discharges usually increase the drift of organisms.

The order Ephemeroptera dominated the drift in the Duyoh Stream with 51.9 individuals per 100m³, in the Cina Stream with 59.1 individuals per 100m³ while in the Serin Stream with 74.4 individuals per 100m³ and Bak Muan Sadir Stream with 112.9 individuals per 100m³. However in the Sabong Stream, the members of the order Diptera was dominant with 22.2 individuals per 100m³. A similar study by Matzinger and Bass (1995) in Oklahoma found that Ephemeroptera was the dominant order from May to January but Dipterans were the dominant order during March. In their study, most of the Dipterans were Chironomidae, and was dissimilar with the presence of Dipterans in the Sabong Stream where Simuliidae was the dominant family present in the stream while only 32.9% of the Dipterans were represented by family Chironomidae. Some studies indicate some that the occurrence of Simuliidae can vary among regions and seasons, according to different parameters such as temperature and dissolved oxygen (McCreadie and Adler, 1998; Fenoglio *et al.*, 2013). It can be said that water temperature and percentage of dissolved oxygen in Sabong Stream favours the life cycle of Simuliidae. Besides that, presence of Simuliidae larvae in Sabong Stream was parallel with the lower water velocity in the Stream compared to other streams which are similar with the study in Po River by Fenoglio *et al.* (2013) which shows that number of

Simuliidae larvae entering the drift decreased as a result of velocity increases and the lowest number of individuals were recorded at highest velocities.

The result of the bivariate correlation of the physicochemical parameters of the streams to drift density of aquatic insects suggest that drift of aquatic insects in the Sabong Stream may be influenced by increase of water depth, water discharge and dissolved oxygen. On the other hand, the drift in the Serin Stream may be influenced by increase of total suspended solid, turbidity and water current. Moreover, the drift in the Duyoh Stream seems to be influenced by temperature and in the Cina Stream by total suspended solid, pH, turbidity, dissolved oxygen and temperature. The drift in the Bak Muan Sadir Stream may be influenced by lower temperature which is caused by rains at night time.

The effect of water temperature on the drift in flowing waters of streams is more difficult to identify (Svendsen *et al.*, 2004). Local rain in the Bak Muan Sadir Stream caused an increase in turbidity which was accompanied by high drift rate of *Baetis* sp. in the stream. The drift density of *Baetis* sp. in the Bak Muan Sadir Stream was far higher compared to other streams. This is because rainfall increases the water flow in the stream and the aquatic insects were swept away by a rapid increase in water flow. Pearson and Franklin (1968) had similar findings with an increase in drift rate of *Baetis* sp. after rain. However, result of this study was not similar to the studies in Gombak River as researches in Gombak River (Bishop, 1973; Bright, 1982) found that the abundance of mayflies fluctuated during wet season due to scouring of heavy rains.

The higher concentration of suspended solids in water causes adverse effect on bottom – dwelling organisms (Angie, 2014). The habitat of a stream is filled with sediments

which directly affect the decrease in the number of species and abundance in aquatic insect drift. As a result, it causes a decrease in diversity and richness of aquatic insects drifting in the Bak Muan Sadir Stream. Besides, aquatic insects from the order Trichoptera were not found in the Bak Muan Sadir Stream. Caddisflies seem to be influenced by a combination of natural physicochemical parameters such as increase in total suspended solid (Pirvu and Pacioglu, 2012).

Drift of aquatic insects of the Sabong Stream responded negatively to increase of pH, specifically with decrease in the number of drifting organisms. Based on CCA result, it can be said that the order Diptera (*Simulium* sp., *Cricotopus* sp., *Clinotanypus* sp. and *Tipula* sp.), order Trichoptera (*Tinodes* sp., *Psychomyia* sp. and *Hydropsyche* sp.), Coleoptera (*Petrophila* sp.), Odonata (*Neurobasis* sp.), Plecoptera (*Neoperla* sp. and *Phanoperla* sp.) and Ephemeroptera (*Potamanthus* sp. and *Drunella* sp.) were tolerant to low pH of Sabong Stream. In general, aquatic insects are tolerant to acid conditions at least for a period of time which is less than one week (Bell and Nebeker, 1969). The Plecopterans can tolerate low pH in short duration. Bell and Nebeker (1969) have stated that Trichopterans usually very tolerant to low pH especially *Hydropsyche* sp. which can be found in streams with pH value of 4.0 to 5.7. *Hydropsyche* sp. only present in high numbers in Sabong Stream while absent in Cina Stream, Serin Stream and Bak Muan Sadir Stream. Diversity of aquatic insects in the Sabong Stream significantly correlated with dissolved oxygen where the numerous species of aquatic insects found drifting Stream reduced with increase in dissolved oxygen.

Based on the results obtained, the order Odonata was only found in the drift at the Sabong Stream. Odonata has been considered as a potential indicator of environment disturbance and pollution (Yong and Yule, 2004). Only one species of Odonata was recorded

in the Sabong Stream namely *Neurobasis* sp. Most of the aquatic insects of this order tend to live in slow moving or lentic water (Norma-Rashid *et al.*, 1996). Further, the species which are intolerant to turbid and polluted water such as *Simulium* sp. was dominant in the drift in the Sabong Stream as this stream has better water quality with no sedimentation and major pollution. A similar result was found by Ramírez and Pringle (1998) in a lowland neotropical stream in Costa Rica where the most abundant family in the drift was Simuliidae. The Simuliidae drift during turbidity fluctuation which relates to turbidity level of the Sabong Stream. This family of aquatic insects are invertebrates without legs and they are also called mobile larvae (Grzybkowska *et al.*, 2006).

Studies show that the family Tipulidae is found in both fast and slow flowing streams (Dudley and Blair, 1992). However in this study Tipulidae was only found in the Sabong Stream and Duyoh Stream. This family is important in providing food for other species besides being eaten by other invertebrates and fish in the stream (Dudley and Blair, 1992). The drift density of Tipulidae in both the streams can be considered as one of the lowest among drifting organisms. This family is known as the ancient group of Diptera and they need certain level of moisture in their habitat to survive (Yong and Yule, 2004).

Aquatic Collembola which belongs to the family Isotomidae was only found drifting in the Duyoh Stream throughout the study. Only three families of aquatic Collembola namely Isotomidae, Sminthurididae and Bourletiellidae are found in Southwest Asia (Suhardjono, 1989; Yong and Yule, 2004). The family Isotomidae is uncommon in trophic countries (Deharveng and Lek, 1993; Yong and Yule, 2004). Members of Collembola are primarily terrestrial where generally this family inhabit soil and other moisture habitat and often inhabit on water surface for temporary or accidentally associated with aquatic environment. As it

requires high humidity, these insects choose habitats nearby aquatic environment to survive (Dudley and Blair, 1992).

Megaselia deningi from the family Phoridae and *Dasyhelea* sp. from the family Ceratopogonidae were found in the Duyoh Stream, but not present in other streams. *Megaselia* sp. tend to submerge itself fully in water (Yong and Yule, 2004) and the water depth in the Duyoh Stream might favour the occurrence of this species while the presence of family Ceratopogonidae could be due to the occurrence of oil from tributaries near housing area that occurs at upstream of the stream.

The high level of food availability which is suitable for the family Psephenidae in the Cina Stream and Serin Stream could have resulted in the presence of this family in both these streams. The family Psephenidae which is also known as water penny tend to live by attaching at the substrate in streams but they are not frequently found in well oxygenated streams. The larvae of this family is highly adapted to stones and feed on periphyton on the substrate (McCafferty, 1981).

Drift density of aquatic insects shows that Ephemeroptera is the dominant order found in the Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream while Diptera was dominant in the drift in the Sabong Stream. Drift in tropical regions are mainly dominated by mayflies and dipterans (Hynes, 1975; Turcotte and Harper, 1982; Flecker, 1992; Ramírez and Pringle, 1998). Ephemeroptera, Plecoptera and Trichoptera are common aquatic insects found drifting in the streams. These aquatic insects are more common in the drift due to their exceptional drift abilities where they easily enter and leave the water column (Benke *et al.*, 1986; Grzybkowska *et al.*, 2006). Trichoptera was found drifting in the Sabong Stream,

Duyoh Stream, Cina Stream and Serin Stream but absent in the Bak Muan Sadir Stream. This order of aquatic insects may be intolerant to high turbidity and total suspended solid in the Bak Muan Sadir Stream as they are found in cleaner streams. Azrina *et al.* (2006) have proposed that Trichoptera species are potential bioindicators for clean river ecosystem.

Ephemeroptera, Plecoptera and Tichoptera mostly found drifting at night although some of the families from these order drift during the day (Brittain and Eikeland, 1988; Castro *et al.*, 2013). In this study, the appearance of Ephemeroptera larvae in the drift mainly during hours of darkness suggests that it is a consequence of a diurnal rhythm in their activity. Greater activity of the Ephemeroptera larvae at night suggest they prefer to obtain food at night time (Schreiber, 1995). There is thus greater concentration of algae growing at night time (McLay, 1968).

Generally, water discharge has influenced the drift densities in the Sabong Stream, Cina Stream and Serin Stream. It is observed that the drift of aquatic insect increases with a reduction in water discharge. Studies show that flow fluctuation influences the macroinvertebrate drift (Ramírez and Pringle, 1998; Castro *et al.*, 2013). Richness of aquatic insect species in the Cina Stream was negatively correlated with water discharge and mean water discharge in the Cina Stream was recorded as the lowest compared to other streams while diversity of aquatic insects in the drift at Bak Muan Sadir Stream is significant with water discharge in the stream. According to studies, water discharge in streams is one of the major abiotic factors which influence the drift densities (Brittain and Eikeland, 1988; Schreiber, 1995). Sudden increase and decrease in water discharge can result in drift densities associated with catastrophic drift (Watson, 1971). It is observed that sudden increase in water

discharge occurs mainly at night. Predator avoidance at night also may result in differences in number of drifting organism during day time and night (Allan, 1978; Fazimah *et al.*, 2005).

Diversity of aquatic insects present in this study were 1.759 (Bak Muan Sadir Stream) to 2.512 (Duyoh Stream) which is far higher compared to diversity of aquatic insects (0.760 to 1.280) in the study in the Okhalama River by Matzinger and Bass (1995). Differences in number of aquatic insects between streams also may be due to the life cycles of the aquatic insects such as unfavourable physical condition, food availability and biotic interaction (Matzinger and Bass, 1995; Merritt and Cummins, 1996). Greater number of species in the streams compared to other study may be because of the usage of smaller mesh size as proposed by Bass (1986) and Matzinger and Bass (1995).

Generally, a limited number of species is found in high temperature (Matzinger and Bass, 1995; Merritt and Cummins, 1996). This study shows that water temperature in the Duyoh Stream supports high diversity and richness of aquatic insect in the drift. Zoobenthos density and composition are the main biotic factors which influences the drift rate of aquatic insects in streams while water current is the important abiotic factors affecting rift activity of aquatic insects (Lencioni *et al.*, 2002; Grzybkowska *et al.*, 2006). Changes in temperature also might play a role in determining drift periodicity (Ramírez and Pringle, 1998). A similar decrease in temperature was recorded in the streams of the present study after sunset until morning.

Species richness in the drift of the Serin Stream inversely correlated with water current in the stream. The water velocity in Serin Stream was higher compared to other streams. Watson (1971) has stated that drift of aquatic insects decreases as the water current continues

to increase. It can be said that the aquatic insects drifted and disperse to safer places. Besides that, changes in habitat suitability and food resources can affect each aquatic insect taxon differently and can cause variable density responded to an increase and decrease in water flow. In some cases, drift increases with water current because the invertebrate caught out on most exposed areas of substrate. A drastic increase and decrease in flow leads to increase in drift density of aquatic insects (Pearson and Franklin, 1968; Watson, 1971). Most larvae are flushed at the beginning and at the end of peak flows (Céréghino *et al.*, 2004).

Most studies showed that drift pattern of aquatic insect increases after sunset and remain high with irregular pattern until sunrise (Schreiber, 1995). The drift of aquatic insects in streams reduces drastically after sunrise and remains low throughout the daytime. The number of individuals drift in the stream were not static at night time but the number of individuals in the stream were higher at night time compared to daytime (Schreiber, 1995). Increase in drift rate at night may be due to predation avoidance mechanism adopted by the aquatic insects in streams (Bishop and Hynes, 1969; Waters, 1969; Allan, 1978; Fazimah *et al.*, 2005). The downstream movement of aquatic insects at daytime may increases the mortality rate of aquatic insects as the insectivorous fish are active during the daytime (Fazimah *et al.*, 2005). The present study has shown similar result as Fazimah *et al.* (2005). In addition, Schreiber (1995) has stated that sunset and sunrise are considered as two events that could potentially change the level of drift.

In studies on drift, day and night drift samples have been compared by pooling the samples together by day and night and testing them for the differences between day and night as in studies by Benson and Pearson (1987) and Schreiber (1995). Diel drift periodicity in studies has showed a peak at 1800 hours and sometimes at 0300 hours (Ramírez and Pringle,

1998). Lower food resource can also enhance drift as aquatic insects become dislodged and drift to search for food (Kohler, 1983; Kohler, 1985; Ramírez and Pringle, 1998). Diurnal periodicity of drifting of *Baetis* sp. has been reported by Pearson and Franklin (1968). A similar pattern of *Baetis* sp. was observed in this study where there was a dramatic increase of *Baetis* sp. drift after sunset. A species is usually considered to show nocturnal drift if peaks in drift density occur at night (Waters, 1972; Schreiber, 1995). Drift in most of lotic systems shows a rapid increase soon after sunset (Waters, 1972). Nocturnal increase in drift density of *Baetis* sp. has been well documented by Waters (1962) and Wilzbach (1990). Similarly, in this study the diel pattern of *Baetis* sp. was clearly observed. Although, drift activity of this species in this study is much greater at night than during the daylight hours as studies by Tanaka (1970) and Allan (1978) but there was no significant differences of day and night drift of *Baetis* sp.

3.5 Conclusion

In this study, a total of 462.3 individuals of aquatic insects per 100m³ of volume filtered which belonged to 38 species, 25 families and 7 orders of aquatic insects were recorded from the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. The aquatic insects in the drift were most diverse in the Duyoh Stream while Bak Muan Sadir showed the least diversity of aquatic insects in the drift. *Baetis* sp. was the common species which was dominant in the drift in the Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream whereas *Simulium* sp. was dominant in the Sabong Stream. Low pH of Sabong Stream effected the drift of aquatic insect in the stream while high water discharge which caused by physical disturbance such as rain relating to high number of aquatic insects in drift in Bak Muan Sadir Stream.

The community structure of aquatic insects in the Sabong Stream was significantly influenced by pH and dissolved oxygen while drift of aquatic insects in the Cina Stream was significantly influenced by temperature and water discharge. Aquatic insect density in the Serin Stream was influenced by pH, temperature, turbidity and water current, and the drift in the Bak Muan Sadir affected by water discharge and total suspended solid.

Drift density of aquatic insects occurred just after sunset in every stream, Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. There was no significant differences between day drift and night drift of aquatic insects at the streams except in Serin Stream. Drift activity of *Baetis* sp. in this study is much greater at night than during the daylight hours but there was no significant differences of day and night drift of *Baetis* sp.

CHAPTER 4

COMMUNITY STRUCTURE OF BENTHIC MACROINVERTEBRATES (INSECTS) IN SELECTED STREAMS IN SARAWAK

4.1 Introduction

Benthic macroinvertebrates which are also called benthos or aquatic insects are animals without backbones that are larger than 0.5 millimetre. Crustaceans, mollusc, aquatic worms and immature forms of aquatic insects are among the common benthos (Aweng *et al.*, 2012). They refer to organisms that inhabit the bottom substrates of freshwater ecosystems such as sediments, debris, logs, macrophytes and filamentous algae for at least some part of their life cycle (Rosenberg and Resh, 1993). These organisms are usually referred to as invertebrates which can be observed by the naked eye and categorised as those retained by a mesh size more than 0.2-0.5 millimetre (Bae *et al.*, 2005).

The presence and composition of benthic macroinvertebrates are good indicators of the health of freshwater ecosystems because they live in the water for all or most of their life cycle (Lenat and Barbour, 1994; Richards and Host, 1994; Sivaramakrishnan, 2000; Davis *et al.*, 2003; Thompson, 2005; Dinakaran and Anbalagan, 2007; Aweng *et al.*, 2012). They have different range of tolerance towards pollution and habitat alterations and they also have less capacity of movement, and also can be collected easily for the purpose of studies (Aweng *et al.*, 2012).

Some researchers have found that aquatic insects assemblage randomly and abundantly in freshwater ecosystems (Bogan, 2005). Species of aquatic insects that live at

lotic environments form complex communities with different functional feeding groups that have essential ecological roles at some trophic levels (Bogan, 2005). However, the detailed diversity of aquatic insects in some parts of the world especially in the tropical regions is not well known (Aweng *et al.*, 2012).

Bogan (2005) reported, large and well-connected stream systems in tropical and temperate regions are the areas where most studies on the diversity of lotic aquatic insects and their community structure have been carried out. He has further stated that aquatic insect communities in isolated habitats can be influenced by various local habitat characteristics. In particular, the diversity and community structure of the aquatic insects in the streams may be influenced by the physicochemical parameters and the habitats for example water temperature, pH, conductivity, substrate composition and also the stream elevation (Bogan, 2005).

Aquatic benthic macroinvertebrates especially benthic organisms are considered as suitable organisms for the study and analysis of water quality and ecological changes in freshwater systems (Kleine and Trivinho-Strixino, 2005). Englund *et al.* (2007) have stated that many species of aquatic insects' species are becoming endangered or extinct due to factors like loss of habitats and threat by invasive species.

Despite the availability of this information on aquatic insects in freshwater systems, there is still lack of documented information on the community structure of aquatic insects and their composition in freshwater streams in relation to the physicochemical parameters of water quality. Thus, the present study highlights the composition of benthic aquatic insects in five selected streams in the state of Sarawak in Malaysia, namely in the Sabong Stream,

Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. It analyses the community structure of the aquatic insects in the five streams during sunrise and sunset with the following objectives: identify the composition of aquatic insects during sunrise and sunset, study the abundance and diversity of the aquatic insects of the streams during sunrise and sunset and to investigate the relationship of community structure of benthic aquatic insects with physicochemical parameters in the streams.

4.2 Methodology

4.2.1 Sampling Locations

Refer to Section 3.2.1

4.2.2 Physicochemical Parameters of Streams

Refer to Section 3.2.2

4.2.3 Sampling and Identification of Aquatic Insects

Samplings of aquatic insect samplings in the five streams were carried out using a Kick-net with a frame size of 30cm and 40cm, and a mesh size of 0.5mm. The net was placed against the water current in the streams. An area of approximately 1 m² was disturbed for thirty minutes to collect the aquatic insect samples. The aquatic insects that were washed out by the water current were then trapped in the Kick net. Large debris such as leaves that were trapped in the Kick net were washed carefully to ensure the aquatic insects that were attached to the debris were collected in the net. The Kick net was placed in a pail filled with water. The rock surfaces and stones within the area were washed by hand inside the pail and the Kick net

in order to collect the aquatic insects that became attached to the surfaces. Any non-macroinvertebrates such as fish that got caught in the Kick net were immediately returned to the stream. Then, the samples were immediately poured into a 250 micron sieve before being placed in plastic bags filled with 80% ethanol, and brought to the laboratory for sorting and analysis.

All the plastic bags with samples were labelled accordingly. In the laboratory, the samples of aquatic insects were sorted accordingly to their morphological characteristics and identified under Olympus SN: 3LO9174 stereo microscope. The identification of the aquatic insects was carried out to the lowest possible species using keys available in McCafferty (1981); Yule and Yong (2004); Thorp and Rogers (2011); and Pravin (2012). After identification, the aquatic insects were placed in vials with 95% ethanol for preservation.

4.2.4 Data Analyses

Refer to Section 3.2.4

4.2.4.1 Correlation between Aquatic Insects and Physicochemical Parameters of Streams

Correlation analysis was conducted to examine the relationships between the aquatic insects and the physicochemical parameters of the five streams. The correlation analysis applied in this study was the Pearson's correlation analysis that was carried out using IBM SPSS Statistics 21 for Windows to analyse the community structure of the aquatic insects and its relationship to the physicochemical parameters of the streams. Canonical Correspondence Analysis (CCA) was performed using PAST 3.14. CCA was performed to identify and describe the pattern in community structure of the aquatic insects during sunrise and sunset

and match them with the physicochemical parameters of the streams by summarising the structure of a species by sample data matrix.

4.3 Results

4.3.1 Composition of Aquatic Insects

A total of 36 species belonging to 19 families and five orders of aquatic insects were recorded in the five streams during sunrise. The order Ephemeroptera was the highest in number of families recorded during sunrise and it was represented by Baetidae, Ameletidae, Heptageniidae, Leptophlebiidae, Caenidae and Ephemeridae. The order Diptera was represented by five families and recorded as the second highest in the number of families namely Smuliidae, Chironomidae, Tipulidae, Phoridae and Ceratopogonidae. Besides, the order Trichoptera was represented by the family Philopotamidae, Psychomyiidae, Hydropsychidae and Ecnomidae. Whereas, the order Coleoptera was represented by three families namely, Elmidae, Scirtidae and Psephenidae. The order Plecoptera was represented by one family, Perlidae as in Table 4.1.

The composition of the aquatic insects in the five streams recorded in this study during sunset showed the presence of 30 species, 18 families and five orders of aquatic insects. The orders Plecoptera and Coleoptera were each represented by two families whereby the order Coleoptera was represented by the family Elmidae and Psephenidae while the family Perlidae and Perlodidae were represented by the order Plecoptera. The order of Ephemeroptera and Diptera recorded the highest number of families during sunset, which were five families each. The order Trichoptera was represented by the family Philopotamidae, Hydropsychidae, Ecnomidae and Rhyacophilidae as in Table 4.2.

Table 4.1: List of orders and families of aquatic insects in during sunrise in the five streams, Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream.

Order	Family	Species	Locations				
			SSA	SD	SC	SSE	SBMS
Ephemeroptera	Baetidae	<i>Baetis</i> sp.	42.0	45.0	79.0	51.0	77.0
		<i>Platybaetis</i> sp.	2.0	3.0	0.0	0.0	0.0
	Ameletidae	<i>Ameletus</i> sp.	0.0	3.0	0.0	0.0	0.0
	Heptageniidae	<i>Thalerosphyrus</i> sp.	0.0	5.0	0.0	1.0	0.0
		<i>Campsoneuria</i> sp.	0.0	0.0	0.0	19.0	0.0
		<i>Epeorus</i> sp.	0.0	1.0	1.0	10.0	10.0
	Leptophlebiidae	<i>Choroterpes</i> sp.	0.0	7.0	10.0	17.0	27.0
		<i>Habrophlebiodes</i> sp.	0.0	8.0	5.0	14.0	5.0
		<i>Thraulius</i> sp.	0.0	0.0	0.0	0.0	11.0
	Caenidae	<i>Caenis</i> sp.	1.0	13.0	3.0	11.0	14.0
	Potamanthidae	<i>Potamanthus</i> sp.	0.0	0.0	0.0	0.0	0.0
	Ephemerellidae	<i>Drunella</i> sp.	0.0	0.0	0.0	0.0	0.0
	Ephemeridae	<i>Ephemera</i> sp.	0.0	1.0	0.0	0.0	0.0
Plecoptera	Perlidae	<i>Phanoperla</i> sp.	2.0	2.0	0.0	0.0	2.0
		<i>Tetropina</i> sp.	0.0	0.0	1.0	0.0	0.0
		<i>Neoperla</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Kamimuria</i> sp.	0.0	0.0	0.0	0.0	0.0
	Perlodidae	<i>Isoperla</i> sp.	0.0	0.0	0.0	0.0	0.0
Trichoptera	Philopotamidae	<i>Doloclanes</i> sp.	0.0	2.0	0.0	2.0	0.0
	Psychomyiidae	<i>Tinodes</i> sp.	0.0	1.0	0.0	0.0	0.0
		<i>Psychomyia</i> sp.	0.0	1.0	0.0	0.0	0.0
	Hydropsychidae	<i>Cheumatopsyche</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Hydropsyche</i> sp.	0.0	1.0	0.0	3.0	0.0
	Ecnomidae	<i>Ecnomus</i> sp.	0.0	1.0	0.0	0.0	0.0
	Rhyacophilidae	<i>Rhyacophila</i> sp.	0.0	0.0	0.0	0.0	0.0
Diptera	Simuliidae	<i>Simulium</i> sp.	16.0	5.0	0.0	10.0	25.0
	Chironomidae	<i>Cricotopus</i> sp.	5.0	16.0	10.0	1.0	3.0
		<i>Chironomus</i> sp.	0.0	15.0	0.0	0.0	2.0
		<i>Polypedium</i> sp.	0.0	11.0	2.0	2.0	9.0
		<i>Clinotanypus</i> sp.	0.0	4.0	2.0	0.0	5.0
		<i>Pseudodiamesa</i> sp.	0.0	3.0	0.0	0.0	0.0
	Tipulidae	<i>Tipula</i> sp.	1.0	0.0	0.0	0.0	0.0
	Phoridae	<i>Megaselia deningi</i>	0.0	1.0	1.0	0.0	0.0
	Culicidae	<i>Culex</i> sp.	0.0	0.0	0.0	0.0	0.0

Table 4.1 continued

Order	Family	Species	Locations				
			SSA	SD	SC	SSE	SBMS
Coleoptera	Ceratopogonidae	<i>Bezzia</i> sp.	2.0	2.0	1.0	0.0	0.0
		<i>Dasyhelea</i> sp.	0.0	1.0	0.0	0.0	0.0
		<i>Culicoides</i> sp.	0.0	0.0	0.0	0.0	0.0
	Elmidae	<i>Stenelmis</i> sp.	0.0	1.0	1.0	3.0	2.0
		<i>Optioservus</i> sp.	0.0	3.0	7.0	0.0	7.0
		<i>Zaitzeviaria</i> sp.	0.0	0.0	1.0	0.0	3.0
		<i>Scirtes</i> sp.	0.0	3.0	0.0	0.0	0.0
	Psephenidae	<i>Psephenus</i> sp.	0.0	0.0	1.0	4.0	0.0
		<i>Eubrianax</i> sp.	0.0	0.0	4.0	3.0	0.0
		<i>Ectopria</i> sp.	0.0	1.0	0.0	0.0	0.0
	Pyralidae	<i>Petrophila</i> sp.	0.0	0.0	0.0	0.0	0.0
Odonata	Calopterygidae	<i>Neurobasis</i> sp.	0.0	0.0	0.0	0.0	0.0
Collembola	Isotomidae	<i>Isotomurus</i> sp.	0.0	0.0	0.0	0.0	0.0
Total			71.0	160.0	129.0	151.0	202.0

*Note: SSA= Sabong Stream, SD = Duyoh Stream, SC = Cina Stream, SS = Serin Stream and SBMS = Bak Muan Sadir Stream.

Table 4.2: List of orders and families of aquatic insects in during sunset in the five streams, Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream.

Order	Family	Species	Locations				
			SSA	SD	SC	SSE	SBMS
Ephemeroptera	Baetidae	<i>Baetis</i> sp.	15.0	70.0	52.0	59.0	54.0
		<i>Platybaetis</i> sp.	0.0	6.0	0.0	0.0	0.0
	Ameletidae	<i>Ameletus</i> sp.	0.0	6.0	0.0	0.0	3.0
	Heptageniidae	<i>Thalerosphyrus</i> sp.	0.0	5.0	3.0	0.0	0.0
		<i>Camponeuria</i> sp.	0.0	2.0	4.0	17.0	0.0
		<i>Epeorus</i> sp.	0.0	0.0	0.0	11.0	4.0
	Leptophlebiidae	<i>Choroterpes</i> sp.	0.0	16.0	11.0	28.0	19.0
		<i>Habrophlebiodes</i> sp.	0.0	14.0	9.0	18.0	15.0
		<i>Thraulius</i> sp.	0.0	0.0	0.0	0.0	10.0
	Caenidae	<i>Caenis</i> sp.	0.0	18.0	5.0	10.0	26.0
	Potamanthidae	<i>Potamanthus</i> sp.	0.0	0.0	0.0	0.0	0.0
	Ephemerellidae	<i>Drunella</i> sp.	0.0	0.0	0.0	0.0	0.0
	Ephemeridae	<i>Ephemerella</i> sp.	0.0	0.0	0.0	0.0	0.0
Plecoptera	Perlidae	<i>Phanoperla</i> sp.	0.0	0.0	4.0	0.0	0.0
		<i>Tetropina</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Neoperla</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Kamimuria</i> sp.	0.0	0.0	0.0	0.0	0.0
	Perlodidae	<i>Isoperla</i> sp.	0.0	0.0	0.0	2.0	0.0
Trichoptera	Philopotamidae	<i>Doloclanes</i> sp.	0.0	9.0	0.0	4.0	0.0
	Psychomyiidae	<i>Tinodes</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Psychomyia</i> sp.	0.0	0.0	0.0	0.0	0.0
	Hydropsychidae	<i>Cheumatopsyche</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Hydropsyche</i> sp.	0.0	4.0	0.0	4.0	0.0
	Ecnomidae	<i>Ecnomus</i> sp.	0.0	2.0	0.0	0.0	0.0
	Rhyacophilidae	<i>Rhyacophila</i> sp.	0.0	0.0	0.0	1.0	0.0
Diptera	Simuliidae	<i>Simulium</i> sp.	6.0	16.0	2.0	55.0	17.0
	Chironomidae	<i>Cricotopus</i> sp.	2.0	20.0	6.0	0.0	3.0
		<i>Chironomus</i> sp.	0.0	28.0	1.0	0.0	0.0
		<i>Polypedium</i> sp.	0.0	14.0	5.0	2.0	5.0
		<i>Clinotanypus</i> sp.	0.0	15.0	6.0	0.0	6.0
		<i>Pseudodiamesa</i> sp.	4.0	20.0	0.0	0.0	0.0
	Tipulidae	<i>Tipula</i> sp.	0.0	0.0	0.0	0.0	0.0
	Phoridae	<i>Megaselia deningi</i>	0.0	1.0	0.0	0.0	0.0

Table 4.2 continued

Order	Family	Species	Locations				
			SSA	SD	SC	SSE	SBMS
Coleoptera	Culicidae	<i>Culex</i> sp.	0.0	0.0	1.0	0.0	0.0
		<i>Bezzia</i> sp.	0.0	6.0	1.0	0.0	0.0
		<i>Dasyhelea</i> sp.	0.0	4.0	0.0	0.0	0.0
		<i>Culicoides</i> sp.	0.0	2.0	0.0	0.0	0.0
	Elmidae	<i>Stenelmis</i> sp.	0.0	5.0	0.0	0.0	0.0
		<i>Optioservus</i> sp.	0.0	3.0	10.0	6.0	6.0
		<i>Zaitzeviaria</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Scirtes</i> sp.	0.0	0.0	0.0	0.0	0.0
	Psephenidae	<i>Psephenus</i> sp.	0.0	0.0	3.0	5.0	0.0
		<i>Eubrianax</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Ectopria</i> sp.	0.0	0.0	0.0	0.0	0.0
		<i>Petrophila</i> sp.	0.0	0.0	0.0	0.0	0.0
Odonata	Calopterygidae	<i>Neurobasis</i> sp.	0.0	0.0	0.0	0.0	0.0
Collembola	Isotomidae	<i>Isotomurus</i> sp.	0.0	0.0	0.0	0.0	0.0
Total			27.0	286.0	123.0	222.0	168.0

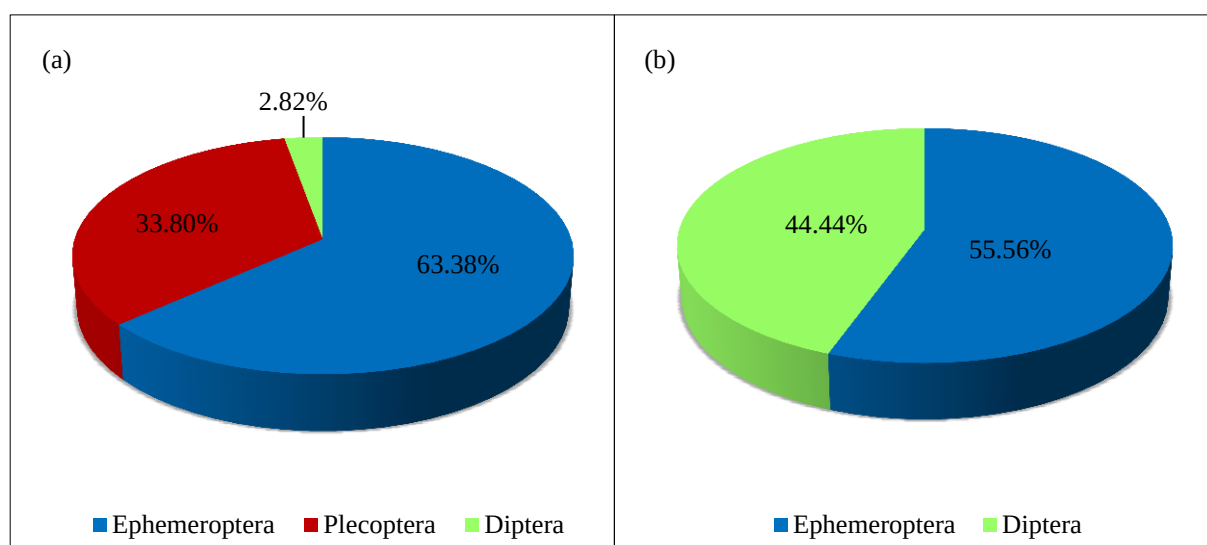
*Note: SSA= Sabong Stream, SD = Duyoh Stream, SC = Cina Stream, SS = Serin Stream and SBMS = Bak Muan Sadir Stream.

4.3.1.1 Sabong Stream

A total of 98 individuals of benthic aquatic insects were found in Sabong Stream during both sunrise and sunset. The benthic aquatic insects found in Sabong Stream belong to 10 species from three orders and seven families.

There were only nine genera belonging to seven families represented by three orders that were recorded during sunrise in the Sabong Stream. These were the order Ephemeroptera (63.38%), Diptera (33.80%) and Plecoptera (2.82%) as in Figure 4.1. The order Ephemeroptera comprised two families (Baetidae and Caenidae) which were represented by the dominant genera in the Sabong Stream, namely *Baetis* sp. (59.5%) followed by

Platybaetis sp. (2.82%) and *Caenis* sp. (1.41%). There were four genera from the order Diptera belonging to Simuliidae (*Simulium* sp.), Chironomidae (*Cricotopus* sp.), Tipulidae (*Tipula* sp.), Ceratopogonidae (*Bezzia* sp.). One genus was identified in the order Plecoptera and belonging to the family Perlidae, namely *Phanoperla* sp. The list of aquatic insects inhabit in Sabong Stream during sunrise are listed in Table 4.1.



Note: (a) = Relative abundance of benthic aquatic insects during sunrise, (b) = Relative abundance of benthic aquatic insects during sunset.

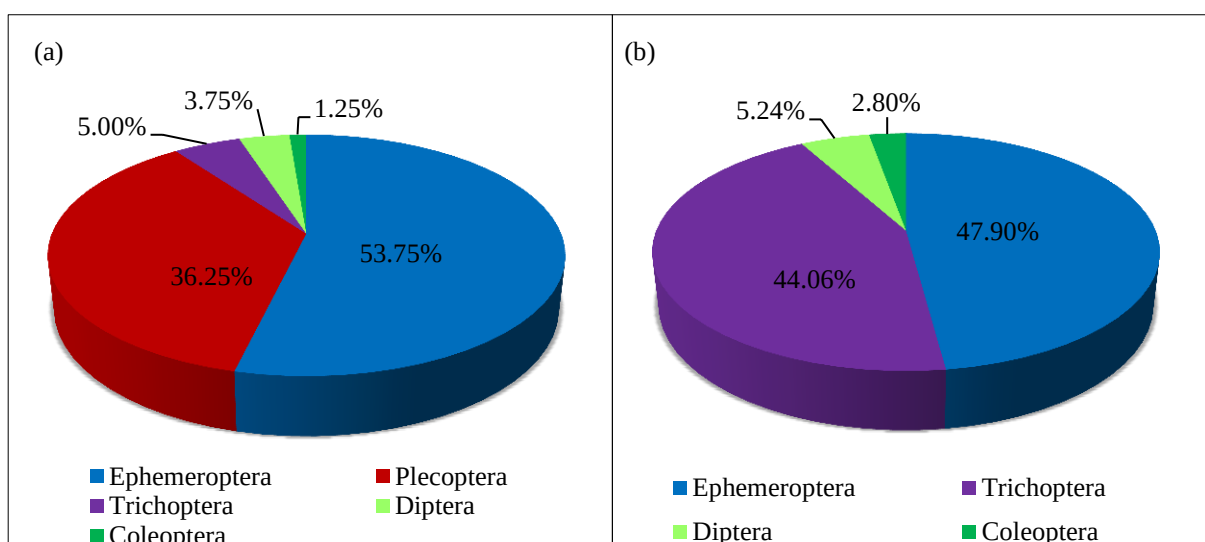
Figure 4.1: Relative abundance of benthic aquatic insects in Sabong Stream during sunrise and sunset.

In the Sabong Stream, four genera from three families belonging to two orders were recorded during sunset. The composition of aquatic insects in the Sabong Stream consisted of Ephemeroptera (55.56%) and Diptera (44.44%) as in Figure 4.1. The order Ephemeroptera comprised one family which was Baetidae and genus *Baetis* sp. (55.56%) which also recorded as the highest number of individuals of aquatic insects in the Sabong Stream during sunset. There were two families representing the order Diptera, Simuliidae (*Simulium* sp., 22.22%) and Chironomidae represented by *Cricotopus* sp. (6.99%) and *Pseudodiamesa* sp. (14.81%) (see Table 4.2).

4.3.1.2 Duyoh Stream

A total of 446 individuals of benthic aquatic insects were found in Duyoh Stream during both sunrise and sunset. The benthic aquatic insects found in Duyoh Stream belong to 28 species from five orders and 18 families.

A total of 28 genera belonging to 18 families from five orders of aquatic insects were found in the Duyoh Stream during sunrise, namely Ephemeroptera (53.75%), Diptera (36.25%), Coleoptera (5.00%), Trichoptera (3.75%) and Plecoptera (1.25%) (see Figure 4.2). The order Plecoptera was represented by genus *Phanoperla* sp. (1.25%). There were six families representing the order Ephemeroptera, Baetidae (*Baetis* sp. and *Platybaetis* sp.), Ameletidae (*Ameletus* sp.), Heptageniidae (*Thelersophyrus* sp. and *Epeorus* sp.), Leptophlebiidae (*Choroterpes* sp. and *Habrophlebiodes* sp.), Caenidae (*Caenis* sp.) and Ephemeridae (*Ephemera* sp.). The order Trichoptera was represented by 5 genera belonging to four families (Philopotamidae, Psychomyiidae, Hydropsychidae and Ecnomidae) (see Table 4.1). While the order Plecoptera was represented by one genus which was *Phanoperla* sp. (Perlidae). The most abundant genera with the highest number of individuals recorded in the Duyoh Stream were *Baetis* sp. (45.0 individuals per m²), followed by *Cricotopus* sp. (16.0 individuals per m²), *Chironomus* sp. (15.0 individuals per m²), *Caenis* sp. (13.0 individuals per m²) and *Polypedium* sp. (11.0 individuals per m²). The least number of individuals (1.0 individual per m²) in the stream were *Epeorus* sp., *Ephemera* sp., *Tinodes* sp., *Psychomyia* sp., *Hydropsyche* sp., *Ecnomus* sp., *Megaselia deningi*, *Dasyhelea* sp., *Stenelmis* sp. and *Ectopria* sp.



Note: (a) = Relative abundance of benthic aquatic insects during sunrise, (b) = Relative abundance of benthic aquatic insects during sunset.

Figure 4.2: Relative abundance of benthic aquatic insects in Duyoh Stream during sunrise and sunset.

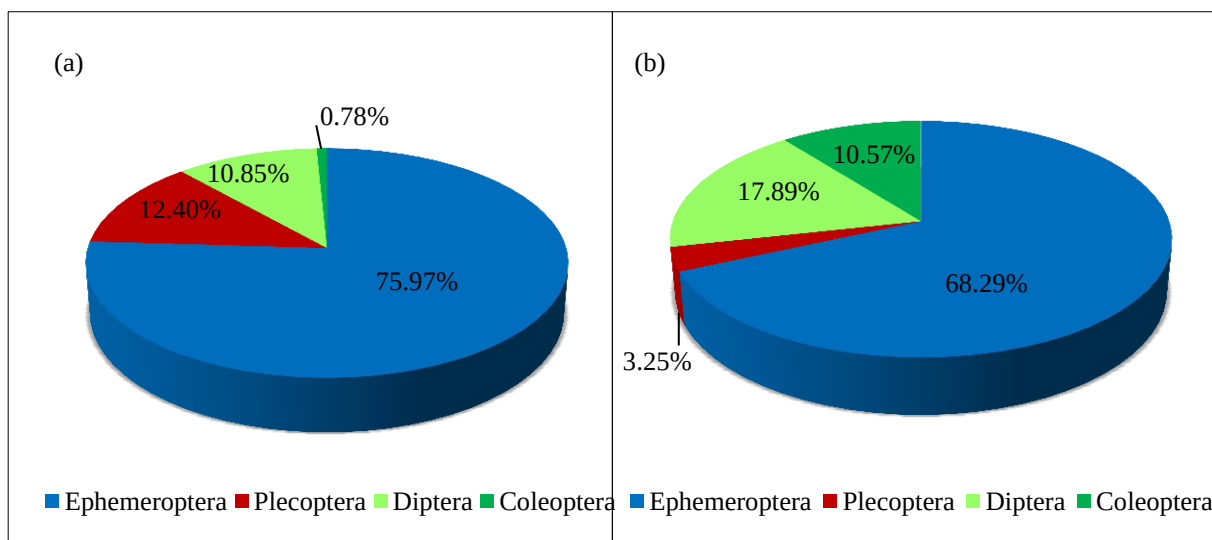
Four orders of aquatic insects consisting of 13 families and 33 genera were recorded in the Duyoh Stream during sunset, namely Ephemeroptera (47.90%), Diptera (44.06%), Trichoptera (5.24%) and Coleoptera (2.80%) as in Figure 4.2. The order Ephemeroptera was the dominant order in the stream during sunset with 5 families and 8 genera, namely Baetidae (*Baetis* sp. and *Platybaetis* sp.), Ameletidae (*Ameletus* sp.), Heptageniidae (*Thalerosphyrus* sp. and *Camponeuria* sp.), Leptophlebiidae (*Choroterpes* sp. and *Habrophlebiodes* sp.) and Caenidae (*Caenis* sp.). There were 10 genera from the order Diptera belonging to Simuliidae (*Simulium* sp.), Chironomidae (*Cricotopus* sp., *Chironomus* sp., *Polypedium* sp., *Clinotanypus* sp. and *Pseudodiamesa* sp.), Phoridae (*Megaselia deningi*) and Ceratopogonidae (*Bezzia* sp., *Dasyhelea* sp. and *Culicoides* sp.). Only one genus was identified from the order Coleoptera during sunset which was represented by the family Elmidae (*Stenelmis* sp. and *Optioservus* sp.). Whereas the family Philopotamidae, Hydropsychidae and Ecnomidae belonging to the order Trichoptera were also recorded in this stream (see Table 4.2).

4.3.1.3 Cina Stream

A total of 252 individuals of benthic aquatic insects were found in Cina Stream during both sunrise and sunset. The benthic aquatic insects found in Sabong Stream belong to 22 species from four orders and 12 families.

In the Cina Stream, 16 genera belonging to 10 families representing four orders of aquatic insects were recorded during sunrise. They were represented by 75.97% of Ephemeroptera, 12.40% of Diptera, 10.85% of Coleoptera and 0.78% of Plecoptera as in Figure 4.3. The dominant genus was *Baetis* sp. belonging to Ephemeroptera with 79.0 individuals per m² individuals followed by *Cricotopus* sp. (10.0 individuals per m²) and *Choroterpes* sp. (10.0 individuals per m²) from the family Chironomidae and Leptophlebiidae respectively. The other 13 genera recorded during sunrise are as listed in Table 4.1 and have less than 10.0 individuals per m².

A total of 16 genera belonging to 11 families represented by four orders of aquatic insects were present in this stream during sunset. These were represented by the order Ephemeroptera (68.29%), Diptera (17.89%), Coleoptera (10.57%) and Plecoptera (3.25%) as in Figure 4.3. The most abundant genera with the most number of individuals of aquatic insects recorded during sunset were *Baetis* sp. (52.0 individuals per m²), followed by *Epeorus* sp. (11.0 individuals per m²) both from the order Ephemeroptera. The *Optioservus* sp. was the third dominant genus recorded in this stream during sunset which belonged to the order Coleoptera. The other 13 genera of aquatic insects are as listed in Table 4.2 and have less than 10.0 individuals per m² individuals.



Note: (a) = Relative abundance of benthic aquatic insects during sunrise, (b) = Relative abundance of benthic aquatic insects during sunset.

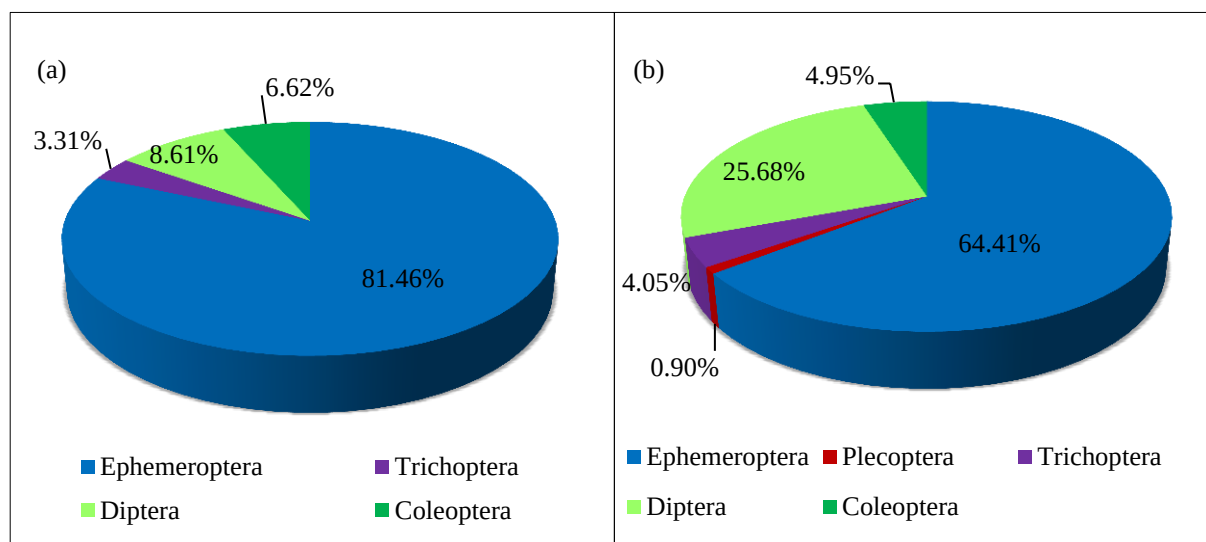
Figure 4.3: Relative abundance of benthic aquatic insects in Cina Stream during sunrise and sunset.

4.3.1.4 Serin Stream

A total of 373 individuals of benthic aquatic insects were found in Serin Stream during both sunrise and sunset. The benthic aquatic insects found in Sabong Stream belong to 18 species from five orders and 12 families.

There were 15 genera from 10 families belonging to four orders recorded in the Serin Stream during sunrise. The compositions of aquatic insects' were: Ephemeroptera (81.46%), Diptera (8.61%), Coleoptera (6.62%) and Trichoptera (3.31%) as in Figure 4.4. There were 7 genera from order Ephemeroptera representing the family Baetidae (*Baetis* sp.), Heptageniidae (*Thalerosphyrus* sp., *Campsoneturia* sp. and *Epeorus* sp.), Leptophlebiidae (*Choroterpes* sp. and *Habrophlebiodes* sp.) and Caenidae (*Caenis* sp.). The order Diptera was represented by two families, namely the Simuliidae, Chironomidae while Coleoptera was represented by the families Elmidae and Psephenidae. Whereas *Doloclanes* sp. and

Hydropsyche sp. belonging to the families Philopotamidae and Hydropsychidae respectively from the order Trichoptera. *Baetis* sp. was recorded as the most dominant number of individuals during sunrise in the Serin Stream with 51.0 individuals per m². The aquatic insects inhabiting in the Serin Stream during sunrise are listed in Table 4.1.



Note: (a) = Relative abundance of benthic aquatic insects during sunrise, (b) = Relative abundance of benthic aquatic insects during sunset.

Figure 4.4: Relative abundance of benthic aquatic insects in Serin Stream during sunrise and sunset.

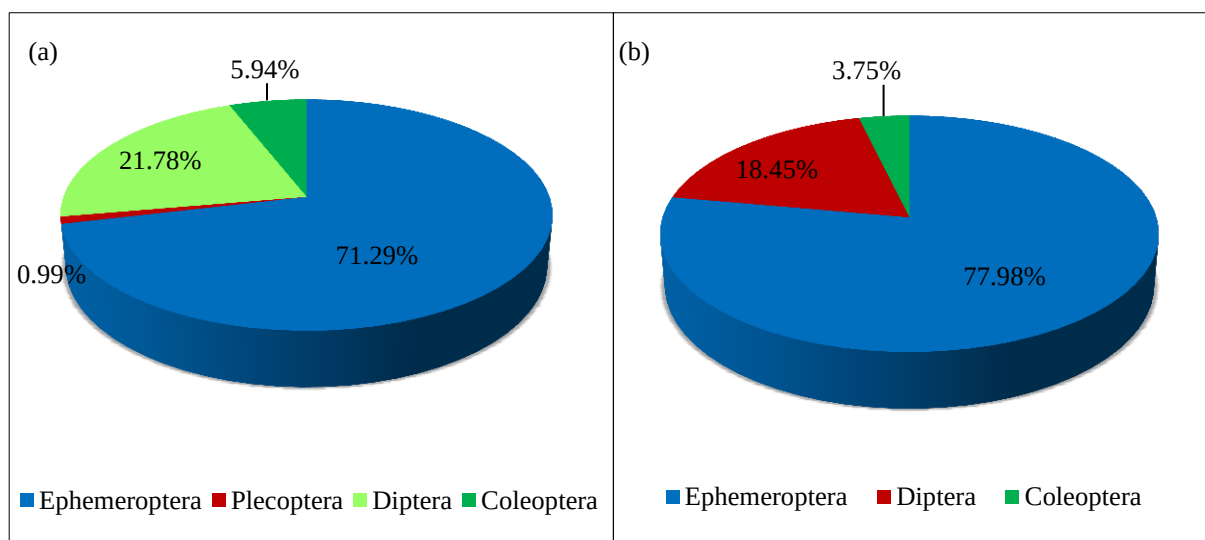
A total of 14 genera representing to 12 families and belonging to five orders of aquatic insects were recorded in this sampling area during sunset. They were represented by 64.41% of Ephemeroptera, 25.68% of Diptera, 4.95% of Coleoptera, 4.05% of Trichoptera and 0.90% Plecoptera as in Figure 4.4. The least number of individuals (1.0m²) recorded in this stream during sunset was *Rhyacophila* sp. from the family Rhyacophilidae of the order Trichoptera. There were six genera from the order Ephemeroptera belonging to Baetidae (*Baetis* sp.), Heptageniidae (*Camponeuria* sp. and *Epeorus* sp.), Leptophlebiidae (*Choroterpes* sp. and *Habrophlebiodes* sp.) and Caenidae (*Caenis* sp.). While the order Plecoptera was only represented by one family, namely Perlodidae belonging to *Isoperla* sp. while Trichoptera was represented by the families Philopotamidae, Hydropsychidae and Rhyacophilidae. *Simulium*

sp. and *Polypedium* sp. belonging to the order Diptera were from family Simuliidae and Chironomidae respectively (see Table 4.2).

4.3.1.5 Bak Muan Sadir Stream

A total of 370 individuals of benthic aquatic insects were found in Sabong Stream during both sunrise and sunset. The benthic aquatic insects found in Sabong Stream belong to 16 species from four orders and nine families.

A total of 15 genera belonging to eight families from four orders of aquatic insects were found in the Bak Muan Sadir Stream during sunrise, namely Ephemeroptera (71.29%), Diptera (21.78%), Coleoptera (5.94%) and Plecoptera (0.99%) as in Figure 4.5. There were 5 genera (*Baetis* sp., *Epeorus* sp., *Choroterpes* sp., *Habrophlebiodes* sp., *Thraulius* sp., and *Caenis* sp.) belonging to the order Ephemeroptera recorded during sunrise. The order Coleoptera was represented by 3 genera belonging to the family Elmidae whereas, 5 genera were identified in the order Diptera representing the family Simuliidae (*Simulium* sp.) and Chironomidae (*Cricotopus* sp., *Chironomus* sp., *Polypedium* sp. and *Clinotanypus* sp.). *Baetis* sp. was the dominant genus (N=77.0 individuals per m²) recorded in this stream during sunrise. The least number of individuals (2.0 individuals per m²) were *Phanoperla* sp., *Chironomus* sp. and *Stenelmis* sp. belonging to the family Perlidae, Chironomidae and Elmidae respectively as listed in Table 4.1.



Note: (a) = Relative abundance of benthic aquatic insects during sunrise, (b) = Relative abundance of benthic aquatic insects during sunset.

Figure 4.5: Relative abundance of benthic aquatic insects in Bak Muan Sadir Stream during sunrise and sunset.

The results of the study in the Bak Muan Sadir Stream during sunset revealed the presence of 12 genera of aquatic insects which belonged to eight families and three orders. Analysis based on the total number of individuals recorded in the Bak Muan Sadir Stream showed that 77.98% of the aquatic insects present in this stream during sunset were from the order Ephemeroptera, 18.45% from the order Diptera and 3.57% from the order Coleoptera as shown in Figure 4.5. The least dominant genera of aquatic insects recorded in the Bak Muan Sadir Stream during sunset were *Ameletus* sp. from the family Ameletidae and *Cricotopus* sp. from the family Chironomidae, both with 1.79% each.

The order Ephemeroptera was found in this stream during sunset recorded the highest number of aquatic insects (54.0 individuals per m²). Seven genera from five families of the order Ephemeroptera were found in this stream during sunset while the family Simuliidae and Chironomidae from the order Diptera were also present in this stream during sunset. The

Optioservus sp. was the only genus from the order Coleoptera that was recorded in the Bak Muan Sadir Stream during sunset (see Table 4.2).

4.3.2 Community Structure of Aquatic Insects in the Streams

The Shannon-Wiener's diversity index (H) of aquatic insects in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream ranged from 1.370 to 2.713 (Table 4.3). The highest H was recorded in the Duyoh Stream with 30 species of aquatic insects while the lowest H was recorded in Sabong Stream which comprised only 10 species. The lowest Margalef's species richness index (d) was recorded in the Sabong Stream (1.963), followed by Bak Muan Sadir Stream (2.537), Serin Stream (2.871), Cina Stream (3.798) and Duyoh Stream (9.514) as in Table 4.3.

Table 4.3: Diversity and richness value of benthic aquatic insects in the streams during both sunrise and sunset.

Sampling Site	Sabong Stream	Duyoh Stream	Cina Stream	Serin Stream	Bak Muan Sadir Stream
Species (S)	10	30	22	18	16
Individuals (N)	98	446	252	373	370
Shannon species diversity (H)	1.370	2.713	1.929	2.179	2.134
Margalef's species richness (d)	1.963	4.754	3.798	2.871	2.537

4.3.3 Physicochemical Parameters in accordance to the Interim National Water Quality Standards (INWQS)

The physicochemical water parameters were used to classify the streams in accordance to the Malaysia's Interim National Water Quality Standards (INWQS, 2008) developed by the Department of Environment, Malaysia. The physicochemical parameters of the rivers surveyed are summarised in Table 4.4.

Table 4.4: Physicochemical parameters at the streams based on INWQS classifications.

Parameters	Streams	Value	INWQS	Class
Dissolved Oxygen	Sabong Stream	5.9 – 6.3	5 – 7	II
	Duyoh Stream	6.1 – 6.3	5 – 7	II
	Cina Stream	5.4 – 6.8	5 – 7	II
	Serin Stream	5.6 – 6.3	5 – 7	II
	Bak Muan Sadir Stream	5.6 – 6.7	5 – 7	II
pH	Sabong Stream	4.21 – 4.77	6.5 – 9.0	-
	Duyoh Stream	6.29 – 6.62	6.5 – 9.0	II
	Cina Stream	6.46 – 6.66	6.5 – 9.0	II
	Serin Stream	7.59 – 7.81	6.5 – 9.0	II
	Bak Muan Sadir Stream	6.98 – 7.52	6.5 – 9.0	II
Turbidity	Sabong Stream	0	5	-
	Duyoh Stream	0 – 2.44	5	I
	Cina Stream	0.28 – 2.93	5	I
	Serin Stream	0.70 – 3.28	5	I
	Bak Muan Sadir Stream	0.42 – 28.56	5	I
Temperature	Sabong Stream	25.1 - 25.9	Normal	-
	Duyoh Stream	25.0 – 26.0	Normal	-
	Cina Stream	25.1 – 26.7	Normal	-
	Serin Stream	25.8 – 26.5	Normal	-
	Bak Muan Sadir Stream	23.4 – 24.4	Normal	-
Total Suspended Solids	Sabong Stream	0.02 – 0.04	25	I
	Duyoh Stream	0.04 – 0.83	25	I
	Cina Stream	0.52 – 12.1	25	I
	Serin Stream	11.0 – 15.8	25	I
	Bak Muan Sadir Stream	12.8 – 32.9	25	I

The dissolved oxygen of all studied streams ranged from 5.4 to 6.8 mg/l and classified in Class II as in Appendix (Table 3). The pH of the stream in Sabong Stream was acidic while the other streams were neutral and ranged from 6.29 to 7.81, where the streams were classified into Class II based on the pH value. The turbidity in Sabong Stream was 0 mg/l

while the other streams were ranged between 0 – 28.56 mg/l for Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir. The temperature in the streams was ranged from 23.4 to 26.7 °C. The total suspended solids of the streams were classified as Class I since the total suspended solids were ranged from 0.02 – 32.9 mg/l. The stream water in this study is sensitive to aquatic species and the water can be used for recreational use while only conventional treatment is needed for the water quality before it is used for daily usage as the streams are mostly classified in Class II as shown in Appendix (Table 4).

4.3.4 Paired t-test of Physicochemical Parameters between Sunrise and Sunset

There was significant difference ($p < 0.05$) in the dissolved oxygen between sunrise and sunset in the Serin Stream. The turbidity measured in the Sabong Stream was 0.00mg/L and therefore the paired t-test value not available. Whereas, the turbidity measured during sunrise and sunset in the Serin Stream was found to be significantly different ($p < 0.05$). Water temperature measured during sunrise and sunset during the sampling days from the Sabong Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream were also significantly different ($p < 0.05$), but water current (WCN) measured during sunrise and sunset in the streams was not significantly ($p > 0.05$) different except in the Sabong Stream, as shown in Table 4.15.

Table 4.5: The paired t-test of physicochemical parameters between sunrise and sunset according to sampling sites.

Parameters	Sampling Location				
	Sabong Stream	Duyoh Stream	Cina Stream	Serin Stream	Bak Muan Sadir Stream
DO	0.563	1.000	0.285	0.027	0.375
pH	0.310	0.472	0.683	0.402	0.234
TBY	N.A	0.109	0.902	0.033	0.289
TEM	0.010	0.760	0.029	0.013	0.129
WCN	0.043	0.413	0.136	0.961	0.391
DPH	0.222	0.423	0.241	0.758	0.932
Q	0.155	0.398	0.633	0.878	0.907
TSS	1.000	0.203	0.512	0.272	0.567

* Note: DO = dissolved oxygen, TBY = turbidity, TEM = temperature, WCN = water current, DPH = depth of the stream, Q = water discharge, TSS = total suspended solid.

4.3.5 Correlations between Community Structure and Physicochemical Parameters of Streams

The Pearson correlation analysis shows that the Shannon diversity index (H) of the aquatic insects during sunrise in the Sabong Stream was positively and strongly correlated ($p < 0.05$) with water discharge (Q) ($r^2 = 0.996$) (Table 4.6). There was no correlation between the diversity of the aquatic insects and richness with environmental parameters (Table 4.7). The H of aquatic insects during sunrise in the Cina Stream was positively and significantly correlated ($p < 0.05$) with turbidity (TBY) ($r^2 = 0.998$) and total suspended solid (TSS) ($r^2 = 0.996$) while H of aquatic insects was significantly correlated ($p < 0.01$) with depth (DPH) ($r^2 = 1.000$). The H of aquatic insects in Cina Stream during sunrise had negative and significant relationship with water current (WCN) and water discharge (Q) (see Table 4.8).

The H of aquatic insects during sunrise in the Serin Stream negatively and significantly correlated ($p < 0.01$) with TSS. The d of aquatic insects in Serin Stream during

sunrise was significantly ($p < 0.05$) correlated with dissolved oxygen (DO) (Table 4.9). Whereas, the H of aquatic insects in the Bak Muan Sadir Stream was inversely and significantly ($p < 0.05$) correlated with pH ($r^2 = 0.994$) during sunrise while significantly correlated ($p < 0.05$) with TEM ($r^2 = 1.000$) (see Table 4.10).

Table 4.6: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Sabong Stream during sunrise.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-0.665	-0.697	N.A	-0.925	0.955	0.557	0.998^b	0.661
Margalef's species richness (<i>d</i>)	-0.339	-0.381	N.A	0.717	0.997	0.208	0.902	0.893

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.7: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Duyoh Stream during sunrise.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	0.981	0.365	-0.098	-0.937	0.948	0.578	0.696	0.054
Margalef's species richness (<i>d</i>)	0.546	0.922	0.646	-0.903	0.432	0.988	0.499	0.754

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.8: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Cina Stream during sunrise.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	0.050	-0.929	0.999^a	0.823	-0.998^a	-1.000^b	-1.000^a	0.998^a
Margalef's species richness (<i>d</i>)	0.931	0.646	-0.267	-0.800	0.253	0.316	0.293	-0.260

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.9: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Serin Stream during sunrise.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	0.470	0.971	0.816	0.891	0.907	0.870	0.891	-1.000^b
Margalef's species richness (<i>d</i>)	0.998^a	0.308	0.922	0.856	0.836	0.877	0.856	-0.527

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.10: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Bak Muan Sadir Stream during sunrise.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-0.568	-0.997^a	0.561	1.000^b	-0.917	0.872	0.639	0.573
Margalef's species richness (<i>d</i>)	-0.237	-0.904	0.820	0.933	-0.714	0.640	-0.323	0.827

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

The *H* of aquatic insects in the Sabong Stream collected during sunset was negatively and significantly ($p < 0.05$) correlated with DO (Table 4.11). The Duyoh Stream has no correlation between biological indices of aquatic insect and water quality of the stream (see Table 4.12).

The *H* of aquatic insects of sunset in Cina Stream significantly correlated ($p < 0.01$) with pH ($r^2 = 1.000$) (see Table 4.13). The *d* of aquatic insects in the Serin Stream during sunset was directly and significantly ($p < 0.05$) correlated with pH, WCN and DPH (see Table 4.14). There was negative and significant ($p < 0.05$) relationship between the *H* of the aquatic insects during sunset in the Bak Muan Sadir Stream with DO ($r^2 = 1.000$) (see Table 4.15).

Table 4.11: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Sabong Stream during sunset.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-0.999^a	0.121	N.A	-0.049	-0.558	0.511	-0.408	-0.192
Margalef's species richness (<i>d</i>)	-0.982	0.262	N.A	0.094	-0.671	0.383	-0.534	0.330

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.12: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Duyoh Stream during sunset.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-0.951	0.886	-0.953	0.670	0.970	0.196	0.949	-0.982
Margalef's species richness (<i>d</i>)	-0.970	0.915	-0.931	0.718	0.984	0.260	0.968	-0.968

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.13: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Cina Stream during sunset.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-0.634	1.000^b	-0.239	0.130	-0.963	-0.804	-0.933	0.247
Margalef's species richness (<i>d</i>)	-0.439	0.976	-0.009	-0.101	-0.874	-0.645	-0.825	0.017

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.14: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Serin Stream during sunset.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	0.273	0.848	0.655	-0.035	0.798	0.872	0.770	0.974
Margalef's species richness (<i>d</i>)	0.763	0.999^a	0.965	0.527	0.998^a	0.997^a	0.995	0.682

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 4.15: Pearson's correlation coefficient (r value) among assemblages of aquatic insects and water quality parameters in Bak Muan Sadir Stream during sunset.

	Water Quality Parameters							
Biological Indices	DO	pH	TBY	TEM	WCN	DPH	Q	TSS
Shannon diversity (<i>H</i>)	-1.000^a	0.414	0.491	0.709	0.182	0.664	0.336	0.309
Margalef's species richness (<i>d</i>)	-0.997	0.321	0.402	0.775	0.083	0.586	0.240	0.213

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

4.3.6 Correlations between Abundance of Aquatic Insects and Physicochemical Parameters of Streams

Table 4.16 summarises the results of the CCA (Canonical Correspondence Analysis) of the composition of the aquatic insects with *in-situ* parameters during sunrise in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. The results of the permutation test showed that the test of first canonical eigenvalues was 0.258 and the p value was 0.062, indicating that the first canonical axis was not statistically significant with $p > 0.05$. The test based on the sum of all canonical eigenvalues was 0.666. The resulting p value was 0.666 demonstrating that the relation between aquatic insect composition during sunrise and *in-situ* parameters was significant ($p > 0.05$).

The result of CCA (Canonical Correspondence Analysis) of the composition of the aquatic insects during sunset in the streams with the *in-situ* parameters are summarized in Table 4.17. The results of the permutation test showed that the test of first canonical eigenvalue was 0.297. The resulting p value was 0.121 which indicates that the first canonical axis was statistically significant at $p > 0.05$. The test based on sum of all canonical eigenvalues was 0.567 demonstrating that the relation between composition of the aquatic insects during sunset and *in-situ* parameters was significant ($p < 0.05$).

The aquatic insects that showed similar patterns and related to the same environmental conditions are plotted close to each other on the triplot diagram. The distance between the symbols in the diagram approximates the dissimilarity of their aquatic insect composition. Environmental variable arrows point the direction of steepest increase of environmental

variable. The abbreviations of the aquatic insects in the study which were used in the CCA ordination are shown in Table 4.18.

Table 4.16: Summary of Canonical Correspondence Analysis (CCA) results of composition of aquatic insects during sunrise in the streams.

Axes	1	2
Eigenvalues	0.258	0.189
Species-environment correlations	0.062	0.501
Cumulative percentage variance:		
of aquatic insects-environment relation	38.74	67.12
Sum of all unconstrained eigenvalues		1.205
Sum of all canonical eigenvalues		0.666

Table 4.17: Summary of Canonical Correspondence Analysis (CCA) results of composition of aquatic insects during sunset in the streams.

Axes	1	2
Eigenvalues	0.297	0.134
Species-environment correlations	0.121	0.409
Cumulative percentage variance:		
of aquatic insects-environment relation	52.38	76.01
Sum of all unconstrained eigenvalues		1.126
Sum of all canonical eigenvalues		0.567

The CCA triplot (Figure 4.6) of the composition of the aquatic insects during sunrise and *in-situ* parameters based on two axes which explains 67.12% of the variance in the correlation and the aquatic insects with respect to the environmental variables. Axis 1 was strong positively correlated with turbidity and negatively correlated with dissolved oxygen. Meanwhile, axis 2 had strong positive correlation with pH, water temperature, water current and water discharge and negatively correlated with water depth. The longest CCA vector was

recorded for dissolved oxygen (DO), followed by water discharge (Q), pH, water current (WCN), turbidity (TBY), water depth (DPH) and water temperature (TEM).

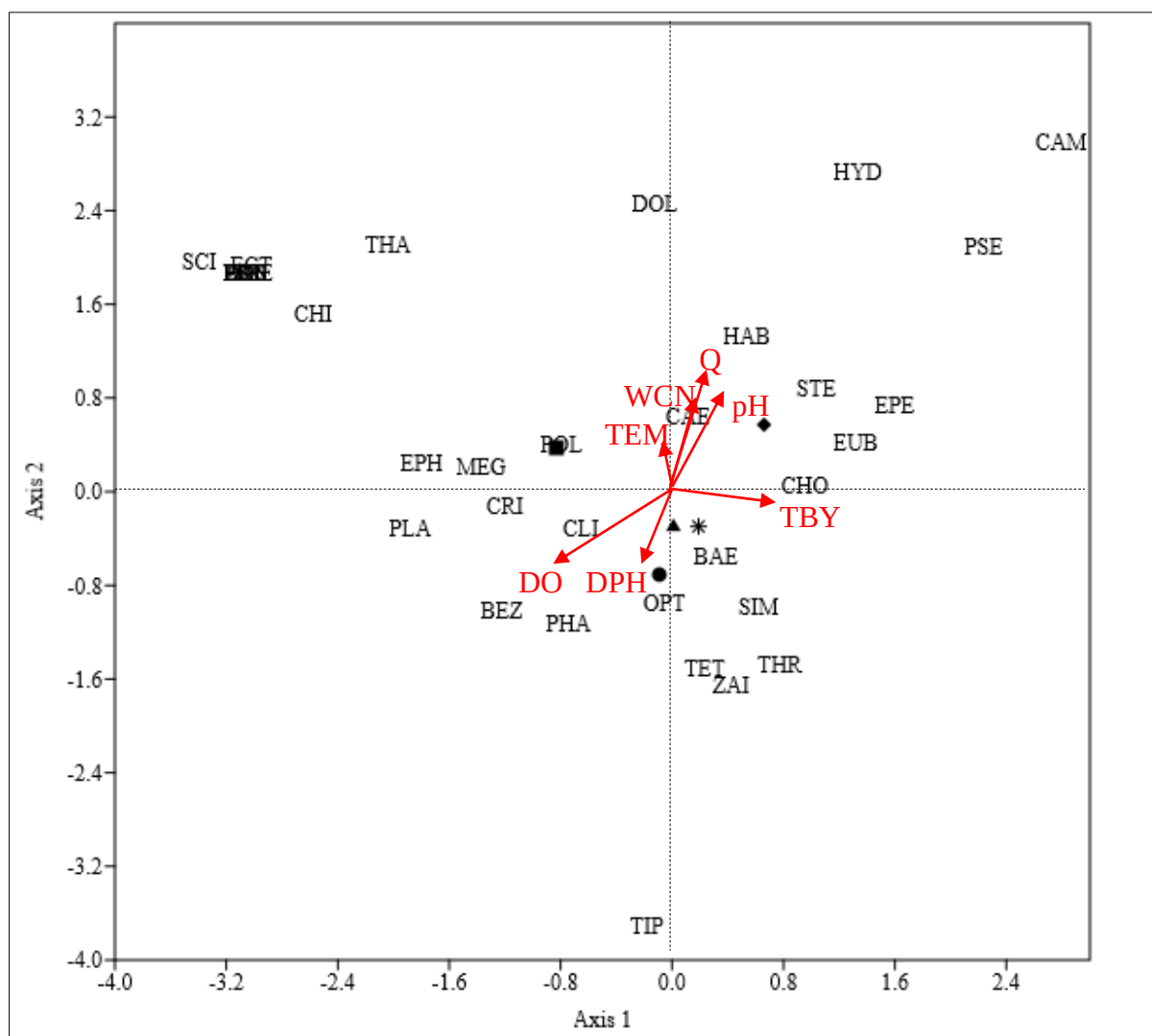


Figure 4.6: Biplot diagram of CCA showing relationship between composition of aquatic insects during sunrise with the *in-situ* parameter in Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. Symbols: Circle (Sabong Stream), Square (Duyoh Stream), Triangle (Cina Stream), Diamond (Serin Stream), Star (Bak Muan Sadir Stream); Red Arrow: Environmental parameters (DO: Dissolved Oxygen, TEM: Water temperature, pH, TBY: Turbidity, DPH: Depth, Q: Water Discharge, WCN: Water Current).

From the biplot ordination graph, sixteen species, *Ameletus* sp., *Thalerosphyrus* sp., *Ephemera* sp., *Doloclanes* sp., *Tinodes* sp., *Psychomyia* sp., *Ecnomus* sp., *Chironomus* sp., *Polypedium* sp., *Tipula* sp., *Megaselia deningi*, *Dasyhelea* sp., *Scirtes* sp., *Psephenus* sp. and

Ectopria sp. were associated with the Duyoh Stream with higher water temperature. Whereas, the Serin Stream was strongly affected by pH, water discharges (Q) and water current (WCN). The Cina Stream and Bak Muan Sadir Stream showed similar composition whereby *Baetis* sp., *Thraulius* sp., *Tetropina* sp., *Simulium* sp. and *Zaitzeviaria* sp. were positively associated with higher turbidity but these species choose habitats with low water temperature as in both Cina Stream and Bak Muan Sadir Stream. The *Baetis* sp. was the only species present in both these streams in higher density than the other streams. Six species which are *Platybaetis* sp., *Phanoperla* sp., *Cricotopus* sp., *Clinotanypus* sp., *Bezzia* sp. and *Optioservus* sp. were associated with habitats such as the Sabong Stream which having deeper water depth and high dissolved oxygen but with low water current, water discharge and pH. The abbreviations of the aquatic insects in the study which were used in the CCA ordination are shown in Table 4.28.

Table 4.18: Aquatic insect species abbreviations used in CCA ordination

Abbreviation	Species Name	Abbreviation	Species Name
BAE	<i>Baetis</i> spp.	SIM	<i>Simulium</i> spp.
PLA	<i>Platybaetis</i> sp.	CRI	<i>Cricotopus</i> spp.
AME	<i>Ameletus</i> spp.	CHI	<i>Chironomus</i> spp.
THA	<i>Thalerosphyrus</i> spp.	POL	<i>Polypedium</i> sp.
CAM	<i>Campsoneuria</i> sp.	CLI	<i>Clinotanypus</i> sp.
EPE	<i>Epeorus</i> spp.	PSE	<i>Pseudodiamesa</i> sp.
CHO	<i>Choroterpes</i> sp.	TIP	<i>Tipula</i> sp.
HAB	<i>Habrophlebiodes</i> sp.	MEG	<i>Megaselia deningi</i>
THR	<i>Thraulius</i> sp.	CUL	<i>Culex</i> sp.
CAE	<i>Caenis</i> spp.	BEZ	<i>Bezzia</i> spp.
EPH	<i>Ephemera</i> sp.	DAS	<i>Dasyhelea</i> spp.
PHA	<i>Phanoperla</i> sp.	CUI	<i>Culicoides</i> sp.
ISO	<i>Isoperla</i> sp.	STE	<i>Stenelmis</i> spp.
TET	<i>Tetropina</i> sp.	OPT	<i>Optioservus</i> sp.
DOL	<i>Doloclanes</i> sp.	ZAI	<i>Zaitzeviaria</i> sp.
TIN	<i>Tinodes</i> sp.	SCI	<i>Scirtes</i> spp.

Table 4.18 continued

PSY	<i>Psychomyia</i> spp.	PSE	<i>Psephenus</i> spp.
HYD	<i>Hydropsyche</i> spp.	EUB	<i>Eubrianax</i> sp.
ECN	<i>Ecnomus</i> sp.	ECT	<i>Ectopria</i> sp.
RHY	<i>Rhyacophila</i> sp.		

The CCA biplot (Figure 4.7) of aquatic insect composition during sunset at the streams and in-situ parameters was based on to the axes which explain 76.01% of the variance in the fitted aquatic insect data, and the same percentage (76.01%) of the variance in the correlations with respect to the environmental variables. The environmental variables such as water current (WCN), water temperature (TEM) and water discharge (Q) were the most influential variables in the Serin Stream which had high density of *Camponeuria* sp., *Epeorus* sp., *Hydropsyche* sp., *Simulium* sp. and *Pseudodiamesa* sp. species. The presence of aquatic insects in Sabong Stream and Duyoh Stream were most closely associated with water depth (DPH) of the stream. Five species, *Cricotopus* sp., *Ameletus* sp., *Thalerosphyrus* sp., *Polypedium* sp. and *Clinotanypus* sp. choose low temperature, water current, and water discharges while seven species including *Baetis* sp., *Choroterpes* sp., *Habrophlebiodes* sp., *Thraulius* sp., *Caenis* sp., *Phanoperla* sp. and *Optioservus* sp. were positively associated with high dissolved oxygen, pH and turbidity but they choose lower water depth as in the Cina Stream and Bak Muan Sadir Stream.

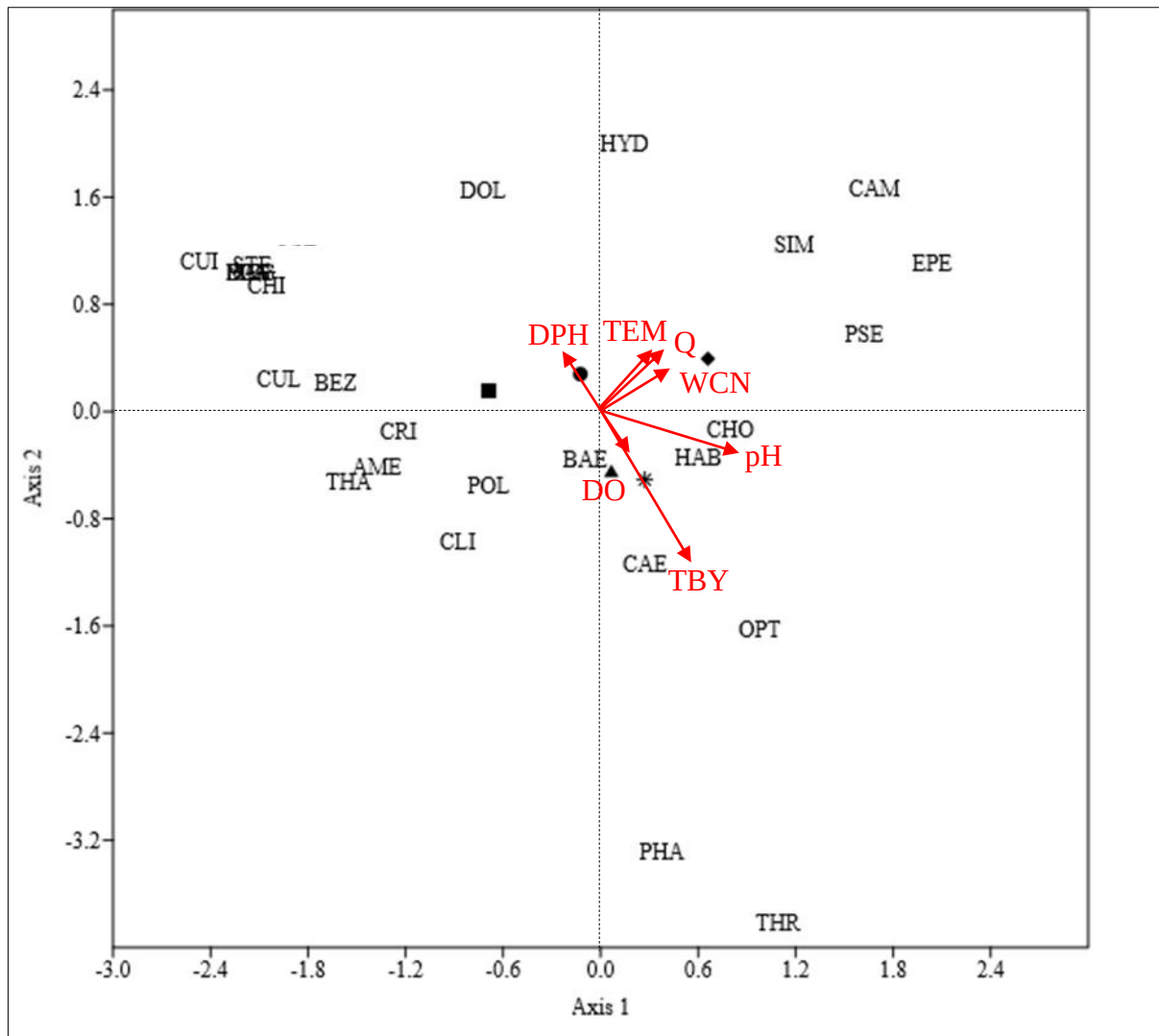


Figure 4.7: Biplot diagram of CCA showing relationship between composition of aquatic insects during sunset with the *in-situ* parameter in Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. Symbols: Circle (Sabong Stream), Square (Duyoh Stream), Triangle (Cina Stream), Diamond (Serin Stream), Star (Bak Muan Sadir Stream); Red Arrow: Environmental parameters (DO: Dissolved Oxygen, TEM: Water temperature, pH, TBX: Turbidity, DPH: Depth, Q: Water Discharge, WCN: Water Current).

4.4 Discussion

In this study, a total of 1539.0 / m² individuals of aquatic insects representing 36 species, 19 families which belongs to five orders during sunrise and 30 species representing 18 families and five orders during sunset were collected and identified from the five streams: Sabong Stream (98.0 / m² individuals), Duyoh Stream (446.0 / m² individuals), Cina Stream (252.0 / m² individuals), Serin Stream (373.0 / m² individuals) and Bak Muan Sadir Stream (370.0 / m² individuals). When compared to studies in other rivers in Sarawak by Shabdin (2010), the numbers of species of aquatic insects found in the study area were higher than that at Rajang River which was only 474 / m² individuals. Bishop (1973) has stated that there were 11 orders such as Ephemeroptera, Plecoptera, Odonota, Hemiptera, Trichoptera, Coleoptera, Lepidoptera, Blattodea, Megaloptera, Neuroptera and Diptera that have been documented in studies on the community structures of aquatic insects in Peninsular Malaysia and Borneo regions from small rivers flowing of the rainforest area in 1968 to 1970 (Yong and Yule, 2004).

Based on the result of this study, Ephemeroptera formed a very large group comprising more than 45.0% of the total number of aquatic insects collected from every stream. In this regard, the result of this study is similar to the findings recorded by Wahizatul *et al.* (2011) in Hulu Terengganu which shows Ephemeroptera as the most dominant order in both streams of their study. The order Ephemeroptera is the group that is usually associated with clean, well oxygenated water. Hence they are shown in higher abundance in the streams of this study. Most of Ephemeropteran are herbivores and detritivores which feed on algae and dead organic matters in the streams (Thorp and Rogers, 2011). The Ephemeroptera inhabit clean streams where they are often abundant in leaf litter, eddies or near the banks

besides a few species may persist in organically enriched streams (Shabdin, 2010). Families belonging to the Ephemeroptera are clear-water fauna (Bouchard *et al.*, 2004) and disappear as pollution load increases (Beyene *et al.*, 2009). Ephemeroptera have advantages for monitoring as they are highly visible, relatively easy to sample and are represented by a few species in such habitats, which makes identification easier. Mayfly nymphs consume epiphytic algae and fine particulate organic matter (Arimoro *et al.*, 2009). The main reasons for the low population density and low diversity of Ephemeropterans could be related to habitat degradation by pollution (Choudhary and Ahi, 2015).

In this study, Baetidae which comprises of *Baetis* sp. and *Platybaetis* sp. were the dominant family of Ephemeroptera and *Baetis* sp. was the dominant species found in every stream during both sunrise and sunset of this study whereby 58.16% of aquatic insects represent *Baetis* sp. was found in Sabong Stream, 25.78% in Duyoh Stream, 51.98% in Cina Stream, 29.49% in Serin Stream and 35.41% in Bak Muan Sadir Stream. A study by Suhaila *et al.* (2011) also shows Baetidae as the most common family with greater occurrence and *Baetis* sp. was the most abundant throughout the study at Terai River and Batu Hampar River in Kedah, Northern Peninsular Malaysia. The *Baetis* present in Terai River and Batu Hampar River was strongly associated with DO content of the rivers which is about 6.62mg/L to 7.67mg/L. The abundance of immature stage has often been reported to be correlated with increased in oviposition which influenced by the availability of egg deposition sites (Elliot, 1972; Suhaila *et al.*, 2011).

Baetis sp. was the only species from order Ephemeroptera found in the Sabong Stream, while the absence of other species and family of Ephemeroptera may due to low pH of 4.27 to 4.77 of the stream throughout the study in Sabong Stream. It has been reported by

Kelly (1991) and Suhaila *et al.* (2011) that mayflies can survive at a pH of 4.5 while Bick *et al.* (1953) and Bell and Nebeker (1969) listed the genera *Stenonema*, *Baetis*, *Blasturus*, *Callibaetis*, and *Paraleptophlebia* as being present in pH values of 4.0 to 5.0. Some species of baetidae have been reported to be associated with high flow velocity (Arimoro and Ikomi, 2009; Edegbene *et al.*, 2015). Hence, the absence of other family from order Ephemeroptera suggests that they cannot withstand lower pH (Suhaila *et al.*, 2011).

The family Caenidae was contributed by only one genus *Caenis* sp. and it was found to be abundant in the Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream and present in very fewer numbers in the Sabong Stream. The genera *Baetis* sp. and *Caenis* sp. from earlier studies have reported to be tolerant to organic pollution (Timm, 1997; Menetrey *et al.*, 2008) but Abhijna *et al.* (2013) stated that *Caenis* sp. appears too sensitive to pollution as number of *Caenis* sp. is lower at the stream in their study which regarded as disturbed area. They also reported that only one genus from *Caenis* sp. was present in their study and it was found that the numbers of *Caenis* sp. were significantly reduced at disturbed sites. The family Caenidae however, is one of those Ephemeropterans that not sensitive to decrease in water quality (Zimmerman, 1993; Flores and Zafaralla, 2012).

Habitat alteration might occur directly due to the effect of human activities on the river ecosystems or indirectly, where human disturbance creates changes in the physical qualities of the water especially temperature and river substrate compositions (Aweng *et al.*, 2012). The Sabong Stream has more sand substrates with boulder and rock substrates compared to other streams and only a total of 60.0 individuals of aquatic insects per m² were recorded. Hawkins (1984) and Baptista *et al.* (2001) have stated that the instability of the sand substrates and the low organic matter availability lead to a low diversity and richness numbers. According to

Courtney and Clements (1998), streams with the lowest pH contains fewer individuals and species than other streams. This shows that lowest pH of Sabong Stream is one of the factors which causes fewer species to inhabit in the stream.

Based on stream health classification by National Interim Water Quality Standards of Malaysia (INWQS, 2008), all the streams are still considered as good water quality. The presence of Chironomid in every stream was also very low. Al-Shami *et al.* (2010) stated that the presence of Chironomids depends on seasonal changes where more chironomids can be found during dry season. With the presence of high numbers of Ephemeroptera, Plecoptera and Trichoptera (EPT) in every stream, thus this study is consistent with the idea that the EPT members were usually found in undisturbed area. In regards to Malaysia's National Interim Water Quality Standards, the physicochemical parameters measured were mostly classified the streams into Class II. DO and pH in Duyoh Stream, Cina Stream, Serin and Bak Muan Sadir Stream were classified as Class II while pH in Sabong Stream was not classified in any class since pH of Sabong Stream is less than 5.0.

In addition, turbidity of every stream except Sabong Stream is classified into Class I. In contrast, total suspended solids in every stream categorised the streams as Class II. These results were not consistent with Mohmad Fikri *et al.* (2015) that reported the Liwagu River tributaries in Sabah had excellent water quality since most of the parameters that measured in the river classified into Class I. Another study by Kamsia Budin *et al.* in 2007 at Telipok River, Sabah where the upper stream was classified into Class II and the downstream is classified into Class III. The classification of water quality of the streams in these studies were consistent with upper stream of Telipok River where both are classified into Class II, which means the stream or river water is sensitive to aquatic species and the water can be used for

recreational use. Only conventional treatment is needed for the water quality before it is used for daily usage.

The highest index value of species diversity and species richness were found at the Duyoh Stream, with a Shannon diversity index (2.713) and Margalef's richness index (4.754) while the lowest was recorded at the Sabong Stream with Shannon diversity index (1.370) and Margalef's richness index (1.963). Duyoh Stream has 30 species of aquatic insects which belong to 5 orders and 18 families while only 10 species which belong to 3 orders and 7 families were found in Sabong Stream. Duyoh Stream has diverse aquatic insects and the number of individuals in each species present in Duyoh Stream was higher compared to other streams. The highest species diversity and richness values recorded in the Duyoh Stream may due to substrate compositions at Duyoh Stream which has more small particles than Sabong Stream while fewer numbers of individuals in Sabong Stream may due to anthropogenic activities, poor habitat type and absence of aquatic macrophytes which serves as microhabitat to species of macroinvertebrates. The higher diversity of aquatic insects could also probably because Duyoh Stream has many plants which act as habitat and favourable to numerous aquatic insects compared to other streams. Ismail *et al.* (2012) has also found highest diversity value in a station of the river with a lot of plants in Keniam River, Pahang. The Shannon-Wiener's diversity index (H) values in this study were more than 1. Türkmen and Kazanci (2010) and Barman and Gupta (2015) found the diversity index value which is less than 1 indicating the polluted nature of stream water.

The diversity of insects in aquatic ecosystems tends to increase with optimum environmental conditions which favour their abundance in the habitats. The present study reveals greater abundance of aquatic insects in the Duyoh Stream compared to other streams

together with increasing species richness and composition while the least abundance and composition were found in Sabong Stream. Abhijna *et al.* (2013) have stated that many habitats, especially disturbed ones are dominated by few species as in the Sabong Stream. The number of species and richness were highest in the Duyoh Stream and could be due to river substrate compositions where the stream has more small particles compared to large particle as stated by Aweng *et al.* (2012). Some studies have reported that species richness, density of invertebrates and diversity increased along a river continuum with increases in pH, hardness and nutrients (Clenaghan *et al.*, 1998; Flores and Zafaralla, 2012). In this study, there was no significant difference in species diversity and species richness among sunrise and sunset samples. This is possibly because of the composition of individuals among the various species remained static for sunrise and sunset. The water quality parameters during sunrise and sunset in all the sampling locations were not significantly different and the water quality parameters were almost the same. Therefore, there was no detectable difference between sunrise and sunset samples. This could probably be due to low differences of water qualities that were observed especially dissolved oxygen and water discharges.

The composition and abundance of aquatic insects varied among the streams. According to Aweng *et al.* (2012), the composition of in benthic macroinvertebrate was assumed to be due to different altitude. Abundance of macroinvertebrates between the sites may be due to change in physical habitat which influences the structure and community of the benthic communities (Downes *et al.*, 2000; Basnet, 2013). Environmental parameters also contribute to the abundance of aquatic insects for example water depth, water current, temperature of the stream water, pH and also types of environment (Ismail *et al.*, 2012). Several factors are known to influence the composition of aquatic insects but the important factors likely to affect the diversity and abundance in an aquatic ecosystem are water

temperature, water velocity. Ward and Stanford (1979) have also suggested that water flow, temperature and substrates are the major factors determining the composition and abundance of benthic invertebrates. According to Minshall and Winger (1968), benthic invertebrates are particularly sensitive to different water velocities and bed sediment stability (Barman and Gupta, 2015). In addition, physical and chemical disturbance, seasonal water flow, temperature, ion concentrations, food base of the stream, interaction with the stream biota and substrate were also major factors in determining the composition and abundance of aquatic insects (Ward and Stanford, 1979).

Lenat *et al.* (1980) and Barman and Gupta (2015) have stated that the Margalef's richness index values greater than 3 indicate clean conditions of the stream. Richness of aquatic insects is depends on the water quality of the stream. More individuals from aquatic insect species that present in both Duyoh Stream and Cina Stream were found. Based on the Margalef's richness value in this study, it can be said that Duyoh Stream and Cina Stream are considered clean streams since Margalef's richness index values in both Duyoh Stream and Cina Stream were 4.754 and 3.798 respectively while the value in Sabong Stream was 1.963, Serin Stream (2.871) and Bak Muan Sadir Stream (2.537). It can be said that based on the richness of aquatic insects present in the streams, both the Duyoh Stream and Cina Stream have clean water. The causes of fluctuations in insect richness and composition may due to variation in the availability of food resources (Selvakumar *et al.*, 2014; Barman and Gupta, 2015). The changes in community structure are generally due to geomorphological changes and associated with destruction of physical habitat of the stream (Selvakumar *et al.*, 2014; Barman and Gupta, 2015).

In the present study, the sum of all Canonical Eigen values during sunrise was found to be 0.666 while 0.567 during sunset which indicated high degree of correspondence of species with sampling sites. During sunrise, the arrow for dissolved oxygen was the longest while the arrow of turbidity was the longest during sunset. The direction and length of each arrow in CCA ordination diagram indicate the direction and rate of maximum changes in each variable (Pielou, 1984; Barman and Gupta, 2015). Based on CCA ordination during sunset, *Chironomus* sp. were associated with reduced DO value. From the association of these organisms and DO, it can be inferred that these group of aquatic insects are pollution tolerant species. Several studies have reported most especially some group of chironomidae to be pollution tolerant species (Arimoro and Ikomi, 2009; Edegbene and Arimoro, 2012; Edegbene *et al.*, 2015).

In this study, the pH of the Cina Stream was positively correlated with diversity of aquatic insects. In general, pH, BOD and electrical conductivity values were positively correlated with aquatic insect diversity in studies by Arimoro and Ikomi, (2008); Müller *et al.* (2009) and El Husseiny *et al.* (2015). The direct correlation of flow velocity with richness of Serin Stream during sunset is indicative of aquatic insects favouring faster currents. Many studies have established that micro-flow dynamics play a key role in the small-scale composition of benthic communities (Statzner and Holm, 1982; Hart *et al.*, 1996). Fenoglio *et al.* (2004) have stated that both invertebrate density and taxonomical richness increased with increasing current velocity. Higher velocities were associated with richer and more abundant invertebrate assemblages. Suspended particles in the water absorb heat thus, could increase water temperatures. This, in turn could reduce the oxygen content of the water since warm water holds less DO than cold (Flores and Zafaralla, 2012). In this study, the Bak Muan Sadir

Stream which has the lowest water temperature compared to other streams and has higher amount of dissolved oxygen than other streams during both sunrise and sunset.

The Plecoptera was the group of insects with the lowest abundance and number of species than the other order of aquatic insects collected in the study. There was no Plecoptera found in the Serin Stream throughout the study. Fewer gravel substrates which were optimally embedded in the sand in Serin Stream were less suitable for many plecopteran larvae. Predation and behaviour of the stoneflies could also contribute to the rareness and absence of the population (Suhaila *et al.*, 2011). The absence of Plecoptera indicates that the water quality degradation and physical alteration. In the present study, the absence of Plecoptera during sunrise in the Sabong Stream, Duyoh Stream and Bak Muan Sadir Stream and during sunset in Serin Stream clearly indicates that there is degradation of water quality and physical alteration. Choudhary and Ahi (2015) have stated that this order of insects usually choose stream environment, where there is low temperature. The Plecoptera is a sensitive order of aquatic insects and restricted to habitats where there is little human interference and presence of clear water, and high dissolved oxygen content (Choudhary and Ahi, 2015). It has earlier been reported that the Plecoptera are very sensitive aquatic insect (Popijač and Sivec, 2009; Edegbene *et al.*, 2015).

In the present study, there was absence of Trichoptera in the Sabong Stream, Cina Stream and Bak Muan Sadir Stream. Choudhary and Ahi (2015) have reported that the Trichoptera is sensitive to pollution. Caddisflies are considered to be of great economic importance as pests, and they are beneficially important in the trophic dynamics and energy flow in aquatic ecosystems. The larvae of caddisfly are useful as biological indicator organisms for assessing water quality. Extensive use of them has been made for this purpose

because larvae of different species vary in sensitivity to various types of pollution (Resh and Unzicker, 1975; Resh, 1993; Dohet, 2002).

Insects restricted to heavily enriched habits bloodworm midge larva indicate that water bodies are organically enriched. Chironomidae was the dominant family in Duyoh Stream during both sunrise and sunset with a total of 146.0 individuals per m². According to Choudhary and Ahi (2015), large numbers of pollution tolerant chironomids are often indicative of poor water quality. The high abundance of *Chironomus* sp. in aquatic body indicates the eutrophic nature of water body. Excellent water quality conditions are often characterised by relatively low densities and high species diversity (Choudhary and Ahi, 2015).

Dipterans were rich in numbers of species after order the Ephemeroptera as well as in number of individuals. The order Diptera was contributed by 6 major families representing Simuliidae, Chironomidae, Tipulidae, Phoridae, Culicidae and Ceratopogonidae. The larvae of most species can be considered aquatic in the broadest sense and they require a moist to wet environment within living plants, amid decaying organic materials, as parasites or in association with water bodies (Footit & Adler, 2009; Abhijna *et al.*, 2013). Many of the dipterans inhabit in heavily polluted water bodies with wide range of tolerance especially the family Chironomidae.

4.5 Conclusion

A total of 36 species belong to 19 families and 5 orders of aquatic insects were recorded during sunrise in the five streams, while 30 species, 18 families and 5 orders of aquatic insects were recorded during sunset. The order Ephemeroptera was most abundant in number of individuals followed by Dipterans and Trichopterans, while other orders of aquatic insects were less abundant in the streams. The order Ephemeroptera was the highest in number of families recorded during sunrise represented by Baetidae, Ameletidae, Heptageniidae, Leptophlebiidae, Caenidae and Ephemeridae while the order Diptera was represented by five families and recorded as second highest in number of families namely Smuliidae, Chironomidae, Tipulidae, Phoridae and Ceratopogonidae and Order Trichoptera were represented by the family Philopotamidae, Psychomyiidae, Hydropsychidae and Ecnomidae. During sunset, the order Ephemeroptera and Diptera recorded the highest number of families which are 5 families each while the order Trichoptera was represented by the family Philopotamidae, Hydropsychidae, Ecnomidae and Rhyacophilidae. This result indicates the relatively high richness and diversity in the group of aquatic insect assemblages in the five streams. Results revealed an acceptable water quality at every stream in these studies according to the classifications by Interim National Water Quality Standard (INWQS). It is concluded that Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream had minimal pollution and good water quality.

There were no significant differences in the diversity of the aquatic insect and richness between sunrise samples and sunset samples in the streams. The environmental variables in the streams had directly and indirectly affected aquatic insect assemblages. The highest

Shannon Index of diversity and Margalef's species richness were recorded in the Duyoh Stream while the lowest were recorded in the Sabong Stream.

Based on the CCA results, aquatic insects present in the Sabong Stream were abundant with high depth and dissolved oxygen while aquatic insects in the Duyoh Stream were affected by higher temperature, aquatic insects in the Serin Stream were abundant in high water current, water discharge and pH whereas aquatic insects in the Cina Stream and Bak Muan Sadir Stream associated with high turbidity level during sunrise. During sunset, aquatic insects in Sabong Stream and Duyoh Stream were abundant with only high depth, Cina Stream and Bak Muan Sadir Stream were affected by high turbidity and pH level and Serin Stream was associated with pH, water current and water discharge of the stream.

In comparison between drift and benthic aquatic insect studies in the streams, 39 species which belong to 25 families and 7 orders of aquatic insect were found in drift while benthic studies consist of 39 species which belongs to 21 families and 5 orders of aquatic insect. Taxa that found in drift include Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera, Odonata and Collembola. In contrast to benthic aquatic insects study, only Ephemeroptera, Plecoptera, Trichoptera, Diptera and Coleoptera were found in the streams. Although there were differences in number of families and orders occurred in drift and benthic studies, the highest number of individuals found in both the studies were from order Ephemeroptera especially *Baetis* sp.

CHAPTER 5

EVALUATION OF WATER QUALITY AND ORGANIC POLLUTION IN STREAMS

5.1 Introduction

Studies on biomonitoring or the biological assessment of human impact on water quality including pollution and its relationship with aquatic insects have been carried out since the early 1900s (Wallace *et al.*, 1996; Hazelton, 2003). Various studies specifically on using benthic macroinvertebrates composition in biomonitoring have been done by many researchers (Ogbeibu and Oribhabor, 2002; Beyene *et al.*, 2009; Basnet, 2013; Harun *et al.*, 2015). Among studies using benthic macroinvertebrates, the rapid-biomonitoring method has been popular as it has been found to be more efficient as the assessment protocols can be set up faster and produces rapid outcomes and results. Moreover, rapid biomonitoring protocols are relatively inexpensive and cost-effective and a wide range of water qualities can be assessed (Barbour *et al.*, 1999; Hazelton, 2003).

Biomonitoring is the use of biological variables in the form of living organisms to assess the quality of freshwater environment and particularly the level of pollution. The purpose of biomonitoring is to identify ideal bioindicators and determine how their presence, abundance and behavior provide indicators on the health of rivers and streams and level of pollution (Bonada *et al.*, 2006; Maneechan and Prommi, 2015). Numerous indices of biological assessment have been used in studies such as Ephemeroptera, Plecoptera and Trichoptera (EPT) richness index and percentage of EPT index. They deal with the toxicology of the freshwater system and evaluation of specific ecology and conservation of various organisms based on taxonomic resolution (Hazelton, 2003).

With regard to the ecological status of freshwater systems such as streams in particular, various types of aquatic organisms have been frequently used as part of biomonitoring tools for the quality of freshwater systems (Kalyoncu and Zeybek, 2011). Around 60% of aquatic organisms used in freshwater monitoring studies are based on analysis of aquatic insects or benthic macroinvertebrates (Yorulmaz *et al.*, 1988; Maneechan and Prommi, 2015). Macroinvertebrates are ideal indicators of water quality assessment as numerous taxa of the insects are associated with different levels of water quality (Bode and Novak, 1995; Hazelton, 2003). Some species of macroinvertebrates have the potential of being bio-indicative, whereby their occurrence in the river or stream can provide information on the pollution status of the river or stream (Arslan *et al.*, 2016). In this regard, studies show that different aquatic insects have different level of sensitivity towards biotic and abiotic factors in the ecosystem (Nasirian, 2014). For example, the Plecopterans are confined to well-oxygenated waters while the flattened body of Ephemeroptera allow them to cling to rocks in fast currents.

Bio-assessment metrics is an evaluation of the biological condition on aquatic environment that uses biological surveys on benthic macroinvertebrates especially the aquatic insects in streams such as Ephemeroptera, Plecoptera and Trichoptera (EPT) index, percentage of EPT (%EPT) in the streams and ratio of EPT and Chironomidae (EPT/C). Insects belonging to the order of Ephemeroptera, Plecoptera and Trichoptera (EPT) are well known as important taxonomic groups in river biota, as they usually live in clean and well oxygenated waters and they are good biomonitoring or water quality indicators (Karr, 1991, Stoyanova *et al.*, 2014). The number of EPT has been observed to increase with improvements in water quality as they are sensitive to pollution (Plafkin *et al.*, 1989). The composition of the three orders of EPT insects mentioned above is affected by their

physiological tolerance to a wide array of environmental variables (Stoyanova *et al.*, 2014). The abundance of EPT thus indicates lower level of pollution. In contrast, aquatic insects of the order Chironomidae have been found to be less sensitive to environmental stress (Plafkin *et al.*, 1989). A community considered to be in good biotic condition will thus display a higher composition of EPT aquatic insects and disproportionately high numbers of Chironomidae may indicate environmental stress (Plafkin *et al.*, 1989).

Biotic indices are tools used in biomonitoring for evaluation of the quality of freshwater systems based on various responses of organisms towards environmental changes (Maneechan and Prommi, 2015). Several biotic indices such as BMWP (Biological Monitoring Working Party) and ASPT (Average Score Per Taxon) Indices have been developed for rivers and streams based on macroinvertebrates, particularly aquatic insects (Callisto *et al.*, 2001; Arslan *et al.*, 2016). Such biotic indices have been known as suitable criteria to understand the quality of aquatic surroundings as they have numerical expressions with the combinations of quantitative values of species diversity and qualitative information on the ecological sensitivity of each taxon (Czerniawska-Kusza, 2005; Arslan *et al.*, 2016). Biotic indices using macroinvertebrates have been developed by giving numerical scores to specific organisms at certain taxonomic level (Armitage *et al.*, 1983) and used to assess the quality and pollution of river waters (Nasirian, 2014).

The accuracy of biotic indices depends on at least a minimum of 100 organisms being processed from each sample (Zimmerman, 1993). There are several biotic indices which have been developed by researchers such as the BMWP (Biological Monitoring Working Party) and the ASPT (Average Score Per Taxon). A high ASPT score is considered indicative of a clean site containing large numbers of high scoring taxa and therefore low level of pollution

(Armitage *et al.*, 1983; Arslan *et al.*, 2016). For example, in neighbouring Thailand, the BMWP^{THAI} (Biological Monitoring Working Party of Thailand) is among the most common biotic indices used in the country. It is derived from a modification of British BMWP (Armitage *et al.*, 1983). The score for the BMWP^{THAI} was applied in a study by Mustow (2002) and Maneechan and Prommi (2015).

Although biomonitoring of water quality in rivers and streams using biotic indices is not new in Malaysia (Yap *et al.*, 2003; Harun *et al.*, 2015), there is no documented research in Sarawak on biomonitoring of water quality in rivers and streams using biotic indices. Hence this study was undertaken to assess the water quality and level of pollution of five various streams in Sarawak using bio-assessment metrics and biotic indices as a tool to evaluate the condition and ecosystem health of the streams.

5.2 Methodology

The composition of aquatic insects used to evaluate the health of streams and level of pollution is based on both sampling techniques where the samples were collected using a Kick net and Surber Sampler. Both techniques of sampling were done on the same days.

5.2.1 Bio-assessment Metrics

5.2.1.1 EPT Index and Percentage of EPT (%EPT)

The Ephemeroptera, Plecoptera, and Trichoptera (EPT) index displays the richness of taxa within the insect groups which are considered to be sensitive to pollution. The EPT index estimates water quality by the relative abundance of three major orders of stream insects that have low tolerance to water pollution. This index is valid for use at the family-level (Plafkin *et al.*, 1989). The index is calculated as below:

where, EPT index = total number of families represented within Ephemeroptera, Plecoptera, and Trichoptera (EPT) orders;

while, percentage of EPT (%) = the total number of families x 100%.

5.2.1.2 Ratio of EPT and Chironomidae (EPT/C)

The EPT/C index is calculated by dividing the sum of the total number of individuals classified as Ephemeroptera, Plecoptera, and Trichoptera by the total number of individuals classified as Chironomidae. The ratio of EPT to Chironomidae abundance shows the number of individuals from sensitive orders which are Ephemeroptera, Plecoptera and Trichoptera compared to pollution tolerant midges (Chironomidae).

5.2.1.3 Percentage Contribution of Dominant Family (% DF)

The percentage contribution of the dominant family or percentage dominance (% DF) was used to measure the abundance of a dominant group of aquatic insects relative to the remaining community. The percentage contribution of the dominant family of aquatic insects indicates the present state of the community balance at the family level (Plafkin *et al.*, 1989). The percentage dominance (% DF) of the aquatic insects = abundance of the numerically dominant family relative to the total number of organisms in the sample.

5.2.2 Biotic Indices

5.2.2.1 Modified Family Biotic Index (FBI)

The tolerance values ranged from 0 (very intolerant) to 10 (highly tolerant) for families of aquatic insects and increase as water quality decreases. The family biotic index (FBI) was originally developed by (Hilsenhoff, 1982) to summarise the various tolerances of the benthic arthropod community with a single value. Although the FBI may be applicable for toxic pollutants, it has only been evaluated for organic pollutants. The formula for calculating the Family Biotic Index is:

$$FBI = \sum \frac{x_i t_i}{n}$$

where, x_i = number of individuals within a taxon, t_i = tolerance value of a taxon and n = total number of organisms in the sample (100).

5.2.2.2 Biological Monitoring Working Party (BMWP)

The Biological Monitoring Working Party score (BMWP) provides single values, at the family level, and is representative of the tolerance of the aquatic insects to pollution (Mandaville, 2002; Nasirian, 2014). In this study, the BMWP was used to calculate the biotic indices for the aquatic insect community. Each family is assigned a score between 1 and 10 (where 1 is extremely tolerant and 10 extremely sensitive).

5.2.2.3 Average Score Per Taxon (ASPT)

The Average Score Per Taxon (ASPT) is based on measures of the relative abundance of various taxa of aquatic insects present or available at a site and the associated tolerance value of these taxa combined in order to produce a numerical score (Canfield, 1998). The ASPT represents the average tolerance score of all taxa within the community and it is calculated by dividing the BMWP by the number of families represented in the sample. The formula for calculating the ASPT is:

$$\text{ASPT} = \text{BMWP} / N$$

Where N is the total number of families used in the calculation of BMWP score.

5.2.2.4 Biological Monitoring Working Party of Thailand (BMWP^{THAI}) and Average Score Per Taxon of Thailand (ASPT^{THAI})

The modified BMWP and ASPT scores from Thailand were initiated in 2002 due to the absence of taxa in the standard BMWP, while several other taxa that present might be a good prospect as useful indicators (Mustow, 2002). Therefore, the standard BMWP and ASPT

have been compared with $BMWP^{THAI}$ and $ASPT^{THAI}$ to see the potential of applying the modified scores.

5.3 Results

5.3.1 EPT Index and Percentage of EPT (%EPT)

The percentage of EPT (%EPT) made up 83.61% (Table 5.2) of the overall aquatic insects found in the Serin Stream and recorded as the highest percentage of EPT recorded compared to other streams which included 10 families and 15 species of EPTs (Figure 5.2). While the Sabong Stream comprises of 53.27% of EPT with 10 families and 14 species (Figure 5.2). A total of 70.61% of EPT (Table 5.2) were found in the Bak Muan Sadir Stream with six families and 10 species from the order Ephemeroptera and Plecoptera. The number of EPT families recorded in the Bak Muan Sadir Stream was far lesser compared to other streams. The Duyoh Stream recorded 12 families and 18 species (Figure 5.2) of aquatic insects from the order EPT and recorded the highest number of families and species compared to other streams. In the order Ephemeroptera, the family Leptophlebiidae and Heptageniidae were presented with the greatest number of species with 3 species compared to other families in the Duyoh Stream, while Heptageniidae had the highest number of species in the Cina Stream and Serin Stream whereas the family Leptophlebiidae had the highest number of species richness in Bak Muan Sadir Stream. However, in the Sabong Stream the family Baetidae, Heptageniidae and Philopotamidae had the same number of species (2) which had the highest number of species compared to other families in recorded in the Sabong Stream.

The order Plecoptera however only comprised by the family Perlidae and Perlodidae where the family Perlidae was found in all the streams in this study except the Serin Stream where only the family Perlodidae was recorded. The most frequent taxon found in the streams in the study was of the order Trichoptera and specifically *Doloclanes* sp. where this taxon was found in every stream of this study except the Bak Muan Sadir Stream. There was no presence of the order Trichoptera recorded in the Bak Muan Sadir Stream. Overall, the percentage of EPT in the five streams in this study was more than 50%, whereby the streams are considered to have good quality of water and relatively lower level of pollution (Table 5.2). Based on the EPT index, the water quality in the Sabong Stream, Duyoh Stream, Cina Stream and Serin Stream were considered having good-fair quality of stream water as the EPT species richness in these streams are within 14-20 species (Table 5.1). Whereas, the water quality in the Bak Muan Sadir Stream was considered having fair water quality based on the number of EPT species identified at the streams.

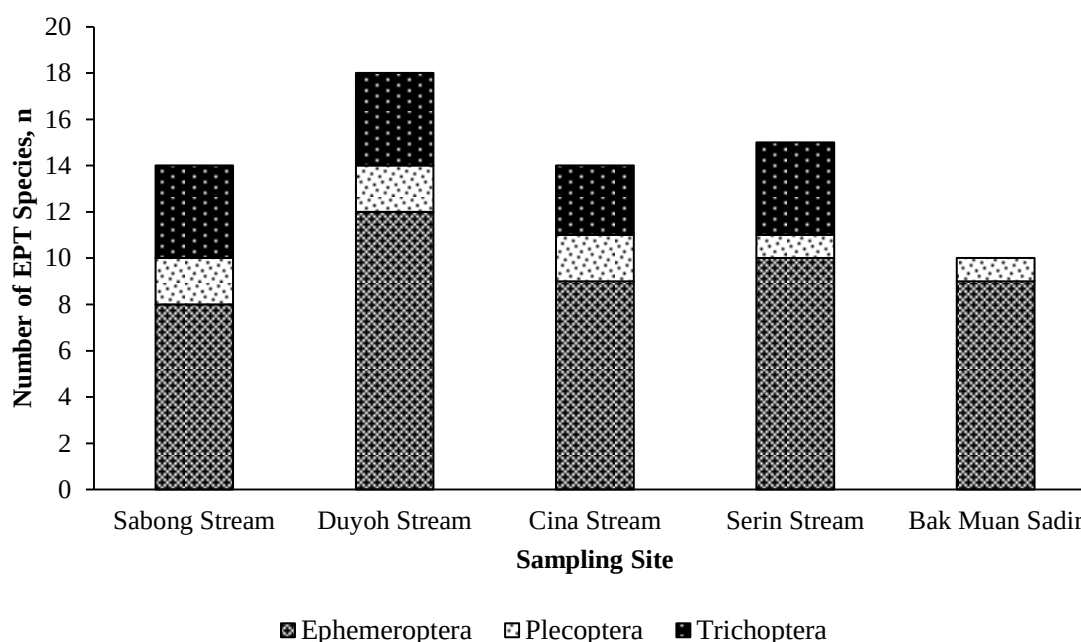


Figure 5.1: Number of Ephemeroptera, Plecoptera and Trichoptera (EPT) species from the study locations.

Table 5.1: Example of EPT index ranges and their corresponding water quality ratings, (Barbour *et al.*, 1999).

Rating	Excellent	Good	Good - fair	Fair	Poor
EPT	> 27	21 - 27	14 - 20	7 - 13	0 - 6

Table 5.2: Water quality ratings based on EPT species richness and percentage of EPTs.

Location	EPT Species Richness	Water Quality Ratings	% EPT	Water Quality Ratings
Sabong Stream	14	Good-fair	53.27	Good
Duyoh Stream	18	Good-fair	65.02	Good
Cina Stream	14	Good-fair	65.47	Good
Serin Stream	15	Good-fair	83.61	Good
Bak Muan Sadir Stream	10	Fair	60.61	Good

5.3.2 Ratio of EPT and Chironomidae (EPT/C)

The abundance of Ephemeroptera, Plecoptera and Trichoptera and Chironomidae (EPT/C) indicates the balance of the community of aquatic insects in the streams. The EPT/C index showed high ratio in every stream (Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream) where the number of Chironomidae was lower than the EPT present in every stream (Table 5.3). The ratio of the EPT/C in the Serin Stream was higher compared to other streams where 1025 individuals from EPT were present in the Serin Stream while only 7 individuals of Chironomids were found in the stream (Figure 5.2). Every stream showed higher species richness in the number of the total communities of insects, thus indicating that the streams are considered to have good quality of water and relatively lower level of pollution.

Table 5.3: Ratio of Ephemeroptera, Plecoptera and Trichoptera (EPT) and Chironomidae according to sampling locations.

Location	EPT/C Ratio	Water Quality
Sabong Stream	5.79	Good
Duyoh Stream	3.25	Good
Cina Stream	7.39	Good
Serin Stream	146.43	Good
Bak Muan Sadir Stream	6.25	Good

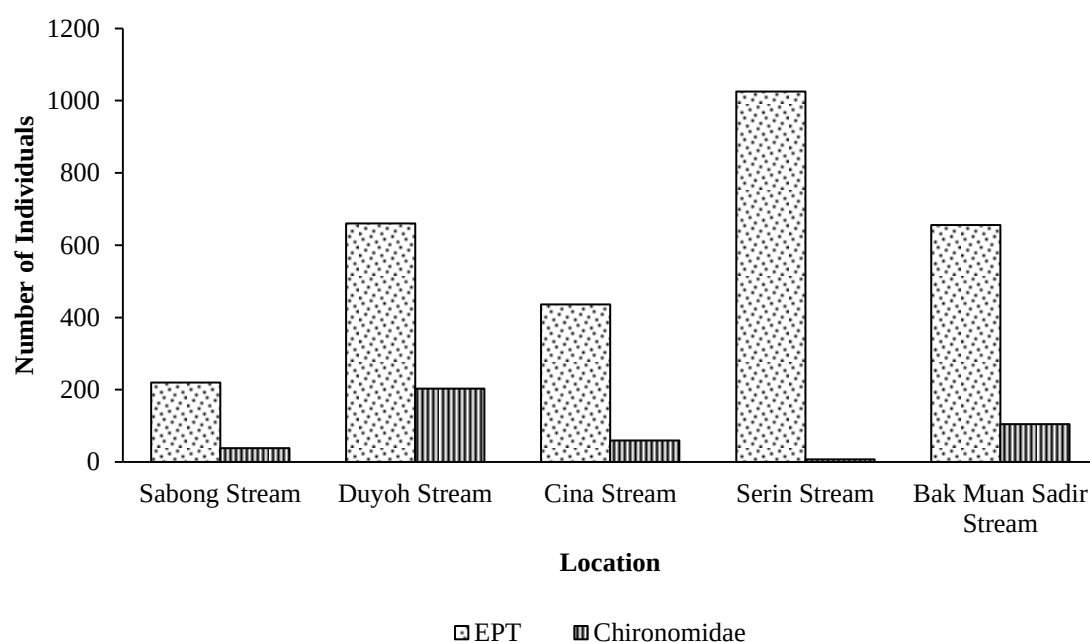


Figure 5.2: Number of individuals in order Ephemeroptera, Plecoptera, Trichoptera (EPT) and Chironomidae.

5.3.3 Percentage Contribution of Dominant Family (% DF)

The percentage of Dominant Family (%DF) equals the abundance of the numerically dominant family in the streams. The family Baetidae is the dominant family in all the streams. The Sabong Stream had the highest percentage of the dominant family whereas low percentage of the family was present during all the sampling days in the Duyoh Stream and Bak Muan Sadir Stream. The water quality in the Sabong Stream, Duyoh Stream and Bak

Muan Sadir Stream can thus be considered as unimpaired as the percentage of the dominant family is less than 40%. Whereas, the water quality in the Cina Stream and Serin Stream is considered to be impaired as the percentage of the dominant family is more than 45% (Table 5.4).

Table 5.4: Percentage of dominant family and water quality conditions in every stream.

Location	Family	% Dominant Family	Water Quality
Sabong Stream	Baetidae	37.38	unimpaired
Duyoh Stream	Baetidae	30.44	unimpaired
Cina Stream	Baetidae	47.15	impaired
Serin Stream	Baetidae	46.17	impaired
Bak Muan Sadir Stream	Baetidae	37.78	unimpaired

5.3.4 Family Biotic Index (FBI)

There was a variation in the water quality and level of pollution among the different streams based on the Family Biotic Index (FBI). Table of family – level pollution tolerance scores used in FBI shown in Appendix (Table 1). The water quality in the Duyoh Stream and Serin Stream were found to be very good quality which indicates possible slight organic pollution only where the FBI range was within 3.76 – 4.35 (Table 5.5). Besides that, the FBI within the range of 4.26 – 5.00 was recorded in the Sabong Stream, Cina Stream and Bak Muan Sadir Stream. The water quality in these three streams can be considered to be of good quality indicating some organic pollution has occurred in the stream (Table 5.6).

Table 5.5: Evaluation of water quality using the family-level biotic index (FBI) (Hilsenhoff, 1988).

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00 – 3.75	Excellent	No apparent organic pollution
3.76 – 4.25	Very good	Possible slight organic pollution
4.26 – 5.00	Good	Some organic pollution
5.01 – 5.75	Fair	Fairly significant organic pollution
5.76 – 6.50	Fairly Poor	Significant organic pollution
6.51 – 7.25	Poor	Very significant organic pollution
7.26 – 10.00	Very poor	Severe organic pollution

Table 5.6: Water quality at different streams in Sarawak classified on the basis of Family Biotic Index (FBI).

Location	Family Biotic Index	Water Quality	Degree of organic pollution
Sabong Stream	4.66	Good	Some organic pollution
Duyoh Stream	4.04	Very good	Possible slight organic pollution
Cina Stream	4.29	Good	Some organic pollution
Serin Stream	4.09	Very good	Possible slight organic pollution
Bak Muan Sadir Stream	4.51	Good	Some organic pollution

5.3.5 Biological Monitoring Working Party (BMWP), Average Score Per Taxon (ASPT), $BMWP^{THAI}$ and $ASPT^{THAI}$

The Biological Monitoring Working Party (BMWP) and Biological Monitoring Working Party of Thailand ($BMWP^{THAI}$) scores (Appendix, Table 2) were found to be the highest in Sabong Stream with the value of 102 for both BMWP and $BMWP^{THAI}$, while the lowest BMWP and $BMWP^{THAI}$ scores were found in Bak Muan Sadir Stream with same value for both indices which is 48 (Table 5.7). The Average Per Taxon (ASPT) and $ASPT^{THAI}$ represents the average tolerance score of all species within the community where the ASPT and $ASPT^{THAI}$ scores were higher in every stream of this study where Sabong Stream, Duyoh

Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream are considered to have clean water quality as the ASPT and ASPT^{THAI} values were more than 6 (Table 5.8).

Table 5.7: Evaluation of water quality and organic pollution in the selected sampling locations based on BMWP, BMWP^{THAI}, ASPT and ASPT^{THAI}.

Location	BMWP	BMWP ^{THAI}	ASPT	ASPT ^{THAI}	Water Quality Assessment
Sabong Stream	102	102	7.29	7.29	Clean Water
Duyoh Stream	94	99	7.23	7.07	Clean Water
Cina Stream	79	84	7.18	7.00	Clean Water
Serin Stream	78	83	7.09	6.92	Clean Water
Bak Muan Sadir Stream	48	48	6.86	6.86	Clean Water

Table 5.8: Values of Average Score Per Taxon and the water quality conditions (Mandaville, 2002; Armitage *et al.*, 1983).

ASPT value	Water Quality Assessment
> 6	Clean Water
5 - 6	Doubtful quality
4 – 5	Probable moderate pollution
< 4	Probable severe pollution

5.4 Discussion

The richness of the EPT (Ephemeroptera, Plecoptera and Trichoptera) species indicated that the streams with the higher number of EPTs have good water quality or non-impacted streams. The EPT Index is based on the premise that high quality streams usually have the greatest species richness and hence lowest level of pollution (Selvanayagam, 2016). The members of the EPT are considered very sensitive to environmental stress, and their abundance shows comparatively clean environment (Armitage *et al.*, 1983). In other words, the EPT can be taken as an accurate bioindicators of unpolluted ecosystem. The Sabong Stream, Duyoh Stream, Cina Stream and Serin Stream have good-fair quality of water in the

streams as the EPT species value is within the range of 14 – 20. The EPT index increases with improving water quality thus; there should be a greater number of EPT insect species in cleaner and less polluted water.

Between the five streams, the Duyoh Stream had the most diverse EPT assemblages where 18 species were recorded in the stream. Therefore, it was presumed that the Duyoh Stream was unpolluted and provided suitable habitats for EPTs. In this study, the diversity of EPTs in all streams was calculated based on the number of EPT genera recorded in each river at a coarse taxonomic resolution. Higher number of taxa (species) collected from a habitat implies a richer community that usually lives in a healthier environment. However, a high preference of certain species was observed, such as dominance of the mayfly *Baetis* sp. in all streams.

Comparing the generic compositions in the five streams, almost all streams shared more common genera, while the Sabong Stream was different from the other rivers. Vegetation around the fast flowing Duyoh Stream was also different when compared with the four other streams, and it had a high abundance of *Baetis* sp. Such differences in the stream's physical habitat and hydrological conditions could contribute to the observed dissimilarities in the EPT compositions. On the other hand, only 10 species were recorded in Bak Muan Sadir Stream and the stream was considered having fair water quality. This may due to moderate flowing water in the stream and it may also due to substrate at bottom of the stream which have sand and gravel particles. Aquatic insects prefer to live in larger substrate streams rather than smaller substrate streams.

The members of EPT are considered to be sensitive to environmental stress, thus their presence in high abundance at the upstream signified a relatively clean environment (Armitage *et al.*, 1983; Wahizatul *et al.*, 2011). The greater the pollution, the lower the species richness expected, as only a few species are pollutant tolerant. The study by Wahizatul *et al.* (2011) also found that the EPT species were abundant in upstream of both Sungai Bubu and Sungai Peres which indicates that a better water quality was recorded in the upstream. The high EPT species showed that the stream has well-oxygenated and clean water quality as the EPT species is very sensitive to pollution (Azrina *et al.*, 2006; Mohmad Fikri *et al.*, 2015).

Based on the results of this study, all the streams (Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream) have shown to have good quality of water based on the percentage of EPT recorded in every stream. This result is consistent with the studies done by Wahizatul *et al.* (2011) where the EPT were abundant in both streams in their study. Several factors such as substrate and food availability may influence the occurrence and diversity of the EPT (Crisci-Bispo *et al.*, 2007; Milesi *et al.*, 2008; Hepp and Santos, 2009; Hepp *et al.*, 2013). In this regard, the lowest EPT species richness was found at the Bak Muan Sadir Stream with only 10 species. Thus, the result may indicate that a fair water quality was recorded in the Bak Muan Sadir Stream compared to other streams. A study by Kubendran and Ramesh (2016) has stated that anthropogenic or human activities might influence the water quality and composition of aquatic insects in the River Puyo, Puyo, Pastaza, and Ecuador (Selvanayagam, 2016). A slight change in water characteristics can thus affect the composition of these insects (Hepp *et al.*, 2013). When using the EPTs, and other aquatic insects to evaluate water quality, it should be remembered that rapid bio-assessment indices only measure the relative health of the water from the relative abundance of species and diversity of the community (Vinson and Hawkins, 1996; Hazelton, 2003). Compared to

the study by Kubendran and Ramesh (2016), where in the present study only one family (Perlidae) of stoneflies (Plecoptera) was recorded. This suggests that stoneflies require very high amount of oxygen and are very sensitive to organic pollution (Basnet, 2013). The greater the pollution, the lower the richness of the species richness expected, as only a few species are pollutant tolerant.

The ratio of Ephemeroptera, Plecoptera and Trichoptera (EPT) and Chironomids is calculated by dividing the number of EPT and Chironomids recorded by the total abundance of aquatic insects in each study station (Arimoro and Ikomi, 2009; Edegbene *et al.*, 2015). The ratio of EPT abundance to Chironomidae abundance has been used as an indicator of the quality of water in streams (Resh and Grodhaus, 1983; Bruce, 2002). The ratio of EPT/Chironomidae in every stream is considered higher as the EPTs are more abundant than Chironomids. The EPT/Chironomidae is one of the biometrics that characterises the community of aquatic insects, representing the proportion between sensitive and tolerant species and providing consistent information with respect to the fauna and stream conditions. Species in the Chironomidae family are generally more tolerant to degraded water quality than Ephemeroptera, Plecoptera, and Trichoptera (EPT) species (Rosenberg and Resh, 1993). This EPT/Chironomidae metric is efficiently corroborated in the observation of studies (Couceiro *et al.*, 2010; Couceiro *et al.*, 2012; Selvanayagam, 2016). A stressed environment generally shows an imbalance between EPT and Chironomidae, with a greater proportion of Chironomids. A community therefore considered to be in good biotic condition and display an even composition among these four groups, while communities with disproportionately high numbers of Chironomidae may indicate environmental stress (Plafkin *et al.*, 1989; Mandaville, 2002).

In this study, the Sabong Stream, Duyoh Stream, and Bak Muan Sadir Stream having the percentage of dominant family with percentage less than 40.0%, which is considered of unimpaired water quality and lower level of pollution in these three streams. While the Cina Stream and Serin Stream are considered to be impaired streams with higher level of pollution as the dominant family in both of these streams have percentage of more than 45.0%. In every stream in this study, the family Baetidae represented the dominant family that was present. The presence of a higher genus richness, especially intolerant organisms (Ephemeroptera, Plecoptera and Trichoptera) in places with poor water quality may be an indication that the water quality in this study might not being a limiting factor for the occurrence of organisms as also stated by Barbour *et al.* (1999). A community dominated by relatively few families would have a high %DF value, thus indicating that the community is under the influence of environmental stress and experiencing higher level of pollution (Plafkin *et al.*, 1989; Mandaville, 2002; Nasirian, 2014). This value increases with increasing perturbation where scores more than 45 is considered impaired, 40 - 45 possibly impaired and less than 40 is unimpaired (Barbour *et al.*, 1999; Sripongpun, 2003).

The Duyoh Stream and Serin Stream had very good water quality with FBI (Family Biotic Index) scores of 4.04 and 4.09 respectively, which indicate possible slight organic pollution might have occurred in the streams. Whereas, the Sabong Stream, Cina Stream and Bak Muan Sadir Stream had good quality of water with scores 4.29 – 4.66, which indicates some organic pollution may happened in the streams. As a comparison with studies in Malaysia, Wahizatul and Geok (2016) have found that both Sg. Cacing and Sg. Perpek streams in their studies had excellent water quality based on FBI with the scores of 3.09 and 3.55 respectively. This index indicates that no organic compound pollution was detected in both streams (Armitage *et al.*, 1983) while FBI values in Sungai Peres and Sungai Bubu were

3.67 and 4.08, indicating that the water quality of both streams was excellent (Wahizatul *et al.*, 2011). High FBI values are associated with adverse impacts of organic pollution while low FBI value indicates that the macro invertebrate community is not impacted with organic pollution (Abhijna *et al.*, 2013). Based on these considerations, this study indicates that disturbance arising from anthropogenic activities might have happened in all the five streams as there is no excellent water quality found in any of them.

Studies show that pollution intolerant families have high BMWP scores, while pollution tolerant families have low scores while the Average Score Per Taxon (ASPT) represents the average tolerance score of all species within the community (Barman and Gupta, 2015). The BMWP and ASPT values for all the streams in this study namely, the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream indicates that the water quality was in the clean category with probably no pollution having occurred. Both the $BMWP^{THAI}$ and $ASPT^{THAI}$ have indicated similar results.

Previous studies carried out in Malaysia show that both the standard BMWP and ASPT and modified $BMWP^{THAI}$ and $ASPT^{THAI}$ scores indicate that the Lower Kinabatangan River Catchment as having moderate water quality during all the seasons which are inter-monsoonal, wet and dry seasons (Harun *et al.* 2015). Whereas, the upstream of the Semenyih River, Selangor was categorised as clean based on BMWP scores while the downstream was found to be polluted (Yap *et al.*, 2003). The final score is obtained by summing the values of all components of each sample and determining the water quality (Mandaville, 2002; Selvanayagam, 2016). The lower performance could be due to rains and faunal community at the time of sampling appears to be largely washed away and also could be due to change in

quality condition of the water at the site which receives domestic and industrial wastes waters (Suleiman and Abdullahi, 2011).

5.5 Conclusion

The use of biotic indices in biomonitoring to evaluate the quality of water in freshwater is a helpful tool for evaluating the health of rivers and streams. Correspondingly, it is a useful indicator of the level of pollution of the freshwater system. Generally, the water quality of every stream in this study (Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream) can be considered as clean based on the values of biological indices and metrics used. The percentage of Ephemeroptera, Plecoptera and Trichoptera (EPT) with the range of 53.27% to 83.61% and ratio of EPT to Chironomidae was higher in every stream (3.25 – 146.43), which shows no impact of anthropogenic activities on the water quality and composition of the stream. The EPT species richness shows every stream as having good-fair water quality except the Bak Muan Sadir Stream which has fair quality of water with 10 EPT species present in the stream. Moreover, the percentage of the dominant family shows that the Sabong Stream (37.78%), Duyoh Stream (30.44%) and Bak Muan Sadir Stream (37.78%) have unimpaired water quality while the Cina Stream (47.15%) and Serin Stream (46.17%) have impaired water quality due to less of the family present in both streams. The Family Biotic Index shows that the Duyoh Stream (4.04) and Serin Stream (4.09) have very good quality of water while the Sabong Stream (4.66), Cina Stream (4.29) and Bak Muan Sadir Stream (4.51) have good quality. Whereas the biotic indices (BMWP, ASPT, $BMWP^{THAI}$ and $ASPT^{THAI}$) indicate that the water quality of each streams in this study as clean and experiencing low level of pollution.

In conclusion, the composition of the community of aquatic insects in this study provides useful bioindicators of the quality and health of the five streams. They also indicate that in general the level of pollution due to anthropogenic activities in the streams in the study is relatively low. It is hoped that the results of the study and the biomonitoring methods used may be of possible use to monitor the health and level of pollution in other streams and rivers in Malaysia especially in Sarawak.

CHAPTER 6

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

6.1 Conclusion

The study aimed to document the diversity and abundance of aquatic insects in the drift and benthic aquatic insects during sunrise and sunset besides examine the relationship between the composition of drift and benthic aquatic insects of five streams in Sarawak with the physicochemical parameters in the stream and the level of pollution and water quality in the streams. The five streams that were identified for the study were the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream.

A total of 462.3 individuals of aquatic insects per 100m³ of volume filtered which belonged to 38 taxa, 25 families and 7 orders of aquatic insects were recorded in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. In general, the composition of these aquatic insects suggested that there is a wide diversity of aquatic insects in these five streams in Sarawak in comparison to Rajang River. The *Baetis* sp. from the family Baetidae was the common taxa which dominated the drift in the Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream, while the drift in Sabong Stream was dominated by *Simulium* sp. The richness of the EPT (Ephemeroptera, Plecoptera and Trichoptera) species indicated that the streams in this study have higher number of EPTs and considered having good water quality or non-impacted streams. The Duyoh Stream had the most diverse EPT assemblages where 18 species were recorded in the stream. Therefore, it

was presumed that the Duyoh Stream was unpolluted and provided a high abundance of suitable habitats for EPTs.

The presence of dissolved oxygen was not significantly different between the samplings in Sabong Stream, Duyoh Stream and Bak Muan Sadir Stream, while the total suspended solid (TSS) was not significantly different in Sabong Stream, Duyoh Stream and Serin Stream. Moreover, the water temperature was not significantly different between the samplings in the Duyoh Stream and Bak Muan Sadir Stream. In addition the pH was not significantly different in the Cina Stream and Bak Muan Sadir Stream, while turbidity and water depth showed no significant difference in the Bak Muan Sadir Stream.

The community structure of the aquatic insects in the drift in the Sabong Stream was significantly influenced by pH and dissolved oxygen. On the other hand, the drift of aquatic insects in the Cina Stream was significantly influenced by temperature and water discharge. The aquatic insect density in the Serin Stream was influenced by pH, temperature, turbidity and water current. Whereas, the drift in Bak Muan Sadir Stream was affected by water discharge and total suspended solid (TSS).

The important parameters that determined the Shannon diversity index (H) of the aquatic insects in the Sabong Stream was dissolved oxygen, while the H of aquatic insects in the Serin Stream was affected by the turbidity of the stream, the H of the aquatic insects in the Cina Stream affected by water temperature, and the H of the aquatic insects in the Bak Muan Sadir Stream was influenced by water discharge. In addition, the Simpson's reciprocal index ($1/D$) of the aquatic insects in the Cina Stream can be predicted by water discharge. The Margalef's species richness index (d) of aquatic insects in the Sabong Stream significantly

correlated with pH, while the d of aquatic insects in the Serin Stream was influenced by water temperature and water current. The results show that no important parameters influenced the community structure of the aquatic insects in the Duyoh Stream.

On drift density, the results of this study indicate that the drift density of the aquatic insects increased just after sunset in every sampling in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. The peak of the aquatic insect drift in every stream was different, but the increase in drift density just after sunset shows that the aquatic insects choose to drift after evening and during darkness. Irregular patterns of aquatic insects drifting throughout night time were observed in the streams and the drift density of aquatic insects fluctuated just after sunrise in the streams. No significant difference between day drift and night drift at the streams was observed except in the Serin Stream.

The drifting of the *Baetis* sp., which is the common taxa in the drift in almost every stream reduced just after sunrise and was encountered in greatest numbers in late evening until early morning hours in all the streams. The *Baetis* sp. also showed nocturnal peak throughout the samplings in every stream and at the same time the number of *Baetis* sp. increased just after sunset which shows a minor peak in every stream. There was no significant difference between day drift and night drift of *Baetis* sp. in all the streams.

In terms of diversity of the aquatic insects, the results of the study shows that a total of 36 taxa belonging to 19 families and five orders of aquatic insects were recorded during sunrise while 30 taxa, 18 families and five orders of aquatic insects were recorded in the five streams during sunset. The order Ephemeroptera was most diverse in terms of number of individuals followed by Dipterans and Trichopterans, while other orders of aquatic insects

were less abundant in the streams. Further, the order Ephemeroptera was the highest in number of families recorded during sunrise while during sunset the order Ephemeroptera and Diptera were recorded as the highest number of families.

Moreover, there were no significant differences in the diversity and richness of the aquatic insects between the sunrise samples and sunset samples in the Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream. The highest Shannon index of diversity and Margalef's species richness were recorded in the Duyoh Stream while the lowest was recorded in the Sabong Stream.

Another result of the study indicates that the aquatic insects present in the Sabong Stream choose high depth and dissolved oxygen while the aquatic insects in the Duyoh Stream were affected by higher temperature. Moreover, the aquatic insects in the Serin Stream were abundant in high water current, water discharge and pH whereas aquatic insects in Cina Stream and Bak Muan Sadir Stream associated with high turbidity level during sunrise. During sunset, the aquatic insects in Sabong Stream and Duyoh Stream were abundant with only high depth, Cina Stream and Bak Muan Sadir Stream were affected by high turbidity and pH level and the Serin Stream was associated with pH, water current and water discharge of the stream.

One very important result of this study is that it reveals that generally, the water quality of every stream in this study (Sabong Stream, Duyoh Stream, Cina Stream, Serin Stream and Bak Muan Sadir Stream) can be considered as clean based on the values of biological indices and metrics used. In this regard, the percentage of Ephemeroptera, Plecoptera and Trichoptera (EPT) with the range of 53.27% to 83.61% and ratio of EPT to

Chironomidae was higher in every stream that was studied. The EPT taxa richness shows every stream as having good-fair water quality except the Bak Muan Sadir Stream which has fair quality of water. Moreover, the percentage of the dominant family shows that the Sabong Stream, Duyoh Stream and Bak Muan Sadir Stream have unimpaired water quality while the Cina Stream and Serin Stream have impaired water quality due to less of the family being present in both streams. Further, the Family Biotic Index shows that the Duyoh Stream and Serin Stream have very good quality of water while the Sabong Stream, Cina Stream and Bak Muan Sadir Stream have good quality. The biotic indices (BMWP, ASPT, $BMWP^{THAI}$ and $ASPT^{THAI}$) indicate that the water quality of each stream in this study is clean and experiences low level of pollution.

Therefore, it can be concluded that overall the level of pollution due to anthropogenic or human activities in the five streams in the study is relatively low and correspondingly, the water quality is good.

6.2 Limitations

Although the research has met its objectives of using aquatic insects as bioindicators to indicate the level of pollution and water quality of the streams, there are a few limitations to the study. First, it was challenging to identify the aquatic insects due to lack of previous studies on aquatic insects in Malaysia. Second, lack of accurate weather forecast data in the areas where the streams were located resulted in many inaccurate samplings take when there was an increase in the water level of the streams. No data on rainfall was acquired for this study although it was raining during the period when the samplings were taken. On the other hand, it was difficult to carry out chemical oxygen demand on the samplings due to lack of

suitable chemicals and tools. Light intensity of sunlight during samples collected at sunrise and sunset could not be measured as there were no tools and suitable chemicals to carry out water quality index analysis.

Nonetheless, these limitations did not seriously affect the accuracy of the final results and analysis of the study.

6.3 Recommendations

It is hoped that this study has yielded useful information on the presence and distribution of aquatic insects. At the same time, this study would also like to offer some recommendations for future research. In studies on the role of aquatic insects as useful bioindicators of water quality of freshwater systems, a wider coverage and continuous monitoring of the assemblages of aquatic insects in relation to health of the stream are crucial to improve the accuracy of data and document the appropriate dataset. Based on the experience of this study, a few recommendations are proposed that could help improve the accuracy of the data gathered. These are as follows:

- (i) More sampling stations could be included in sampling areas with various substrate and habitat characteristics and addition of water quality parameters such as heavy metal;
- (ii) Water quality index (WQI) could be carried out to classify the water quality in the streams;
- (iii) Comparison could be made on the efficiency of different sampling tools for aquatic insects sampling.

As stated earlier, there is very little study on the use of aquatic insects as bioindicators of the level of pollution and water quality of freshwater systems in Sarawak. This study represents a small contribution to the subject. It is hoped that the results of the study will encourage more studies of this type to be carried out on other streams as well as rivers in the state so that the results could be used by relevant authorities to minimize any potential adverse effects on the rich and diverse freshwater systems due to anthropogenic activities.

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APPENDIX

Table 1: Family-level pollution tolerance scores for the Hilsenhoff Biotic Index.

Plecoptera	Capniidae 1, Chloroperlidae 1, Leuctridae 0, Nemouridae 2, Perlidae 1, Perlodidae 2, Pteronarcyidae 0, Taeniopterygidae 2
Ephemeroptera	Baetidae 4, Baetiscidae 3, Caenidae 7, Ephemerellidae 1, Ephemeridae 4, Heptageniidae 4, Leptophlebiidae 2, Metretopodidae 2, Oligoneuriidae 2, Polymitarcyidae 2, Potomanthidae 4, Siphonuridae 7, Tricorythidae 4
Odonata	Aeshnidae 3, Calopterygidae 5, Coenagrionidae 9, Cordulegastridae 3, Corduliidae 5, Gomphidae 1, Lestidae 9, Libellulidae 9, Macromiidae 3
Trichoptera	Brachycentridae 1, Glososomatidae 0, Helicopsychidae 3, Hydropsychidae 4, Hydroptilidae 4, Lepidostomatidae 1, Leptoceridae 4, Limnephilidae 4, Molannidae 6, Odontoceridae 0, Philopotamidae 3, Phryganeidae 4, Polycentropodidae 6, Psychomyiidae 2, Rhyacophilidae 0, Sericostomatidae 3
Megaloptera	Corydalidae 0 , Sialidae 4
Lepidoptera	Pyralidae 5
Coleoptera	Dryopidae 5, Elmidae 4, Psephenidae 4
Diptera	Athericidae 2, Blephariceridae 0, Ceratopogonidae 6, Blood-red Chironomidae (Chironomini) 8, Other (including pink) Chironomidae 6, Dolochoptodidae 4, Empididae 6, Ephydriidae 6, Psychodidae 10, Simuliidae 6, Muscidae 6, Syrphidae 10, Tabanidae 6, Tipulidae 3
Amphipoda	Gammaridae 4, Talitridae 8
Isopoda	Asellidae 8
Acariformes	4
Decapoda	6
Gastropoda	Amnicola 8 Bithynia 8, Ferrissia 6, Gyraulus 8, Helisoma 6, Lymnaea 6, Physa 8, Sphaeriidae 8
Oligochaeta	Chaetogaster 6, Dero 10, Nais barbata 8, Nais behningi 6, Nais bretscheri 6, Nais communis 8, Nais elinguis 10, Nais pardalis 8, Nais simplex 6, Nais variabilis 10, Pristina 8, Stylaria 8, Tubificidae: Aulodrilus 8, Limnodrilus 10
Hirudinea	Helobdella 10
Turbellaria	4

Table 2: Comparison of scores between BMWP and BMWP^{THAI} for benthic macroinvertebrate taxa.

Taxa	BMWP	BMWP ^{THAI}	Taxa	BMWP	BMWP ^{THAI}
Coleoptera			Odonata		
Chrysomelidae	5	5	Aeshnidae	8	6
Clambidae	5	-	Agriidae	8	6
Curculionidae	5	5	Chlorocyphidae	-	6
Dryopidae	5	5	Coengrionidae	6	6
Dytiscidae	5	5	Coenagriidae	-	6
Elmidae	5	-	Cordulegastridae	8	6
Gyrinidae	5	5	Corduliidae	8	6
Haliplidae	5	5	Gomphidae	8	6
Helodidae	5	5	Lestidae	8	6
Hydrophilidae	5	5	Libellulidae	8	6
Hygrobiidae	5	-	Macromiidae	-	6
Psephenidae	-	5	Platyenemididae	6	6
Diptera			Protoneuridae	-	3
Athericidae	-	-	Plecoptera		
Ceratopogonidae	-	-	Capniidae	10	-
Chaoboridae	-	-	Chloroperlidae	10	-
Chironomidae	2	2	Leuctridae	10	10
Simuliidae	5	5	Nemouridae	7	-
Tipulidae	5	5	Perlidae	10	10
Ephemeroptera			Perlodidae	10	10
Baetidae	4	4	Planaridae	5	-
Caenidae	7	7	Taeniopterygidae	10	-
Ephemerellidae	10	10	Trichoptera	10	
Ephemeridae	10	10	Beraeidae	10	-
Heptageniidae	10	10	Brachycentridae	-	10
Leptophlebiidae	10	10	Calamoceratidae	-	-
Nemouridae	7	7	Dipseudopsidae	-	-
Potamanthidae	10	10	Ecnomidae	10	-
Siphonuridae	10	4	Goeridae	-	10
Hemiptera			Helicosychidae	5	-

Table 2 continued

Belostomatidae	-	-	Hydropsychidae	6	5
Corixidae	5	5	Hydroptilidae	10	6
Gerridae	5	5	Lepidostomatidae	10	10
Hydrometridae	5	5	Leptoceridae	10	10
Mesovelidae	5	5	Limnephilidae	10	7
Naucoridae	5	5	Molannidae	10	10
Nepidae	5	5	Odontoceridae	10	10
Notonectidae	5	5	Philopotamidae	8	8
Pleidae	5	5	Phryganeidae	10	10
Megaloptera			Polycentropodidae	7	7
Corydalidae	-	4	Psychomyiidae	8	8
Neuroptera			Rhyacophilidae	7	7
Sialidae	4	4	Sericostomatidae	10	-
Lepidoptera					
Pyralidae	-	-			

Notes: "-" indicates "unknown"

Table 3: National Water Quality Standards for Malaysia.

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity*	µS/cm	1000	1000	-	-	6000	-
Floatables	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	%	0.5	1	-	-	2	-

Table 3 continued

Taste	-	N	N	N	-	-	-
Total Dissolved Solid	mg/l	500	1000	-	-	4000	-
Total Suspended Solid	mg/l	25	50	50	150	300	300
Temperature	°C	-	Normal + 2 °C	-	Normal + 2 °C	-	-
Turbidity	NTU	5	50	50	-	-	-

Table 4: Interim National Water Quality Standard (INWQS) Class Definitions.

Class	Uses
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species
Class IIA Class IIB	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species. Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III – Common of economic value and tolerant species; livestock drinking.
Class IV	Irrigation.
Class V	None of the above.