IMPACT OF HUMAN ACTIVITIES – RIVER INTERACTION ON AQUATIC INSECTS AT SELECTED RECREATIONAL AREAS IN NORTHERN PENINSULAR MALAYSIA

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2017

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by

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Thesis submitted in fulfillment of the requirements

for the degree of

Master of Science

September 2017

ACKNOWLEDGEMENT

First of all, my sincere gratitude to Allah S.W.T. for His blessing allowed me to complete my study.

My utmost thanks and genuine appreciation goes to my supervisor, Dr. Suhaila Ab. Hamid for her continuous guidance, support, encouragement, and patience in providing excellent supervision from the beginning of this research until the end of it.

I was indebted to many people who contributed in this research in many ways. I wish to thanks Prof. Che Salmah, Prof. Abu, Dr. Nurul Huda, Dr. Zul, ‘Amila, and Siti Hamidah for their support, help, and suggestions in this research. Special thanks to laboratory assistants; Pn. Siti Khadijah and En. Hafizul and drivers; En. Sukor, En. Nordin and En. Kalimuthu for their helps during sampling and laboratory studies. I sincerely acknowledge their helps and support.

Finally, my heartiest appreciation and gratitude to my family: my parents, Normi Othman and Noraini Ishak, my husband, Mohd Haidir Mohamed Yunus and my siblings for their continuous support and helps in finishing this study.

Last but not least, thank you to Ministry of Higher Education for sponsoring my study via MyBrain-MyMaster programme.

THANK YOU, ALL.

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LIST OF ABBREVIATIONS AND SYMBOLS

µm	micrometre
AN	Ammoniacal Nitrogen
ASH	After school holiday
ASPT	Average Score per Taxon
BHJ	Bukit Hijau River
BHP	Batu Hampar River
BI	Biotic Index
BMJ	Bukit Mertajam River
BMWP	Biological Monitoring Working Party
BOD	Biochemical oxygen demand
BSH	Before school holiday
CCA	Canonical Correspondence Analysis
COD	Chemical oxygen demand
COL	Catalogue of Life
CPOM	Coarse particulate organic materials
df	degree of freedom
DID	Department of Irrigation and Drainage
DO	Dissolved oxygen
DOE	Department of Environmental
DSH	During school holiday
EE	Environmental Education
EPT	Ephemeroptera, Plecoptera, Trichoptera
EQA	Environmental Quality Act
FBI	Family Biotic Index
FFG	Functional feeding group
FPOM	Fine particulate organic materials
IRBM	Integrated River Basin Management
km	Kilometre
L	Litre
mg	Miligram
ml	Mililitre
MOH	Ministry of Health
MPN	Most Probable Number

MVSP	Multi-Variate Statistical Package
NEP	New Environmental Paradigm
NPE	National Policy on the Environment
NRE	Ministry of Natural Resources and Environment
NWQS	interim National Water Quality Standards
SA	School of Art
SBS	School of Biological Sciences
SC	School of Communication
SCS	School of Chemistry
SDM	Sedim River
SDR	Species Diversity and Richness
SE	Standard error
SE	School of Education
sec	seconds
SH	School of Humanities
SHBP	School of Housing, Building and Planning
SI	Sub Index
SM	School of Mathematics
SMN	School of Management
SOLLAT	School of Language, Literacy and Translation
SPSS	Statistical Package for Social Science
SS	Suspended Solid
SSC	School of Computer Sciences
SSS	School of Social Sciences
STI	School of Technology Industry
TBH	Teluk Bahang River
THY	Titi Hayun River
TSS	Total suspended solid
UN	United Nation
UPGMA	Unweighted Pair Group Method Analysis
WHO	World Health Organization
WQI	Water Quality Index

IMPAK INTERAKSI AKTIVITI MANUSIA – SUNGAI TERHADAP SERANGGA AKUATIK DI KAWASAN REKREASI TERPILIH DI UTARA SEMENANJUNG MALAYSIA

ABSTRAK

Serangga akuatik dan kesedaran orang awam telah dikaji secara intensif untuk memahami interaksi antara manusia dengan sungai dalam mengekalkan ekosistem. Serangga air dipungut bermula Mei 2014 hingga April 2015 dari enam batang sungai rekreasi; Batu Hampar, Titi Hayun, Bukit Hijau, dan Sedim di Kedah, Bukit Mertajam dan Teluk Bahang di Pulau Pinang diwakili oleh 119 genera terdiri daripada 23,072 individu daripada 69 famili dan 9 order. Serangga air yang dikumpul semasa persampelan didominasi oleh order Ephemeroptera, Diptera, dan Trichoptera. Indek ekologi menunjukkan serangga air yang dipungut di Sungai Batu Hampar lebih pelbagai, kaya, dan sekata berbanding sungai-sungai lain. Walaubagaimanapun, indeks biologi seperti 'Family Biotic Index (FBI)', 'Biological Monitoring Working Party (BMWP)', dan 'EPT taxa richness' menandakan kualiti air di Sungai Bukit Hijau adalah sederhana bersih ke sangat bersih. Merujuk kepada Indek Kualiti Air (WQI), kesemua sungai rekreasi pilihan diklasifikasikan dalam kelas II (bersih) kecuali Sungai Batu Hampar yang jatuh ke dalam kelas I (sangat bersih) WQI. Waktu persampelan dibahagikan kepada tiga musim iaitu sebelum musim cuti sekolah, semasa musim cuti sekolah, dan selepas musim cuti sekolah. Kelimpahan serangga air berbeza antara setiap musim. Sebelum musim cuti sekolah, kelimpahan serangga air didominasi oleh order Ephemeroptera, manakala semasa musim cuti sekolah, ia didominasi oleh order Diptera, sementara order Trichoptera mendominasi kelimpahan serangga air selepas musim cuti sekolah. Indek ekologi

seperti indek kepelbagaian dan indek kesekataan menunjukkan serangga air yang dipungut selepas musim cuti sekolah lebih pelbagai dan sekata manakala indek kekayaan menunjukkan serangga air yang dipungut sebelum musim cuti sekolah lebih kaya berbanding musim lain. Kesemua indek biologi menggambarkan kualiti air setiap musim sebagai 'bersih' kecuali FBI yang menggambarkan kualiti air semasa musim cuti sekolah sebagai sederhana. Untuk WQI, kualiti air sebelum musim cuti sekolah diklasifikasi dalam kelas I, manakala semasa musim cuti sekolah dan selepas musim cuti sekolah, kualiti air diklasifikasi dalam kelas II. Setiap parameter menunjukkan pelbagai hubung kait dengan famili-famili serangga air. Kebanyakan serangga air dipengaruhi oleh kelebaran dan kedalaman sungai, begitu juga oksigen terlarut dan suhu air. Seramai 136 orang pengunjung telah melengkapkan borang soal selidik yang diberikan. Responden telah terlebih menilai Sungai Sedim sebagai sungai terbersih tetapi dalam keadaan yang sebenar, Sungai Sedim mencatatkan nilai WQI yang terendah dalam kelas II. Secara menyeluruh, kesedaran responden mengenai serangga air disimpulkan sebagai memuaskan, begitu juga kesedaran 106 orang pelajar. Walaubagaimanapun, pelajar (41.5%) mempunyai kesedaran yang rendah berbanding pengunjung (44.1%) dan antara pengunjung, responden yang mempunyai pendidikan yang tinggi (16.7%) mempunyai sedikit pengetahuan mengenai serangga air. Kajian ini menunjukkan populasi serangga akuatik ini disebabkan oleh perubahan parameter air dan juga musim cuti sekolah kerana aktiviti rekreasi yang dilakukan oleh pengunjung. Kajian ini mendapati kesedaran dan pengetahuan mengenai serangga kauatik ini masih rendah dalam kalangan orang awam mahupun pelajar.

IMPACT OF HUMAN ACTIVITIES – RIVER INTERACTION ON AQUATIC INSECTS AT SELECTED RECREATIONAL AREAS IN NORTHERN PENINSULAR MALAYSIA

ABSTRACT

Aquatic insects and public awareness were studied intensively to understand the interaction between human and river in maintaining the ecosystem. Aquatic insects collected from May 2014 to April 2015 from six recreational rivers; were namely Batu Hampar, Titi Hayun, Bukit Hijau, and Sedim in Kedah, Bukit Mertajam and Teluk Bahang in Pulau Pinang were represented by 119 genera of which 23,072 individuals from 69 families and 9 orders. Aquatic insects collected during sampling was dominated by order Ephemeroptera, Diptera and Trichoptera. Ecological indices showed that aquatic insects collected at Batu Hampar River were more diverse, rich and even compared to other rivers. However, biological indices such as Family Biotic Index (FBI), Biological Monitoring Working Party (BMWP) and EPT taxa richness implied water quality at Bukit Hijau River as moderately good to very good. Referring to Water Quality Index (WQI), all selected recreational rivers were categorized into class II (clean) except for Batu Hampar River which fall into class I (very clean) of WQI. The sampling periods were divided into three seasons which were before school holiday, during school holiday season and after school holiday season. Abundance of aquatic insects were differed significantly among the seasons. Before school holiday, the abundance of aquatic insects dominated by order Ephemeroptera, while during school holiday, it was dominated by order Diptera, whereas order Trichoptera dominated the abundance of aquatic insect after school holiday season. Ecological indices such as diversity and evenness indices indicated that aquatic insects collected after school holiday season were more diverse and even while richness index indicated that aquatic insects collected before school holiday season were more rich in species among seasons. All biological indices described water quality for all seasons as 'clean' except for FBI which described the water quality during school holiday season as moderate. For WQI, water quality before school holiday classified into class I, while during and after school holiday seasons, water quality were classified into class II. Each parameters showed varied correlations with families of aquatic insects. Most of aquatic insects influenced by width and depth of the river as well as dissolved oxygen and water temperature. About 136 of visitors completed the questionnaire given. Respondents over rated Sedim River as the cleanest river while the truth was Sedim River recorded the least value of WQI which classified into class II. Overall, respondents' awareness on aquatic insects conclude as satisfactory, same goes to awareness of 106 students. However, students (41.5%) had lower awareness than visitors (44.1%) and among visitors, respondents with higher education (16.7%) were least known about aquatic insects. This study revealed the aquatic insects population were affected by the changes of water parameter as well as school holiday seasons due to recreational activities conducted by visitors. This study found that awareness and knowledge regarding aquatic insects still sparse among public and students.

CHAPTER 1

INTRODUCTION

1.1 Background

More than 97% of earth's water belong to the seas, about 2% contribute by icecaps and left less than 1% of inland water known as freshwater (Yule, 2004). Malaysia are gifted with diverse freshwater habitats such as rivers, lakes, streams, freshwater swamps and peat swamps.

Karr and Ellen (2000) stated that, people have long relied on rivers for cleaning, recreation, commerce, transportation and as long as humans have inhabited the Earth, rivers have provided them with drink, food and as well as site for settlement. Human has used water for many purposes such as public bathing, recreational purposes and et cetera, but in doing so has overlooked their importance in supporting the freshwater ecosystem (Jill *et al*., 2014).

Application of aquatic insects, especially from orders Ephemeroptera, Plecoptera and Trichoptera (EPT) are proven as excellent tool in water quality indication (Che Salmah *et al*., 2001; 2007). Aquatic insects have beaucoup of advantages as bio-indicator of freshwater (Nurul Huda, 2012). They are ubiquitous, diverse and can be found in all types of freshwater habitats. Certain aquatic insects required a specific habitats as their diversity depends on changes of physical and chemical changes of the habitats itself (Cummins *et al*., 2008). In addition, most aquatic insects are relatively immobile and some of them are bottom dwellers which make them contact directly with water and sediments of freshwater habitats (Dudgeon, 1999).

Hence they act as an excellent biological tool to measure the degree of freshwater pollution.

Aquatic insects are used in monitoring water quality due to its availability in freshwater ecosystem. They are easy to collect and identify as taxa of many groups are well known especially in temperate country. As stated before, aquatic insects are sensible, so they cannot escape pollution, habitat changes and severe natural events make them as the best water quality indicator (Voshell, 2002; Cairns *et al*., 1993). Thus, their relatives abundance has been used to make inferences about pollution status of the freshwater as they are classified into very sensitive, sensitive, tolerant and very tolerant groups (McGeoch, 1998; Cummins *et al*., 2008). To supplement the inferences, chemical analysis of water sample can be conducted.

The use of invertebrates as biological indicator of environment condition has long been recognized and originated from the idea of 'The Saprobien' by Kolkwitz and Marsson (1908,1909) in which measuring the degree of contamination by measuring organic matter and the resulting of decrease in dissolved oxygen (Cairns *et al*., 1993). The observations of relative restriction in occurrence of certain taxa by environment condition were then led to the development of list of indicator organism and it has been extended and revised repeatedly by European scientists such as Kolkwiltz (1950) himself, Liebman (1951, 1962), Fjerdingstand (1965), Sládeček (1965, 1973), Bick (1971) and Foissner (1988).

In Malaysia, most of the studies were to investigate the distribution, abundance, assemblages of aquatic insects and water quality monitoring. Ahmad *et al*. (2002) conducted a study on local benthic macroinvertebrates as a biological monitoring tool for river water quality assessment in Linggi River, Negeri Sembilan. Meanwhile, Azrina *et al*. (2006) studied the anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Selangor. In Temenggor catchment, Perak, Che Salmah *et al*. (2007) focused on the diversity of Ephemeroptera, Plecoptera and Trichoptera in few tributaries. Study on effect of water parameters on Ephemeroptera abundance was conducted by Kamsia *et al*. (2008) in Telipok River, Sabah. Al-Shami *et al*. (2010) conducted a study on morphological deformities of Chironomidae larvae as a tool for impact assessment of anthropogenic and environmental stresses on three rivers in the Juru River system, Penang. The studies were then further to determine the influence of agricultural, industrial, and anthropogenic stresses on the distribution and diversity of macroinvertebrates by Al-Shami *et al*. (2011).

The disturbance of aquatic ecosystems by human is widely known as the key factor explaining the alteration of aquatic insect composition, distribution, biodiversity and loss of their ecological functioning (Dudgeon, 2000; Al-Shami *et al*., 2011; Al-Shami *et al*., 2013, Che Salmah *et al*., 2013). There is a strong relationship between human activities and disturbance of the aquatic habitats (Hodkinson and Jackson, 2005). Recognition of this relation, and the need to protect human health and recreational area, led to the National Policy on the Environment (NPE) on October 2002 which aims at promoting economic, social and cultural progress through environmentally sound and sustainable development (Ministry of Science, Technology and Environment, Malaysia. 2002).

Many study and papers has suggested on the use of aquatic insects as bio-monitoring tools, effect of physico-chemical parameters towards aquatic insects, and influence of anthropogenic stresses. The influence of humans on rivers for recreational purpose, such as community bathing and camping has caused habitat impairment (Dinakaran and Anbalagan, 2007) by changing the habitat structure and chemical characteristics of water. Continuously and high increase of recreational activities in many rivers, may precipitate the degradation of assemblages of EPT (Karr and Dudley, 1981). However, none of the study on aquatic insects in Malaysia have been done at recreational rivers discussing on the effect of human recreational activities towards aquatic insects. Yet, with lots of study has been conducted, Malaysian still lack of knowledge on the existence and importance of aquatic insects. Hence, this study would provide such information regarding human-river interaction especially on the effect of recreational activities towards aquatic insects as well determining the level of public awareness on existence and importance of aquatic insects.

1.2 Objectives

The objectives of this study are:

i. To determine the aquatic insects (Ephemeroptera, Plecoptera, and Trichoptera) communities and water quality at selected recreational rivers.

ii. To investigate the effect of human recreational activities to the assemblages of aquatic insects and water quality of the recreational rivers.

iii. To study visitors and students awareness level on aquatic insect and river's health.

CHAPTER 2

LITERATURE REVIEW

2.1 River: Meeting societal and ecological needs

One major,

overwhelming reason why we are running out of water

is that we are killing the water we have.

WILLIAM ASHWORTH, Nor Any Drop to Drink, 1982

River is vital to human life and societal well-being. People have long relied on rivers for their sites settlement, cleaning and waste removal, as well as commerce and transportation, not to mention, recreation (Karr and Ellen, 2000). Thus its utilization for the listed purposes has long taken precedence over the commodities and services provided by the freshwater ecosystems (Jill *et al*., 2002; Karr and Ellen, 2000). As long as human have inhabited the Earth, rivers keep being their vital needs.

Nowadays, river is basically used for source of clean water, flood control, irrigation, and water reservoir as well as recreational purposes such as sport fishing, swimming and many more to be listed. From Ahmad Ainuddin and Ali Muhammad, (2013) rivers has an important relationship with humanity as a recreational resource with many types of recreation activities such as swimming to kayaking. Rivers and its surrounding provide several valuable natural and aesthetic sites for cultural, historical (May, 2006) and physical attributes for the purpose of recreational users. From the

Malaysia Well- Being Report (2013), the recreational park visitors index increased by 38.1 points from year 2000 to 2012 showed that outdoor activities have become popular among Malaysian.

However, with the used of river as recreational sites have exposed human to few health conditions caused by Coliform bacteria. Coliform bacteria can be pathogenic for humans and animals when present either in the gut (enteropathogenic *E. coli*) or in other parts of the body (*Klebsiella* pneumonia in the respiratory tract). The presence of *E. coli* in water demonstrates the possibility that pathogens are present (Lisa, 2006). Total coliforms is a group of bacteria that naturally found on plants and in soils, water, and in the intestines of humans and warm-blooded animals (Health Canada, 2012). Total coliform are sometimes also found in soil (*Citrobacter*, *Enterobacter* and *Kleibsiella*) on various plants, including grains and trees (*Klebsiella* and *Enterobacter*) and in certain industrial wastes. Besides, river recreational users are also exposed to pathogenic *Leptospires* which may lead to fatal by ingesting contaminated water or transmitted through cut or wound on human body (Vikneswaran *et al.*, 2011).

River also habitats for thousands of freshwater organisms such as fish, snails, and aquatic insects, and some of them rely on very clean freshwater to survive. Aquatic organisms are essentials in balancing the freshwater ecosystems which allowed us to fully utilize the freshwater. However, the used of river by human society for agricultural, industrial activities, and recreational purposes has overlooked its value in supporting other organisms including its own ecosystem (Jill *et al*., 2002). From Malaysia Environment Quality Report (2014), it was reported that overall statistics of clean rivers kept decreasing from 64% of total rivers monitored in 2007 to only 52% of monitored rivers which were considered as clean and the number of polluted river kept increased from 36% in 2007 to 48% in 2014.

In order to ensure the river from deterioration, government has taken few actions including nurturing river awareness among public. Awareness program conducted by Malaysian government including "River Adoption" "Love Our Rivers" were launched in 1993 by Department of Irrigation and Drainage (DID), followed by "River Expedition", "River Beautification" and "River Watch" (Love Our River Campaign, 2013). In 2005, "Satu Negeri, Satu Sungai" (1N1S) program was launched by Ministry of Natural Resources and Environment (NRE) under the system of Integrated River Basin Management (IRBM) which currently managed by DID, Malaysia (Hasil Inisiatif, 2013).

The seriousness of government in counteract the unexpected increase of deterioration of water quality was proven by establishment of related laws and regulations such as Environmental Quality Act (EQA) in 1974 and development of National Policy on the environment which aims in promoting Environmentally sustainable of economic, social and cultural (Rozita Ibrahim, 2004). Besides, government have taken serious on the matter of environment by implementing Environmental Education (EE) in educational systems in Malaysia from primary school to tertiary level (Kamidin, *et al.,* 2011; Arbaat *et al.,* 2011). Arbaat *et al.* (2011) suggested that EE is considered essential education to ensure students are provides with knowledge on environment and nurturing awareness as well as develop positive vibes of attitude towards environment.

Despite of many awareness program conducted, human are still lacking in awareness when it comes to the environmental problem (Noor Mohammad, 2011). Niklas and Tommy (1999) suggested people are likely to care about environment when it cause any harm to them and the statement was supported by Stern (1992), that suggested four different value of environmental concern; i) represents a new way of thinking called the New Environmental Paradigm (NEP), ii) people care about environmental quality mainly because deterioration of environmental quality poses threat to human being, iii) environmental concern express self-interest, and iv) environmental concern is a function of some deeper cause such as religious beliefs. It conclude that human are more concern on environment when it comes to their own benefits instead of the harm to the environment itself.

2.2 River as recreational sites

It was reported that the recreational parks; included river, cave and national parks visitors increased by four times from 137 000 visitors in 2000 to 640 000 visitors in 2012 (Malaysian Well-being Report, 2013). It shows that, Malaysian has increased their awareness on adopting healthy lifestyle such as doing outdoor activities. In general, outdoor activities promote healthy lifestyle and well-being as well as strengthen family relationship (Malaysian Well-being Report, 2013). However, to cope with the increasing demand for recreation purposes, government or recreational river management must provide adequate and high quality of infrastructure (Norlida Hanim, 1999) without neglecting the nature.

Recreational river also part of eco-tourism site which has several impacts and it can be both positive force by bringing benefits to destination such as revenues or negative as a degraded machine to the nature itself (Klara, 2011). Water rafting, river exploration, kayaking and leisure are part of major fun and excitement activities that can be done at recreational rivers (Mohamad Hafizudin and Arham Muchtar, 2013). Besides, recreational rivers are also a potential major contributor to local economies through the employment on recreational rivers management or administration, recreational facilities maintainers, and also by selling craft products and food and beverages on site.

The terms “sustainable ecotourism” should imply sustainability in all forms such as the conservation of nature, cultural, and economic aspects and as well as social considerations (Klara, 2011). Ecotourism should engage with the merging of environmental conservation with development (Mohd Rusli *et al.*, 2011). However, this term does not always translate into practical or real life. Over-used or over-utilised of nature especially in freshwater ecosystem to meet societal needs had caused degradation of water quality, flora and fauna of the aquatic ecosystems (Jill *et al.*, 2002). Continuous utilization of rivers without proper management may cause such catastrophe to human beings, for example flood and outbreak of water-borne disease. Hence, such conflict between human’s society needs and nature had occurred over past decades ago (Kirkpatrick, 2001).

2.3 Aquatic insects

Aquatic insects is defined as a member of class insecta that has been adapted to live in water (Borror *et al*., 1981). An outstanding 95% of over a million species of the world are invertebrates. Aquatic insects are classified under invertebrates, have lived on earth for about 350million years ago, and compared to less than 2 million years of human (Triplehorn and Johnson, 2005). Current estimates place over 44,000 of the world's over two million scientifically described species as coming from freshwater ecosystems (Reaka-Kudla, 1997). Over 30 orders of insects, about 13 orders are aquatic insects (Merritt *et al.* 2008).

Like other terrestrial insects, aquatic insects have three major parts to their anatomy, which are head, thorax and abdomen (Voshell, 2009). The head part consists of antennae, eyes and mouthparts. Thorax comprise of three segments with a pair of legs for each segment. The abdominal section of most aquatic insects are equipped with gills.

Aquatic insects inhabit all types of freshwater such as lakes, flowing rivers and stagnant water. The main physiological difference between aquatic and terrestrial insects is the adaptation of their respiration systems (Yoshimura, 2012). Some of aquatic insects breathe through their abdominal gills such as Ephemeroptera, Plecoptera, and Trichoptera, and some of aquatic insects developed small siphon or snorkel tube that extends to the surface of water to gets oxygen, for example Hemiptera and some Diptera (Abowei and Ukorojie, 2012).

2.4 The importance of aquatic insects

The ecology of aquatic insects has been studied intensively from many perspectives, reflecting their diversity, abundance, and important role in the aquatic ecosystems (Hershey *et al.,* 2010). Aquatic insects plays important role as they are essential in completing food webs in freshwater due to their variety of functional feeding group (FFG). Aquatic insects can be categorized into five functional feeding groups: i) shredders that feed on coarse leaf materials, ii) gatherers or detritivorous which gathers fine particulate organic materials (FPOM) iii) filterers which filter FPOM from water column, iv) scrapers known as grazers that graze on algae or biofilm and v) predators which consume other animals or engulf prey (Merrit *et al*., 2008). Aquatic insects function as predators themselves and serve as food for either invertebrates or vertebrates predators (Hershey *et al.,* 2010).

Apart from being functionally balancing the freshwater ecosystem, some of the aquatic insects have medical importance as disease vectors (Abowei and Ukorojie, 2012) for example mosquitoes and some of the aquatic insects such as flies, bugs and biting midges can caused nuisance to human. *Aedes aegypti* well known for being a vector of dengue hemorrhagic fever which able to cause human fatal. Globally, over 3 million cases of dengue fever has been reported in 2013 and about 2.35 million cases reported in America alone, of which 37 687 cases were severe dengue (WHO, 2015).

However, some of these aquatic insects have proven their ability as bio-control agents. Many studies have been conducted since 19th century regarding aquatic insects as bio-controls for mosquitoes, both for larvae and adult stages (Quiroz-Martinez and Rodriguez-Castro, 2007; Mandal *et al*., 2008). Often, the top predators in freshwater ecosystem is fish, which can impact the composition, abundance, and diversity of other macroinvertebrate, especially aquatic insects (Dorn, 2008). The mosquito itself, *Toxorhynchites* became the top predators for other small aquatic insects (Batzer and Wissinger, 1996; Quiroz-Martinez and Rodriguez-Castro, 2007; Culler and Lamp, 2009).

In addition, aquatic insects are known as bio-indicators for monitoring the aquatic ecosystems which also known as bio-monitoring. Bio-monitoring as refer to Cairns *et al*., (1993), is surveillance using the responses of the living organisms in determining whether the environment is favourable for living material. Aquatic insects may consider as the best bio-monitoring tools because of their high abundance, high rate of birth with short generation time, large biomass, and rapidly colonize the freshwater ecosystem (Anjana and Janak, 2015). The adoption of this bio-monitoring tool has been widely reported in tropical and temperate rivers (Hodkinson and Jackson, 2005; Rosenberg *et al*., 2008). In South East Asia, few countries such as China, Japan, South Korea, and Thailand have implemented this bio-monitoring tools in monitoring their freshwater ecosystems (Sripongpun, 2002; Mustow, 2002; Hoang and Bae, 2006; Boonsong *et al*., 2009; Yung-Chul *et al.*, 2012). However in Malaysia, the application of aquatic insects as bio-monitoring tools in monitoring the quality of freshwater ecosystems scarcely reported (Che Salmah *et al*., 2007; Al-Shami *et al*., 2010a; Al-Shami *et al*., 2011).

Moreover, human also get benefits from aquatic insects in directly from fishing, education, art, and commercial or organizational symbols as well as potential physical and chemical value (Glenn and Susan, 2014). As for fishing purposes, anglers often use tie "flies" that resembles imagos of mayfly or mayflies itself as fish bait (Anjana and Janak, 2015). Besides, Klein and Merrit (1994) stated that aquatic insects have been widely used for education in biology and ecology. For example, in America, the Girls and Boys Scouts of America learn about stream ecology and benthic invertebrates, and they are given merit badge or other form of recognition for their effort (Glenn and Susan, 2014). Besides, aquatic insects were used as commercial symbols by world-known company such as NIKE, the sport apparels in which using mayfly as their line of marketing their lightweight mayfly running shoes (NIKE, 2016). Apart from that, aquatic insects have potential physical and chemical value. For example, Addison *et al*. (2013) stated that, a synthetic version of adhesive silk produce by underwater architects, the caddisflies to build up their retreats which able to withstand the water current is being considered for development as underwater adhesive and artificial human tendons and ligaments.

2.5 Distribution of aquatic insects

About 1.5 million species of kingdom Animalia were estimated all over the world and world's insects estimated more than half, about 65% of the world's estimated animal species. Over 1 million world's insects were estimated, and about 80% (812,217) of known-species insects recorded in Catalogue of Life (COL) databases up to January 2016, (COL, 2016). While most insects live on land, their diversity also includes many species that are aquatic. Not many aquatic insects were listed under endangered or extinct species, that's only because researcher have only begun to study their distribution and population (Voshell, 2009).

Aquatic insects are found highly associated with water for most of their life cycle and any changes in number and composition of their population at a given space or time may indicate a profound changes of the ecosystems (Anjana and Janak, 2015). Aquatic insects are among the most ubiquitous and diverse in most freshwater (Strayer, 2006) either lotic or lentic habitats (Hershey *et al*., 2010).

Dudgeon (2000a) stated that tropical Asian river able to support a rich but incomplete biota, including diverse array of aquatic insects. Due to recent increases of anthropogenic influences to the tropical Asian streams, great attention has been paid to the loss of biodiversity along with the great concern over the fate of this particular tropical rain forests (Dudgeon, 2000b). It is well documented that aquatic insects in temperate region was more abundant in number compared to the tropical region, however, the diversity of aquatic insects in tropical river seems higher compared to the temperate region (Hoang and Bae, 2006). Higher degree of aquatic insects in tropical rivers were explained by the following hypotheses suggested by Pianka (1994): i) historical event including the continental association, ii) stable and malign environment, iii) rich in microhabitats and food resources, iv) complexity of community. A statement by Ward (1992) regarding the species diversity of aquatic insects positively correlated with the diversity of microhabitats that support one of the hypotheses. Unfortunately, some of these aquatic organisms are completely unknown and taxonomic efforts in identifying them to species or even genus level are still scarce (Morse *et al*., 2007; Jacobsen *et al*., 2008).

2.6 Factors determining distribution and abundance of aquatic insects

Distribution and abundance of aquatic insects is strongly affected by their tolerance towards an array of environmental factors, including water temperature, chemical, physical, and biological factors. Water chemistry is directly influenced by atmospheric conditions, bedrock geology, and biotic interactions and has thus changed over evolutionary time, potentially affecting aquatic insect diversification (Djikstra *et al.*, 2014). The richness of aquatic insects is believed affected by the physical condition of river including the order of river, substrate stability, and velocity (Che Salmah *et al.*, 2007; Al-Shami *et al.*, 2010a; Al-Shami *et al.*, 2013a; Che Salmah *et al.*, 2013). For example, the richness and diversity of aquatic insects is higher in the mid-order river compared to the headwater streams and high-order streams (Arscott *et al.*, 2005).

2.6.1 Water temperature

Water temperature is affected by time of the day; high temperatures may be recorded during day time and become lower at night (Lawson, 2011). Water temperature greatly affects the survivability of aquatic insects (Fawaz *et al*., 2013) and controlling the dynamics of aquatic insects community and being positively related to species richness (Astorga *et al.*, 2011). Besides, water temperature also affects the metabolic rate and the reproductive activities of aquatic insects by influencing the percentage of DO content, biological activities and other parameters (Mohammad Shuhaimi *et al*., 2007).

2.6.2 Chemical factors

Different sources of pollution contributes to variety of chemical parameters such as dissolved oxygen (DO) content, biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH value, ammoniacal-nitrogen (AN), and total suspended solid (TSS).

DO is oxygen that dissolved in the surface water as a result of diffusion from the atmosphere and aquatic-plant photosynthesis (Fawaz *et al*., 2013). Many ecologist or researcher consider DO as the main factor influencing the distribution and abundance of aquatic insects. DO concentrations are varied depends on the changes of water current (Wahizatul, 2004) and altitude (Jacobsen, 2008). Besides, DO also affect the solubility and availability of nutrient (Lawson, 2011) and are consumed by the degradation of organic matter in water. In the lacking of oxygen, the intolerant aquatic insects will be dismissed and replaced by the pollution-tolerant aquatic insects (Azrina *et al.*, 2006). At the same time, a study conducted by Alteiri and Nicholls (2001) reported that in low concentration of DO, high microbial activities tend to increase the acidity of water which cause mortality of aquatic insects (Lewis, 2008), and consequently increased the biochemical oxygen demand (BOD) concentration.

BOD is defined as the amount of dissolved oxygen required by aerobic biological organisms in water body to breakdown the organic material at certain temperature over the specific time (DOE, 2006). BOD concentration depend on rate of natural decaying process by plants or other contributors such as fertilizers, animal farms and construction effluent (Al-Shami *et al.*, 2011). BOD concentration directly associated with DO concentration, high value of BOD shows decline in DO (Fawaz *et al*., 2013). A contrary explanation is that the chemical oxygen demand (COD) is defined as the amount of oxygen needed to chemically oxidize organic and inorganic matter (DOE, 2006). Normally, the value of COD concentration is higher than value of BOD depends on the amount of pollutions.

pH or Hydrogen ion concentration as one of the vital, environmental characteristics decides the survival, metabolism, physiology and growth of aquatic organisms. pH is influenced by acidity of the bottom sediment and biological activities (Lawson, 2011). Petrin *et al*. (2008) suggested that acidity of water or river was associated with anthropogenic pollution and attributed by significant reduction aquatic insects richness. A study performed by Courtney and Clements (1998) on the effect in acidification of river with aquatic insects showed that the community responded strongly with acidic pH as both number of individuals and taxa decreased with the increase of acidification in water. Thus, it is important to maintain the rate of optimum pH, or else, it can be destructive in nature (DOE, 2006).

Ammoniacal-Nitrogen (AN), according to the National Water Quality Standards (NWQS), maximum threshold level in Malaysia rivers which support aquatic life is 0.9 mg/L (DOE, 2006). High level of AN can be toxic to aquatic organisms, but in small concentrations, it could serve as nutrients for excessive growth of algae (Corwin *et al*., 1999).

Total suspended solid (TSS) is the products of runs off, it increases with the increase of rainfall and have adverse effects on DO (Lawson, 2013). TSS in water reduce the light penetration which in turn limited the growth of aquatic plants including macrophytes and algae (Lewis, 2008). Physically TSS increase turbidity of the water, consequently affect the growth of aquatic insects by clogging their respiratory systems and interfering with their feeding organs for filter feeder aquatic insects (Mason, 1981). Soil erosions also considered as the source for suspended solids that comes from surrounding area caused by human activities (Fawaz *et al*., 2013). While turbidity in which highly related to TSS is resulted from the presence of suspended particles such as silt, plankton, clay, organic matter and other microscopic or decomposers organisms (Fawaz *et al*., 2013). The murkier water indicates higher amount of sediments, it can also be the indicator of a high measured of turbidity (Yisa and Jimoh, 2010).

2.6.3 Biological factors

2.6.3(a) Climate change

Aquatic insect assemblages also affected by biological factors such as climate and seasonal change (Hamilton *et al*., 2010). Climate and seasonal changes play a major role in composition and assemblages of aquatic insect (Dudgeon, 1999) and affect their life cycles (Nor Zaiha *et al.*, 2015). Tropical rivers are thermally stable but show seasonality driven by hydrology and climatic aspects (Dudgeon, 1999). Alteration of the season resulted in adverse effects on proper growth, hatching and mortality especially in aquatic insects which undergoes continuous growth and reproduction (Jacobsen *et* *al*., 2008). During the dry season, the increase of sedimentations in streams may significantly diminish the size and availability of adequate microhabitat patches for aquatic insects (Haro and Brusven, 1994). Study by Suhaila *et al.* (2014) prove that the abundance of Ephemeroptera, Plecoptera, and Trichoptera (EPT) was higher in wet season but more diverse in dry season. However, study conducted by Nor Zaiha *et al.* (2015) found that dry season offers an optimum condition for EPT since their diversity and abundance were higher in this season compared to wet season.

2.6.3(b) Competition

Introduction to alien species, competition and interaction of prey-predator in aquatic ecosystems also might affect the diversity of aquatic insects. According to Cummin (1975), when two or more species overlapping in the niche, biotic interactions such as competition for food and space or prey-predator relationship will be higher. Undoubtedly, aquatic insects are one of the major food source for fish in which able to remarkably influence or modify habitat or food associations and local distribution patterns of their prey population.

2.6.4 Physical factors

Heterogeneous microhabitats including waterfall, pool-riffle sequences, and cascades as well as riparian forest along the river bank which contributes allochthonous organic materials as a source of food provides relatively large number of aquatic insects habitats (Hoang and Bae, 2006; Suhaila and Che Salmah, 2011). Size distribution of sediments on the bottom of the river usually referred as substrate. Several characteristics of substrate, including size, surface area, and heterogeneity have been shown to influence the number, density, or diversity of the species inhabiting a given substrate (Darrow and Pruess, 1989). River substrates are important for aquatic insects as a platform to feed, egg deposition and incubation of eggs as well as refuge from predation and as shelter during physical disturbance (Stephanie *et al.,* 2000; Suhaila and Che Salmah, 2011).

Water current speed or velocity is one of the most important physical factors that determines the distribution and diversity of numerous aquatic insects in running water (Al-Shami *et al.,* 2013a). The movement of water creates high stratification of water columns which maintaining high concentration of DO (Warren and Doudoroff, 1971).

Physical disturbance such as removal or changes of microhabitats due to human recreational activities contributing to the instability of substrates (Suhaila and Che Salmah, 2011). Human activities along the freshwater ecosystems impair the river and aquatic organisms habitat quality and cause instant eradication of intolerant taxa, decreasing the community richness and increase the pollution-tolerant aquatic insects (Walsh *et al.,* 2005). Due to human alteration of their habitat and over exploitation of freshwater has caused multiple and ongoing stresses and suffered to freshwater ecosystems (Revenga *et al*., 2005).

2.7 Aquatic insects in bio-monitoring

In fully understanding river, researchers from various background such as ecologist, biologist, environmentalist, and even politicians have been debated over the definition of 'Healthy River' (Norris and Thoms, 1999;

Karr, 1999). The term ‘river health’ associates with the ability of the river to recover from normal stresses, requires minimal outside cares and able to perform its vital functions in many ways (Karr, 1999). However, ‘healthy river’ is often seen as being analogous to human health and the meaning remains obscure (Norris and Thoms, 1999). Thus, researcher have been looking at many aspects including, physical, chemical, biological, geomorphological, and engineering approaches to reviewed the ‘healthy river’ (Brookes and Shields, 1996). Consequently, guidelines for river protection have been shifted towards the physical and chemical measurement rather than biological approach only (Norris and Thoms, 1999).

In Malaysia, water quality monitoring relies on physicochemical and microbial (faecal coliform bacteria) assessments (DOE, 2006). According to Morse *et al.* (2007), based on these criteria, about 72% of Malaysian rivers were classified as polluted or slightly polluted in year 2000. Thus, this situation promote the development of bio-monitoring techniques using aquatic insects to reduce time, cost and effort in assessing water quality.

There is always growing interest among the aquatic researcher to understand the relationship between aquatic insects and its ecosystem with possibility to use aquatic insects as bio-monitoring tools or indicators for river water quality and ecosystem functioning (Bonada *et al.*, 2006). Recently, estimating the ecological biodiversity and the way its responds to various kind of pollutions has proven to be an excellent tool in monitoring the aquatic ecosystems (Larsen and Ormerod, 2010).

Aquatic insects are used in monitoring water quality due to their availability in freshwater ecosystem. They also easy to collect and identify as taxa of many groups are well known especially in temperate country. Generally, aquatic insects are sensible, so they cannot escape pollution, habitat changes and severe natural events making them as the best water quality indicator (Voshell, 2002; Cairns *et al.*, 1993). Besides, aquatic insects vary in sensitivity to organic pollution. Thus, their relatives abundance have been used to make inferences about pollution status of the freshwater as they are classified into very sensitive, sensitive, tolerant and very tolerant groups (McGeoch, 1998; Cummins *et al*., 2008). Furthermore, aquatic insects are visible to naked eyes, sedentary nature and easy to be sampled on are the outlined (Resh *et al.*, 1996).

Nonetheless, the used of aquatic insect as bio-monitoring tools is neither popular nor widespread in Southeast Asia region although this approach is way more cheaper, simple, and efficient, and it is widely used to monitor the river quality in other parts of the world, including America (Bonada *et al.*, 2006; Sahana *et al.*, 2015). Despite it all, a few countries such as South Korea and Thailand has been working on their own index in assessing the quality of water using aquatic insects (Hoang and Bae, 2006; Boonsong *et al.*, 2009; Yung-Chul *et al.*, 2012).

2.8 Biological Indices

All biological indices are used to estimate the quality of water using the macroinvertebrates especially aquatic insects correspond with high diversity (Morse *et al.*, 1994). Family Biotic Index (FBI), Biological

Monitoring Working Party (BMWP), and Average Score Per-Taxon (ASPT) are the most commonly used in biological indices. However, Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness also have been used as part of biological indices.

2.8.1 Family Biotic Index (FBI)

Family Biotic Index provide a rapid, yet less critical evaluation of streams was proposed by Hilsenhoff (1988). When detailed taxonomic information available, FBI was not intended to compensate application of Biotic Index (BI). However, the FBI formula is somewhat similar to the equation of BI, instead of using the average pollution tolerance scores of species (a_i), FBI apply the average pollution tolerance scores of family. The tolerance value given is from 0 (sensitive species) to 10 (pollution-tolerant species). The indication of water quality using FBI is showed in Table 2.1.

The equation of FBI:

$$FBI = n_i \times a_i / N \;;$$

where, n_i = total individuals in each taxon

a_i = tolerance value for each family level

N = total individuals collected

Table 2.1: Indication of FBI (Hilsenhoff, 1988)

Index value	**Water quality classification**	**Degree of organic pollution**
0.00-3.75	Very good	No organic pollution
3.76-4.25	Good	Very less organic pollution
4.26-5.00	Moderately good	Less organic pollution
5.01-5.75	Moderate	Moderately organic pollution
5.76-6.50	Moderately bad	Moderately more organic pollution
6.51-7.25	Bad	More organic pollution
7.26-10.00	Worst	A lot of organic pollution