MACROINVERTEBRATE DISTRIBUTION IN RELATION TO WATER QUALITY IN THE MIDDLE REACH OF KERIAN RIVER BASIN

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2012

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By

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Thesis submitted in fulfillment of the requirements for the degree of Master of Science

January 2012

ACKNOWLEDGEMENTS

First of all, my sincere gratitude to Allah S.W.T. for His blessing allowed me to complete my study. My genuine appreciation goes to my supervisor, Prof. Che Salmah Md. Rawi for her support, encouragement, guidance and patience in providing excellent supervision from the beginning until I finished this research.

My sincere thanks to Prof. Abu Hassan Ahmad, Dean of School of Biological Science, Universiti Sains Malaysia, Penang, for giving me the opportunity and providing all necessary facilities that made my study possible.

I was indebted to many individuals who contributed to the completion of this thesis in many ways. Their criticisms, suggestions and discussions had tremendously improved my thesis. I wish to thank Dr. Salman Al-Shami for his readiness to review my draft while I was writing this thesis. Colleagues in the laboratory of Aquatic Entomology and friends who have helped in several ways during this study included; Adibah, Shafiq, Kak Su, Rina, Wan, Zul, Aiman, Kak Mad, Kak Aida, Kak Nunu, Kumara and many others who may not be mention here. I gratefully acknowledged your support and encouragement.

Special thanks to entomology laboratory assistants; Pn. Siti Khadijah and En. Shukri and drivers; En. Kalimuthu, En. Nordin, and En. Shukur for their invaluable help during sampling and laboratory studies. Thanks is also extended to all the staff of School of Biological Sciences, who help in one way or another, either directly or indirectly for the smoothness of research throughout my study. I also gratefully acknowledged the Universiti Sains Malaysia for awarding me with a research grant and a fellowship during my study.

I am indebted to Dr. Rodolfo Novelo-Gutierrez (Veracruz, Mexico) for his assistance in identifying odonates specimen. Any errors that remain are, of cause entirely my own responsibility. Finally, my heartiest appreciation, gratefulness to my family members; father, mother and sisters who helped me in innumerable ways. Thank you all.

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2. **Nurul Huda, A.** and Che Salmah, M. R. (2010) Aquatic macroinvertebrates assemblages in Middle Reach of Kerian River Basin. Proceeding of The 7th IMT-GT ININET and The 3rd Joint International PSU-UNS Conference. Prince of Songkla University, 7-8 October 2010, Hat Yai, Songkhla, Thailand.

3. **Nurul Huda, A.** (2009) Environmental condition and water quality: factors for habitat selection of Odonata. Proceeding of Symposium of USM Fellowship Holders 2009. Universiti Sains Malaysia, 14-15 November 2009, Penang, Malaysia.

4. **Nurul Huda, A.,** Che Salmah, M.R., Abu Hassan, A., Nur Adibah, M.I. and Amirshah Rudin, M.S. (2009) Comparative biodiversity and distribution of freshwater macroinvertebrate in Middle Reach and Upper Catchment of the Kerian River Basin, Malaysia Peninsula. Proceeding of UNAIR-USM Second Collaborative Conference. Universitas Airlangga, 10-11 February 2009, Surabaya, Indonesia.

LIST OF ABBREVIATION AND SYMBOLS

ANOVA	=	Analysis of Variance
ASPT	=	Average Score Per Taxon
BMWP	=	Biological Monitoring Working Party
BOD	=	Biochemical Oxygen Demand
BR	=	Bogak River
CCA	=	Canonical Correspondence Analysis
cm	=	Centimeter
COD	=	Chemical Oxygen Demand
CPOM	=	Coarse Particulate Organic Matter
Cu	=	Copper
df	=	Degree of Freedom
DO	=	Dissolved Oxygen
DOE	=	Department of Environment
EPT	=	Ephemeroptera Plecoptera Trichoptera
FBI	=	Family Biotic Index
FFG	=	Functional Feeding Group
FPOM	=	Fine Particulate Organic Matter
ISI	=	Important Species Index
KR	=	Kerian River

KRB	=	Kerian River Basin
l	=	Liter
m	=	Meter
mg	=	Milligram
mm	=	Millimeter
Mn	=	Manganese
NH_3-N	=	Ammonia-Nitrogen
Ni	=	Nickel
NO_3^--N	=	Nitrate
PO_4^{3-}	=	Phosphorus
ppm	=	Part per Million
SE	=	Standard Error
SR	=	Serdang River
TSS	=	Total Suspended Solid
WQI	=	Water Quality Index
Zn	=	Zinc
ρ	=	Spearman Rho Correlation Coefficient

TABURAN MAKROINVERTEBRATA DAN KAITANNYA TERHADAP KUALITI AIR DI BAHAGIAN TENGAH LEMBANGAN SUNGAI KERIAN

ABSTRAK

Makroinvertebrata akuatik dipungut bermula dari Mei 2008 hingga Ogos 2009 di tiga sungai; Bogak, Serdang dan Kerian di bahagian tengah Lembangan Sungai Kerian. Makroinvertebrata ini diwakili oleh 120 genera terdiri 8194 individu dari 59 famili dan 13 order. Kelimpahannya berbeza di antara bulan persampelan ($F_{(8,261)} = 2.132$, $p < 0.05$) dan sungai ($F_{(2,267)} = 22.743$, $p < 0.05$). Majoriti makroinvertebrata adalah toleran pemangsa dan pemungut-turas. Jenis tumbuhan riparian yang berbeza, pertumbunhan makrofit, jenis substrat dan perubahan musim adalah faktor penting menentukan kesesuaian habitat untuk makroinvertebrata di kawasan ini. Sembilan parameter air didapati berbeza di antara sungai (Kruskal-Wallis, $p < 0.05$). Pleidae beserta Gomphidae, Palaemonidae dan Chlorocyphidae adalah sangat sensitif terhadap perubahan di habitat air. Kelajuan air sangat mempengaruhi taburan Hemiptera (terutamamya Pleidae) ($\rho = -0.565$, $p < 0.05$). Kelimpahan Gomphidae dipengaruhi secara negatif oleh peningkatan kandungan Zn di dalam sedimen sungai. Kualiti air di tiga sungai ini adalah “bersih” dan “sederhana bersih” (kelas II –III) mengikut Indek Kualiti Air sementara nilai indek biologi; ‘Family Biotic Index’ (FBI), ‘Biological Monitoring Working Party’ (BMWP) dan ‘Average Score Per Taxon’ (ASPT) juga memberi implikasi bahawa kualiti air adalah “bersih” hingga “serderhana bersih”. Di Sungai Serdang, pepatung boleh digunakan sebagai taksa pilihan untuk pemantauan kualiti air. Dalam kalangan 5655 individu (dari 8 famili dan 25 morphospesis), *Pseudagrion* direkodkan paling tinggi kelimpahan (41.22%) diikuti dengan *Onychothemis* (17.12%). Pemilihan habitat oleh beberapa genera dapat dilihat dengan jelas dan komuniti Odonata di kawasan tertutup dengan kanopi tumbuhan adalah berbeza dari kawasan terbuka (Diversiti Beta = 0.688). Namun demikian, terdapat persamaan genera di antara kawasan sebahagian tertutup dan kawasan terbuka. Ciri fizikal sungai, jenis bahan pencemar dan variasi musim didapati mempengaruhi kemandirian pepatung yang membawa kepada perubahan dominasi oleh pepatung di Sungai Serdang.

MACROINVERTEBRATE DISTRIBUTION IN RELATION TO WATER QUALITY IN THE MIDDLE REACH OF KERIAN RIVER BASIN

ABSTRACT

Aquatic macroinvertebrates collected from May 2008 to August 2009 from three rivers; Bogak, Serdang and Kerian in middle reach of Kerian River Basin (KRB) were represented by 120 genera of which 8194 individuals from 59 families and 13 orders. Their abundances varied significantly among sampling occasions ($F_{(8,261)} = 2.132$, $p < 0.05$) in different rivers ($F_{(2,267)} = 22.743$, $p < 0.05$). Majority of the macroinvertebrates were tolerant predators and collector-filterers. Different riparian vegetations, macrophytes' growth, substrates types and seasonal changes were important factors regulating habitat suitability for the macroinvertebrates in this part of KRB. Except for turbidity and TSS, nine water parameters were significantly different among rivers (Kruskal-Wallis test, $p < 0.05$). Pleidae as well as Gomphidae, Palaemonidae and Chlorocyphidae were very sensitive to changes in the aquatic habitats. Water velocity strongly influenced hemipteran's (mainly Pleidae) distribution ($\rho = -0.565$, $p < 0.05$). Abundance of Gomphidae was negatively influenced by increasing amount of Zn ($\rho = -0.557$) in river sediment. The Water Quality Index (WQI) categorized quality of the three rivers as "clean" and "moderately clean" (Classes II – III). Moreover, the scores of biological indices; Family Biotic Index (FBI), Biological Monitoring Working Party (BMWP) and Average Score Per Taxon (ASPT), also implied that the water quality was "clean" to "moderately clean". In Serdang River, dragonfly assemblage could be used as surrogate taxa for water quality monitoring. Out of 5655 individuals (from 8 families and 28 taxa), *Pseudagrion* spp. was the most abundant (41.22%) followed by

Onychothemis sp. (17.12%). Habitat preference of some genera was clearly observed and Odonate community in completely shaded area with vegetation canopy was different from that of unshaded area (Beta diversity = 0.688). However, there are similarities of genera shared between partly shaded and unshaded areas. River physical characteristics, types of pollutants discharge as well as seasonal factor influenced odonate assemblages thus led to shift in odonates dominant in Serdang River.

CHAPTER 1

INTRODUCTION

1.1 Background

Macroinvertebrates refer to those invertebrates that exceed 0.5 mm in size or large enough to be seen by naked eye. They comprise a vital constitution of the aquatic fauna (Galbrand *et al*., 2007; Clarke *et al*., 2008). Ubiquitously, they inhabit all types of water ranging from the larges lakes and rivers to stagnant water in discarded tires and man-made containers. Stream-bottom macroinvertebrates dwellers include prawns, mussels, aquatic snails, aquatic worms, and aquatic insects (McCafferty, 1981; Jacobsen *et al*., 2008).

Freshwater benthic macroinvertebrates community is an important component of the riverine ecosystem. They feed on leaves, flowers or fruits debris scattered in the stream. In addition to lifeless food sources, other living organisms such as algae and as well as other smaller invertebrates are considered essential food source for macroinvertebrates especially the filter-feeders (Wallace and Webster, 1996; Cummins *et al.*, 2008). The foodweb in the freshwater ecosystem is complicated (Dudgeon *et al.*, 2010) and usually the macroinvertebrates become energy source (food) for larger vertebrates such as fish, birds and humans (Hynes, 1970; Dudgeon, 1999; Jacobsen *et al*., 2008).

Application of the aquatic organisms as bioindicator of water quality has been utilized worldwide and proven to be a promising research tool in water resource management. Benthic invertebrates especially aquatic insects have numerous advantages over other freshwater organisms as biological indicators. Their ubiquity and diversity determine their presence in nearly all types of freshwater ecosystems. Although they are widely distributed, aquatic insects have very specific requirements in the habitat. Their abundance and diversity mainly depends on physical and chemical changes in the aquatic ecosystem (Cummins *et al.,* 2008). Additionally, most of them are relatively immobile and dwell on the stream-bottom which makes them in direct contact with both water and sediments (Hynes, 1970; Dudgeon, 1999).

Most freshwater macroinvertebrates species vary in sensitivity to organic pollution. Thus, their relative abundances have been used to make inferences about pollution status of the stream water. Moreover, aquatic insect's distribution and abundance are found to response to subtle physical changes of the aquatic habitat as well as severe destruction of the environment (McGeoch, 1998; Abdulhaqq *et al*., 2008; Cummins *et al.*, 2008).

Benthic macoinvertebrates are very suitable biological indicator organisms due to their longer life span and sedentary nature. Generally, the macroinvertebrates are classified into very sensitive, sensitive, tolerant and very tolerant groups. In other words, some macroinvertebrates are sensitive to pollution while others are rather tolerant. Collectively, invertebrates make good indicators of ecological condition because they are highly diverse and functionally important, can integrate a variety of ecological processes, are sensitive to environmental change and are easily to be collected (McGeoch, 1998; Galbrand *et al*., 2007).

Advantages of utilization of macroinvertebrates in biological monitoring were thoroughly reviewed by Resh *et al*. (1996) and Morse *et al*. (1994). As stated by Resh *et al.* (1996), the taxonomy of many groups is very well known and identification keys are available for the fauna of most of geographical regions. That could be somewhat valid for temperate countries such as the USA and Europe because the taxonomy of their aquatic fauna is well established and thoroughly investigated (Strayer, 2006). By comparison, the protocols of collection, analysis and data treatment are well established in tropical Asian streams especially Malaysia. However, the information about the ecological requirements, taxonomical composition and distribution in various aquatic ecosystems in tropical Asian streams including those in Malaysia are still lacking (Morse *et al*., 2007; Jacobsen *et al.*, 2008; Strayer and Dudgeon, 2010).

Studies on community of river macrobenthic invertebrates as a biological monitoring technique has been widely reported and described in different geographical areas (Cairns and Der Schalie, 1980; Mason and Parr, 2003; Jacobsen *at al.*, 2008). Morse *et al.* (2007) identified several impediments to biomonitoring in some of Asian countries such as China, Japan, South Korea, Malaysia, Mongolia, Russia (Far East) and Thailand. These obstacles can be summarized as: (1) lack of knowledge about macroinvertebrate fauna and their tolerance values, especially during the aquatic, immature stages; (2) the scarcity of research programs and formal training opportunities for biomonitoring offered in universities; (3) the shortage of high-quality microscopes and other necessary equipment; and (4) limited government understanding and support for biomonitoring thus lack of skilled staff and the persistence of old and unusable biomonitoring protocols.

In Malaysia, lack of taxonomic knowledge in almost all groups of aquatic insects makes the development of biological monitoring research very lagging. Owing to the lack of expertise and information, the Department of Environment

(DOE) of Malaysia has not fully implemented macrobenthic invertebrates as bioindicator of pollution for freshwater pollution studies (Azrina *et al*., 2006). Currently, the DOE of Malaysia only uses conventional water quality index (WQI) (DOE, 2009) to monitor the quality of water although monitoring of water quality using aquatic macroinvertebrates is cost-effective compared to conventional methods (Azrina *et al*., 2006). Moreover, chemical assessment often underestimates overall degradation of water quality and over reliance on chemical criteria which could affect the reliability of the remediation effort, costing both money and natural resources.

During the last decade, the studies on effectiveness of macroinvertebrates as bioindicator in running water have expanded to all over Malaysia. Impact of disturbances on the distribution and biodiversity of benthic macroinvertebrates have been reported from Linggi River, in Negeri Sembilan (Ahmad *et al.,* 2002), Langat River, in Selangor (Azrina *et al.,* 2006), Temengor catchment, in Perak (Che Salmah *et al*., 2007), Telipok River, in Sabah (Kamsia *et al*., 2008) and Juru River, in Penang (Al-Shami *et al.,* 2010; Al-Shami *et al.*, 2011). With rapid urbanization in Peninsular Malaysia, most rivers passing through populated areas are suffering from water quality degradation.

Kerian River Basin is the largest river basin in the northern Peninsular Malaysia. It provides potable water and related services to thousands of people downstream in both Perak and Kedah states. It irrigates large acreages of rice field especially in the Kerian rice growing areas in Perak. Previous research on biomonitoring using aquatic insects and fish in Kerian River Basin was reported by few researchers such as Yap (1990), Che Salmah *et al.* (2001), Che Salmah *et al.* (2004), and Wahizatul Afzan (2004). According to Che Salmah *et al*. (2001), the scores of Family Biotic Index (FBI) (Hilsenhoff, 1988) categorized the water quality in this river basin as moderately polluted to excellent.

Wahizatul Afzan (2004) and Che Salmah *et al*., (2004) investigated the Odonata (dragonflies) distribution in the Kerian River tributaries and verified that few species of dragonflies are potential bioindicators of the rivers due to their specific response to different pollutants and stressors. In the same context, Yap (1990) found that the scores of water quality index (WQI) display a discernible longitudinal pattern and downstream of Kerian River are more polluted than the upstream.

The biodiversity threats in the South East Asia tropics including application of aquatic insects in biomonitoring of the ecosystem integrity has been highlighted as hot topics in recent literature (Sodhi and Brook, 2006; Sodhi *et al.,* 2009; Pereira *et al.,* 2010; Butchart *et al.,* 2010). Consequently, compilation of macroinvertebrate fauna especially those in the northern Peninsula Malaysia would add more essential ecological information to overcome the crucial lack of faunal baseline data in the whole tropical Asian region. This study would complement available but incomplete existing body of information about application of macroinvertebrates as bioindicators outlining some conservation aspects in Malaysian aquatic ecosystems.

1.2 Objectives

In view of the importance of the Kerian River Basin to its surrounding population, this research emphasized on the role of macroinvertebrates as bioindicators of environmental quality in the Kerian River Basin focusing on the following objectives:

1. To investigate the distribution, abundance, species richness and diversity of aquatic macroinvertebrates in relation to water quality in middle reach of Kerian River Basin.
2. To investigate the linkage between ecological changes of the habitat and various features of aquatic macroinvertebrate communities associated with water pollution.
3. To study community distribution of Odonata, the major component of aquatic macroinvertebrates along Serdang River, a tributary of the Kerian River.

CHAPTER 2

LITERATURE REVIEW

2.1 Macroinvertebrates distribution

Generally, the macroinvertebrates size reaches at least 3 to 5mm (Cummins, 1975). They are abundant and can be easily observed and collected. Macroinvertebrates live on or among streambed sediments and often referred as macrobenthos. However, some of them (e.g. freshwater prawn, Odonata and Lepidoptera) are adaptable to inhabit unique habitats such as macrophytes or semi-aquatic vegetations (Sweeney, 1993; Colon-Gaud *et al.*, 2004). Majority of the macroinvertebrates are represented by aquatic insects which have an amphibiotic life cycle with aquatic immature and terrestrial adult stages.

Tropical rivers are unique in their geographical evolution, seasonality patterns, humidity and temperature as well as the composition of the canopy cover and habitat vegetation (Ometo *et al*., 2000; Gopal, 2005; Helson *et al*., 2006). The Asian aquatic ecosystems especially rivers are diverse in their ecological patterns, habitats (Dudgeon, 2000a; Dudgeon, 2000b; Gopal, 2005) and fauna composition (Jacobsen *et al*., 2008). It is well documented that diversity of aquatic macroinvertebrates especially insects is high in tropics. Meanwhile, their abundance in tropical streams is very low compared to those in the temperate region (Dudgeon, 1999; Dudgeon *et al*., 2006; Jacobsen *et al.*, 2008). Jacobsen *et al.* (2008) found that the altitude is the main factor determining macroinvertebrates composition and diversity in tropical stream. Hynes (1970) stated that macroinvertebrates of tropical stream is quite similar to that present in temperate stream in term of macroinvertebrate orders. However, according to Jacobsen *et al.* (2008), the macroinvertebrates taxa abundance and richness are different as the tropical stream is relatively rich in decapods crustaceans, snails as well as aquatic insect such as Odonata and Hemiptera but less of Plecoptera. Other insect orders such as Coleoptera and Diptera are similar to those found in streams in the temperate region.

As one of the tropical countries in Asia, Malaysia has diverse freshwater habitats (e.g. rivers, lakes, streams, swamps, ponds, puddle as well as phytotelmata) which are being inhabited by a variety of macroinvertebrates (Yule, 2004). Unfortunately, some of these stream organisms are completely unknown and taxonomic efforts in identifying them to species or even genus level are significantly scarce (Morse *et al*., 2007; Jacobsen *et al*., 2008).

Distribution of macroinvertebrate is strongly determined by tolerance of the individual towards changes in the environmental factors. The river continuum concept predicts a shift from taxa that use allochthonous food sources in headwater communities to taxa that use autochthonous food sources in mid-order streams (Vannote *et al.*, 1980) and suggests that species richness increases with stream size reaching its maximum in mid-order streams. Similarly, Arscott *et al.* (2005) found that species richness was low in headwater streams with an increase in mid-order streams and a decrease in richness in high-order streams. In addition to abiotic factors, the biotic interactions between species play another important role in shaping the distribution patterns of benthic macroinvertebrates in the aquatic ecosystems (Cummins, 1975).

In the heterogeneous streams, diverse benthic macroinvertebrates with different morphological and behavioral mechanisms were found exploiting various types of foods. Cummins and Klug (1979), Cummins and Merritt (1996) and Wallace and Webster (1996) have classified the aquatic macroinvertebrate to functional feeding groups (FFGs) based on morpho-behavioral mechanisms used by the animal to acquire food. Hachmoller *et al*. (1991) noted that headwater streams are populated by macroinvertebrates shredder and shift to higher proportion of scraper in middle reach and collector in lower reach of the river system.

2.2 The roles of macroinvertebrates in flowing water ecosystems

In general, macroinvertebrates play a major role in the overall structure and function of aquatic ecosystem through the carbon cycle in the environment and conversion of carbon compound derived from allochthonous and autochthonous materials in their tissues (temporary storage) which eventually converted into carbon dioxide (Cummins, 1975). In aquatic foodweb, macroinvertebrates act as primary and secondary consumers and are more tied to local habitats compared to larger mobile fish (Cummins, 1973; Jacobsen *et al*., 2008).

Ecosystem functioning of macroinvertebrate in the aquatic food webs was classified according to their functional feeding group (FFGs) (Cummins, 1973; Cummins, 1975; Cummins and Klug, 1979; Wallace and Webster, 1996). For instance, shredders (e.g. Trichoptera, Lepidoptera and Plecoptera) feed on coarse particulate organic matter (CPOM) (e.g. leaves, twigs and barks) and convert it into smaller fragments or fine particulate organic matter (FPOM). Thereafter, these smaller particles will be gathered or filtered by collector macroinvertebrates (e.g.

Diptera, Ephemeroptera and Trichoptera). Ultimately, their excretions (feces) will be food particle for smaller invertebrates or nutrient source of macrophytes and algae. In this cycle of ecological process, herbivores (e.g. Lepidoptera, Trichoptera and Ephemeroptera) graze or scrap the algae or plant tissue and produce small organic particles (feces). At the same time, predators (e.g. Odonata, Coleoptera and Hemiptera) feed on other macroinvertebrates and cycling the prey tissues to organic excretions. For example, the damselfly larvae are voracious predators of waterfleas, larvae of mosquitoes and aquatic bugs. However, the damselfly themselves would be a prey to other larger predators such as fish, frogs and birds (Corbet, 1999; Jacobsen *et al*., 2008).

In addition, some of these macroinvertebrates have medical importance as vectors for many diseases (e.g. mosquitoes and black flies) and cause nuisance (e.g. biting midges and bugs, flies) to human. They harbor many human parasites and also serve as the second intermediate hosts of amphibian and avian flukes (Hussein and Ahmed, 2003; Eamsobhana, 2004). *Aedes aegypti* is a vector of dreadful viral diseases such as dengue and dengue hemorrhagic fever. In tropical countries, water-borne diseases contribute to around 80% of all illness (Dudgeon *et al*., 2006); 46.5 million cases of malaria, 5.8 million cases of lymphatic filariasis, 1.7 million cases of schistosomiasis and 0.5 million cases of onchocerciasis. In addition, Dudgeon *et al*. (2006) stated that an outbreak of these diseases worsens by human alteration on hydrological regimes and expands of irrigation channels.

Macroinvertebrate are identified as important indicator for biological monitoring of aquatic ecosystem. The application of this biomonitoring tool has been widely reported in tropical and temperate streams (Morse *et al*., 1994; Resh, 1996; Mason and Parr, 2003; Hodkinson and Jackson, 2005; Yule and Yong, 2004; Jacobsen *at al*., 2008; Rosenberg *et al*., 2008). However, application of macroinvertebrates in water biomonitoring programs in Malaysia is scarcely documented compared to other countries in the temperate region (e.g. Yap, 1990; Che Salmah *et al*., 2001; Ahmad *et al*., 2002; Che Salmah *et al*., 2004; Wahizatul Afzan, 2004; Azrina *et al.,* 2006; Che Salmah *et al*., 2007; Kamsia *et al*., 2008; Al-Shami *et al*., 2010; Al-Shami *et al*., 2011). Current status of implementation macroinvertebrates biomonitoring in East Asia including China, Japan, South Korea, Malaysia, Mongolia, Russia (Far East) and Thailand was thoroughly reviewed by Morse *et al*. (2007).

Another application of aquatic macroinvertebrates is that a few macroinvertebrate species have proven their effectiveness as bio-control agents. For instance, larvae of the genus *Toxohynchites* (Culicidae) and some species of *Psorophora* (Culicidae) are predaceous and feed upon other species of mosquito larvae (Wallace and Walker, 2008). In the same context, Mandal *et al*. (2008) found that presence of Odonata nymphs (Aeshnidae, Coenagrionidae, Chlorocyphidae and Libellulidae) significantly reduced the *Culex quinquefasciatus* population density under semi-field conditions. Meanwhile, Sivagnaname (2009) documented that *Diplonychus indicus* (Belostomatidae) showed ability to reduce *Aedes agypti* population by suppressing the adult emergence. Other studies of aquatic macroinvertebrates as bio-control agents for mosquitoes larvae was reported by Mogi (2007) and Quiroz-Martinez and Rodriguez-Castro (2007).

Since macroinvertebrates are important components of both aquatic and terrestrial food webs, reductions in macroinvertebrate production and biodiversity have adverse effect on natural environment and ecosystem stability (Chakona *et al*., 2008). Dudgeon *et al*. (2006) documented that global threats to freshwater biodiversity is not only in ecological aspect but also included cultural and economic aspects. Over exploitation of natural resources, water pollution and habitat destruction by different anthropogenic activities will affect the quality of human health and life.

2.3 Factors determining macroinvertebrates distribution and abundance.

Macroinvertebrates assemblages in aquatic environment are influenced by alterations of physical and chemical habitat and changes in the environmental factors (Miserendino and Pizzolon, 2003). In details, the abundance and diversity of aquatic macroinvertebrates is greatly affected by numerous factors including structure and stability of macrohabitat and riparian vegetations (Death, 1996), chemical characteristic of the water including DO, water temperature, pH and TSS (Dudgeon, 1999), physical disturbances that lead to changes in water current, river width and depth as well as climate and seasonal changes (Hynes, 1970). The biotic interaction such as competition and prey-predator relationship also influence the distribution and composition of aquatic macroinvertebrates (Creed, 2006).

The macroinvertebrates community structure has different patterns depending on their relative abundance and diversity. At an early stage of succession, the macroinvertebrate communities fit the geometric series model. When succession proceeds, community structure will change from the log series and log normal distributions and eventually may return to a geometric series at the end of the succession (Taylor *et al*., 1976; Magurran, 2004). Species abundance distribution are less even in unstable sites and strongly dominated by one or two species and form the geometric or log series model (Gray, 1983; Silva *et al*., 2010). On the other hand, the stable habitats are predicted to have more even species distribution and fit the log normal distribution or the broken stick model.

2.3.1 Structure of microhabitat and riparian vegetations

Macroinvertebrate distributions varied from one river to another, depending on the location, geographical characteristics and climate properties. Meanwhile, different macroinvertebrates taxa show unique preferences to specific variations in the macrohabitat structure (Dudgeon, 1994; Dudgeon, 1999). Collier *et al.* (1998) noted that macrophytes and wood can provide potentially stable substrates for invertebrates colonization. Giacomini and De Marco (2008) compared habitat preferences of different Odonata species inhabited macrophytes with those live on the bottom substrate and found that no difference was found between the two groups of species regarding the body size, but shape differences were observed for two morphological variables.

For odonates, the abundance of prey (mainly zooplankton) which can be found higher in the midst of aquatic vegetation is a determinant factor for their abundance. Furthermore, higher stem and canopy densities of aquatic vegetation (e.g. *Hydrilla*) reduced fish predation on odonates (Savino and Stein, 1982; Schramm *et al*., 1987; Colon-Gaud *et al*., 2004). Meanwhile, macroinvertebrates that live on the bottom substrate are under higher risk of predation as they could be detected by other predators such as fish and aquatic birds (e.g. ducks and egrets). Therefore, to ensure their survival, they usually are more abundant in cryptic habits, less active and buried in the sediment or detritus (e.g. gomphids and cordulids dragonflies) (Corbet, 1999).

Structure of the macroinvertebrate communities is also affected by riparian vegetation as well as standing stocks of detritus and algae (Dudgeon, 1994; Iwata *et al.*, 2003). For example, riparian vegetation always provides a favorable environment for foraging of the adult insects because the vegetation provides habitats for their prey (Carchini *et al.*, 2003; Lorion and Kennedy, 2008). Generally, several Odonata species avoid shaded area as reflected by their thermoregulation requirements. However, other species require riparian vegetation as perch structures to guard their breeding territories (Remsburg *et al.*, 2008). At the same time, canopy of riparian vegetations influences the trophic structure by decreasing the autotrophic production (Spanhoff, 2005) and providing a large input of allochthonous detritus in form of coarse particulate organic matter (CPOM) (Hachmoller *et al.*, 1991; Allan, 1995; Polis *et al.*, 1997; Wantzen *et al.*, 2008). Other than predatory odonates, abundance of other macroinvertebrate functional feeding groups such as shredders and collector-gatherers is higher in leaf packs at shaded area due to availability of food source (detritus) while lower algal biomass tends to decrease the scraper and grazers composition (Cummins and Klug, 1979; Cummins *et al.*, 1989; Dudgeon, 1994; Wallace and Webster, 1996; Davies *et al.*, 2008).

In the aquatic habitat, component or type of substrates is an important factor in controlling the distribution and diversity of the benthic macroinvertebrates (Hynes, 1970). Griffin *et al.* (2009) reported that species diversity generally increases with substrate heterogeneity. In other word, there is a specificity of the substrate selection among the macroinvertebrate taxa as their diversity and abundance is attributed to variation in the substrate structure (Collier *et al*., 1998). Several studies have investigated the influence of substrate type on distribution of macroinvertebrates (Vinson and Hawkins, 1998; Buss *et al*., 2004; Che Salmah *et al*., 2005; Subramaniam and Sivaramakrishnan, 2005; Milesi *et al.*, 2009). In rapidly flowing rivers, coarse substrates remains stable while the sedimentation will be washed away resulting in macroinvertebrates adapted for attachment or clinging to the substrate (Cummins and Lauff, 1969). However, in slow moving and organically-enriched streams, many of non-insect group which prefer soft sediment such as amphipods, mollusks, decapods (Hachmoller *et al*., 1991) and tolerant insects (e.g., Chironomidae) are highly encountered (Hawtin, 1998).

2.3.2 Chemical factors

Different sources of pollutants from different human activities lead to variations in chemical parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), water temperature, pH and total suspended solids (TSS).

2.3.2.1 Dissolved Oxygen (DO)

Many ecologists consider the dissolved oxygen (DO) as the key factor controlling the distribution and diversity of aquatic macroinvertebrates. Generally, dissolved oxygen (DO) concentration varies among aquatic habitats following the changes in the water current (Wahizatul Afzan, 2004) and altitude (Jacobsen, 2008). Dissolved oxygen is consumed either through chemical oxidation of the organic and inorganic substances or through the biological respiratory processes of the aquatic biota. Under natural conditions, living organisms (e.g. macroinvertebrates and fish) require constant and sufficient concentrations of dissolved oxygen.

In case of organic pollution, dissolved oxygen suffers severe deterioration and the intolerant aquatic organisms will be eliminated and replaced by pollution-tolerant organisms (Dudgeon, 1999; Azrina *et al*., 2006). Connoly *et al.* (2004) identified the effect of low dissolved oxygen on survival, emergence and drift of tropical stream macroinvertebrates and suggested that macroinvertebrates experienced sublethal effects such as suppressed emergence when dissolved oxygen concentration is low. According to Puckett and Cook (2004), dissolved oxygen tolerance for *Caenis latipennis* (Ephemeroptera: Caenidae) ranged from 4.5 mg/l to 7.0 mg/l. Sensitive mayflies show high sensitivity to low oxygen conditions. Lethal effects on mayflies were observed at DO levels, 20% saturation for several upland and lowland species. Tolerant Chironomidae mortality occured when oxygen concentration is below 8% saturation (Connoly *et al*., 2004).

Low oxygen concentration in the water result with increase in the respiratory rate of the organisms (Mason, 1981) which may lead to high proportion of mortality. In addition to that, the amounts of toxic pollutants affect the organism physiology. Altieri and Nicholls (2001) reported that high microbial activities in polluted habitat with low dissolved oxygen levels in addition to increased acidity of the water contributed to high mortality of aquatic macroinvertebrates. Likewise, the elevated water temperature will reduce the solubility of oxygen in the water (Lewis, 2008).

2.3.2.2 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

Biochemical Oxygen Demand (BOD) is defined as the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material at certain temperature over a specific time period. Most pristine rivers have a 5 day carbonaceous BOD below 1 mg/L. Meanwhile, the BOD ranges from 2 to 8 mg/L in moderately polluted rivers (Sawyer *et al*., 2003). Chemical Oxygen Demand (COD), on other hand, is defined as the amount of oxygen required to chemically oxidize organic and inorganic matter. COD gives an estimation of the amount of organic and inorganic matter present. Normally, the value of COD is higher than that of the BOD.

2.3.2.3 Water Temperature

Water temperature of the aquatic ecosystem is affected by air temperature and solar radiation (Ward and Stanford, 1982). In tropical lentic and lotic ecosystems, the water temperature rarely exceeds 32°C, although smaller water bodies may attain higher temperatures. In general, the temperature is an important factor controlling the animal physiological processes including metabolism, growth and reproduction and respiration (Haslam, 1990). For instance, temperature may affect the egg incubation period, hatching success, duration of hatching and the diapauses process (Ward and Stanford, 1982). All aquatic organisms associated with freshwater except fish and birds are poikilothermic as they are highly dependable on subtle changes in the temperature of the ambient environment (Triplehorn and Johnson, 2005). Consequently, the changes in the community structure of aquatic macroinvertebrates are always associated with alteration in the water temperature. According to Lewis (2008), diverse fauna occurs in habitat with low temperature and limited in hot habitats as high temperature denaturing proteins and alter enzyme function as well as the other metabolism processes.

According to Mason (1981), water temperature is important that not only affecting the metabolic activities and behavior of macroinvertebrates but also alter the physical and chemical status of the pollutant in the water as the toxicity of some pollutant increased with temperature elevation. Reduction in oxygen concentration in water can be caused by thermal pollution. Hence, temperature is one of the major factors determining the distribution and diversity of the aquatic macroinvertebrates (Vannote and Sweeney, 1980; Ward and Stanford, 1982; Huryn *et al*., 2008).

2.3.2.4 pH

The hydrogen ion concentration, expressed as pH, plays an important factor controlling the distribution of macroinvertebrates in the aquatic environment. Petrin *et al*. (2008) suggested that acidity was associated with anthropogenic disturbance and attributed by significant reduction in macroinvertebrate species richness. Although changes in pH occur naturally due to drainage from peat soil or run-off from calcareous rocks (Wahizatul Afzan, 2004), human activities (agricultural and industrial) are the main reason explaining the severe changes in pH in polluted rivers. Nutrients from urban sources such as nitrate, phosphorus and ammonia could also change the water pH through eutrophication incidence (Altieri and Nicholls, 2001). In industrially polluted rivers, detergent containing phosphate is the major source of phosphorus in the water. Furthermore, chemicals pesticides and agricultural manures are considered as the main source of eutrophication and elevation of nutrients in the water (Mason, 1981).

pH in water has the ability to change the toxicity of heavy metal pollutant in the sediment (Mason, 1981). Driscoll *et al.* (2003) found that decreases in pH and increases in aluminum concentrations have diminished the species diversity and abundance of plankton, invertebrates and fish in acid impacted surface water.

2.3.2.5 Total Suspended Solids (TSS)

Generally, the suspended solids in the water reduce the light penetration which in turn hinders aquatic plants' growth such as algae and macrophytes (Davies *et al*., 2008; Lewis, 2008). Physically, the effect of suspended solids is that it increase turbidity of the water and affect macroinvertebrates by abrasion, clogging respiratory surfaces, interfering with feeding organs in the filter-feeding insects (Mason, 1981). For instance, Galbrand *et al*. (2007) found the Trichoptera and Ephemeroptera larvae were almost absent in habitats with high concentrations of suspended solids. On the other hand, deposition of suspended solid on substrates in the river bottom affects macroinvertebrate movement and eliminates their habitat and food. Slimy coating of suspended solids strongly affects immature larvae of macroinvertebrates as they will face difficulties to securely attach themselves to the substrates (Galbrand *et al*., 2007). In the same context, less food (periphyton) attached to the substrates due to high burden of total suspended solids will also influence the distribution of the aquatic insects especially scrapers.

2.3.3 Physical disturbances including climate and seasonal changes

Stream macroinvertebrates biodiversity is at particular risk because of its sensitivity to anthropogenic disturbance and vast and quick paces of urbanization, industrial and civil developments (Urban *et al*., 2006). Physical disturbance is related to modification, alteration or changes in physical characteristics of the river and surrounding areas. Human activities in the watershed impair stream water and habitat quality and cause instant eradication of intolerant taxa, decreasing the total community richness and increasing the dominance of tolerant taxa (Walsh *et al*., 2005). Urbanization may influence stream communities by restricting species dispersal within and among stream reaches (Urban *et al*., 2006). The decrease of the allochthonous inputs and organic matter retentiveness along the river basin (Wantzen *et al*., 2008) were related to habitat clearance and land alteration for human development. Reduction of vegetation canopy has the potential to alter the trophic structure of urban headwater insect communities to an open-canopied stream in middle reaches with abundant autochthonous food resources. Urban *et al.* (2006) suggested that urbanization was associated with the reduced stream invertebrate diversity through the modification of landscape vegetation structure as macroinvertebrates assemblages were different in various streams following the alteration in the land use (Smith and Lamp, 2008). Unfortunately, increase in human population is often associated with loss of aquatic biodiversity (Allan, 2004) since more residential areas, factories and other facilities will be established to support human needs. Consequently, human beings are destroying their environmental themselves with less awareness and poor management of natural resources.

In addition, the increasing use of small-scale dam for hydropower has become serious threats for low-order stream and their diversity (Wantzen *et al*., 2008) by transforming the lotic habitat into lentic habitat. Changes in hydrological regime not only depleted the native biota of the stream but also provided a suitable habitat for alien flora and fauna. Pump houses built for irrigation in the paddy fields resulted in modification of stream flow. Stagnant or very slow flow water are often associated with less macroinvertebrates (Hynes, 1970) which probably attributed to low concentration of dissolved oxygen in the water and high silt loads.

Climate and seasonal fluctuations also play a major role in distribution and diversity of the benthic macroinvertebrate assemblages. In general, tropical rivers are thermally stable but they show seasonality driven by hydrology and climatic aspects (Dudgeon, 1999). Seasonal alterations in tropical streams resulted adverse effects on proper growth, hatching and mortality especially in multivoltine macroinvertebrates which undergo continuous growth and reproduction (Cowell and Vodopich, 1981; Jacobsen *et al*., 2008). For instance, heavy rainfall events in association with high spate during tropical wet season cause significant mortality and changes the food availability. According to Dudgeon (1999), macroinvertebrate densities tend to peak during dry season when the flow and condition of the river are stable. However, their abundance decreases in wet season. Since spate-induced disturbance occur only during the monsoon season thus to some extent, it is predictable. This situation allows the possibility of survival adaptation of some macroinvertebrates (Dudgeon, 2000a; Lake, 2003; Jacobsen *et al*., 2008).

In contrary, spates would be beneficial to other aquatic invertebrates as it would probably create new macrohabitats that provide higher habitat diversity.

Meanwhile, gradual increase in flow during wet season leads to increase in the availability of riparian zone (Wantzen *et al*., 2008). Flooded areas become refugia for aquatic fauna (Naiman *et al*., 1993; Rempel *et al*., 1999). This situation leads to higher macroinvertebrate densities during late wet season and early dry season as concluded earlier by Marchant (1982) and Dudgeon (1999). Additionally, spates provide flood-borne resources to aquatic animal inhabiting the rivers (Wantzen *et al*., 2008).

Briefly, seasonality is considered the main climatic factor structuring the macroinvertebrates community in aquatic environments (Fontanarrosa *et al*., 2009). Seasonal changes can cause variation to the physical and chemical characteristics of the river, thus indirectly influence the river inhabitants. Erosion of land containing contaminants or toxic substances from terrestrial area is carried into the river during heavy rain (Mason, 1981) or extreme flood flow on unstable landscape (Haslam, 1990). According to Lewis (2008), runoff generally reflects the seasonality of precipitation. During the wet season, flood and high water runoff positively reduce the effects of pollution loads as it may dilute the toxicants effluents (Jacobsen *et al*., 2008; Olomukoro and Azubuike, 2009).

Flood that occur regularly in Asian tropical rivers were not only caused by the monsoon but also from human activities (Dudgeon, 1999). Modification of land can excessively lead to severe flood problem. Channel rectification and channel deepening destroyed most of the riparian areas along the river basin (Wantzen *et al*., 2008). Effect of flooding on aquatic food webs was discussed by Wooton *et al*. (1996). It was found that flood disturbance resulted with higher mortality of predator-resistant grazers such as caddisflies, thus decreased their population. Floods also resulted in intense reproduction and high productivity by opportunistic plants and animals which play a critical role in nutrient cycling and food webs of the aquatic ecosystems (Hynes, 1970; Dudgeon, 1999). According to Allan (2004), an extreme disturbance events associated with watershed land use alterations such as flash floods could eliminate habitat specialist animals by homogenizing in-stream habitat variations.

Deforestation is another factor associated with erosion as the soil will be exposed to wind and rain. Thus, forest has lost a natural ability to absorb water, causing erosion and stripping the topsoil. When the river is filled more quickly, it will be more prone to flashfloods. Floods break the banks of the rivers and change the channelization of the river causing severe erosion to that river. River banks that experienced erosion is unsuitable for macroinvertebrate colonization due to high silt load which reduces the effective surface area available for colonization (Haslam, 1990).

2.3.4 Biotic factor (competition and prey-predator relationship)

Biotic interactions such as competition for food and space or prey-predator relationships will be high in aquatic ecosystem when the niche of two or more species is overlapping (Cummin, 1975). As stated earlier, aquatic macroinvertebrates are considered an important food source for stream fish, birds, large crustaceans and insects (Winermiller *et al.*, 2008). In this case, predators (fish) may remarkably influence or modify habitat or food associations and local distribution patterns of their prey (macroinvertebrates) population. Pierce *et al.* (1985) showed that odonate *Enallagma* (Coenagrionidae) population was reduced in the presence of bluegills fish. Other studies about prey and predator relationship were carried out by Mcpeek (1990) and Mcpeek *et al*. (1996) and found that there were differences in *Enallagma* vulnerabilities to predators such as fish and other species of Odonata.

2.4 Biological monitoring concepts

Numerous threats already generated by human activities associated with excessive urbanization and loss of natural habitats. Hence, monitoring the effects of these anthropogenic activities on populations of aquatic organisms is necessary to improve environmental policy, habitat conservation and sustainable management (Jacobsen *et al*., 2008; Rosenberg *et al*., 2008).

In Malaysia, water quality monitoring relies merely on conventional physicochemical and microbial (fecal coliform bacteria) assessments. Based on these criteria, 72% of the Malaysian rivers were classified as polluted or slightly polluted in year 2000 (Morse *et al*., 2007). This critical situation encouraged development of biomonitoring techniques using aquatic organisms to reduce the cost, time and efforts of the water quality assessment. A primary goal of freshwater biomonitoring is to determine the relative impacts of pollution or disturbance on living communities in aquatic environment (Morse *et al*., 1994; McGeoch, 1998; Hodkinson and Jackson, 2005; Morse *et al*., 2007). Therefore, bioindication and biomonitoring using freshwater organisms become commonly applied for effective assessment of the ecosystem health.

Pollution and disturbance restricted the occurrence or distribution of certain taxa (Rosenberg *et al*., 2008). Their response to these changes lead to identification of indicator organisms. Indicator is often referred as parameters, variables or measuring entities (Turnhout *et al*., 2007; Heink and Kowarik, 2010). The parameters or variables are the attributes of the ecosystem itself such as diversity, abundance or presence, composition including population richness and evenness. According to McGeoch (1998), indicator should be able to describe environmental system, analyze environmental changes and evaluate the whole process occurring in the ecosystem.

Of many groups of organisms proposed for application in the biological monitoring of aquatic ecosystem, macroinvertebrates, fish and algae are widely selected (Morse *et al*., 2007). However, selection of which freshwater group is the most appropriate as bioindicator depends solely on the characteristics of studied areas and objectives of the research (Resh, 2008).

According to Rosenberg *et al*. (2008), there are 5 hierarchical levels in using organisms for biomonitoring which cover different ranges from biochemical and physiological levels, individual level, population and species level, community level to ecosystem level. However, population and species assemblage level and community level of the aquatic macroinvertebrates were the most frequently used in biomonitoring approaches.

2.5 Macroinvertebrates as bioindicator

The principles and applications of macroinvertebrates as bioindicator in biological monitoring of aquatic ecosystem have been widely reported and thoroughly discussed in the literature (Cairns and Der Schalie, 1980; Morse *et al*., 1994; Mason and Parr, 2003; Hodkinson and Jackson, 2005; Yule and Yong, 2005;