DIVERSITY AND DISTRIBUTION OF TRICHOPTERA (INSECTA) LARVAE IN SELECTED RIVERS OF ROYAL BELUM STATE PARK, GERIK, PERAK WITH REFERENCES TO HABITAT PREFERENCE AND DIEL PERIODICITY

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By

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LIST OF ABBREVIATIONS

Abbreviation		Caption
ASPT	=	Average Species Per Taxon
BBI	=	Belgian Biotic Index
BI	=	Biotic Index
BMWP	=	Biological Monitoring Working Party
BOD	=	Biochemical Oxygen Demand
CCA	=	Canonical Correspondence Analysis
COD	=	Chemical Oxygen Demand
CPOM	=	Coarse Particulate Organic Matter
DO	=	Dissolved Oxygen
DOE	=	Department of Environment
EPTI	=	Ephemeroptera, Plecoptera and Trichoptera Index
FBI	=	Family Biotic Index
FFG	=	Functional Feeding Group
FPOM	=	Fine Particulate Organic Matter
ISI	=	Important Species Index
NH_3-N	=	Ammonia Nitrate
RBSP	=	Royal Belum State Park
SE	=	Standard Error
SI	=	Sub Index
TDS	=	Total Dissolved Solid

TI = Total Initial

TSS = Total Suspended Solid

TVE = Total Variance Explained

WQI = Water Quality Index

LIST OF PUBLICATIONS

Proceedings Including Oral and Poster Presentations

1. **Siti Mariam Zhafarina, R.,** Che Salmah M. R., Abu Hassan A. and Wan Nur Asiah, W. M. A. (2011). Drift of aquatic insect larvae in selected river of Royal Belum State Park, Gerik, Perak. The Taxonomist and Ecologist Conference. Auditorium, CAIS, Universiti Malaysia Serawak, 19-20 April 2011, **Serawak, Malaysia.**

2. **Siti Mariam Zhafarina, R.,** Che Salmah M. R. and Abu Hassan A. (2010). Diversity and distribution of caddisflies (Trichoptera) larvae in selected rivers of Royal Belum State Park, Gerik, Perak, Malaysia in relation to habitat stability. The 7th IMT-GT UNINET and 3rd Joint International PSU-UNS Conferences. Prince of Songklha University, 7-8 October 2010, **Hat Yai, Songkhla, Thailand.**

3. **Siti Mariam Zhafarina, R.,** Che Salmah M. R., Abu Hassan A. and Wan Nur Asiah, W. M. A (2009). Microhabitat distribution of caddisfly (Trichoptera) and its functional feeding groups in selected rivers of Royal Belum State Park. The 11th Symposium of The Malaysian Society Applied Biology. Grand River View Hotel, **Kelantan, Malaysia**.

KEPELBAGAIAN DAN TABURAN LARVA TRICHOPTERA (INSECTA) DI BEBERAPA SUNGAI TERPILIH DI TAMAN NEGERI DIRAJA BELUM, GERIK, PERAK DENGAN MERUJUK KEPADA PEMILIHAN HABITAT DAN PERKALAAN DIEL

ABSTRAK

Sebanyak 8624 larva Trichoptera daripada 16 famili dan 27 genus telah dipungut dari empat sungai; Kejar, Mes, Tan Hain dan Ruok, di Taman Negeri Diraja Belum, Perak, Malaysia. Kepelbagaian Trichoptera adalah tinggi ($1\text{-}D = 0.83 - 0.85$) tetapi tidak bertabur secara sekata di semua sungai ($E_{1/D}$, 0.29-0.36). Kepadatan larva adalah di antara 6.48 larva/m^2 di Sungai Ruok dan 10.08 larva/m^2 di Sungai Tan Hain. Antara famili Trichoptera, Hydropsychidae dan Philopotamidae adalah paling dominan. *Chimarra* (Philopotamidae) sangat penting di semua sungai. *Lepidostoma* adalah sangat penting (Indek Kepentingan Spesis, ISI > 10) di semua sungai kecuali Sungai Ruok, manakala *Ceratopsyche* adalah penting di Sungai Mes dan Tan Hain. Walaupun pengaruh kesemua parameter fizikal dan kimia yang diukur terhadap kelimpahan larva Trichoptera adalah lemah, biplot CCA menunjukan variasi dalam tindak balas larva Trichoptera terhadap pengaruh parameter fizikal dan kimia air. *Neophylax*, *Hydromanicus*, *Marilia* dan *Lepidostoma* dipengaruhi secara positif oleh COD, pH, TDS, konduktiviti dan kelebaran sungai. *Agapetus*, *Ecnomus*, *Glossosoma*, *Ganonema* dan *Ceratopsyche* dipengaruhi oleh peningkatan DO dan NH_3-N. *Setodes* dan *Stenopsyche* menggemari habitat yang mempunyai kurang teduhan vegitasi.

Sepuluh daripada enam belas famili larva Trichoptera dijumpai di lima mikrohabitat; "gravel", "cobbles", "boulders", himpunan dedaun dan kolam yang biasa ditemui di semua sungai, menunjukkan kecenderungan tehadap "cobble". Antara empat kumpulan pemakanan berfungsi (FFGs); "filterer", "scraper", "shredder" dan pemangsa dikenalpasti, "filterers" (Hydropsychidae, Stenopsychidae dan Philopotamidae), banyak ditemui pada "cobbles", "gravel" dan "boulders". "Scrapers" menggemari "boulders", sementara "shredders" dan pemangsa banyak di dalam kolam. Satu-satunya famili pemangsa iaitu Ecnomidae jarang ditemui di semua sungai.

Kesan faktor abiotik (kadar aliran air dan masa) dan biotik (hubungan mangsa-pemangsa) terhadap larva Trichoptera dikaji melalui corak pergerakan di dalam sungai. Sejumlah 3033 serangga (larva/dewasa) (10 order, 36 famili and 71 genus) telah dikumpul pada selang masa setiap 12 jam (siang/malam) di dalam jaring hanyut (drift net). Trichoptera mendominasi pergerakan komuniti dengan 59.45% (siang) dan 52.73% (malam). *Lepidostoma* (Trichoptera) aktif pada siang (40.18%) dan malam (31.98%). Coleoptera, Lepidoptera, Diptera, Odonata dan Blattodea dijumpai sedikit pada kedua-dua selang masa (<10%). Kelimpahan serangga yang bergerak pada siang dan malam adalah berbeza secara signifikan (Mann-Whitney test, $z = -4.405$, $p<0.05$), dengan kepadatan yang ketara tinggi pada waktu malam walaupun kepelbagaian adalah hampir sama (siang: H’=2.39, malam: H’=2.49). Berbanding pemangsa, mangsa lebih aktif bergerak pada siang dan malam. Hanya pergerakan *Lepidostoma, Ceratopsyche* dan *Potamomusa* dipengaruhi oleh jumlah pengeluaran air.

DIVERSITY AND DISTRIBUTION OF TRICHOPTERA (INSECTA) LARVAE IN SELECTED RIVERS OF ROYAL BELUM STATE PARK, GERIK, PERAK WITH REFERENCES TO HABITAT PREFERENCE AND DIEL PERIODICITY

ABSTRACT

A relatively rich community of immature Trichoptera (8624) from 16 families and 27 genera were collected from four rivers; Kejar, Mes, Tan Hain and Ruok, in Royal Belum State Park, Perak, Malaysia. Trichopteran assemblages were diverse (I-D = 0.83 - 0.85) but unevenly scattered in all rivers ($E_{1/D}$, 0.29-0.36). Their densities ranged between 6.48 larvae/m^2 in Ruok River and 10.08 larvae/m^2 in Tan Hain River. Among Trichoptera families, Hydropsychidae and Philopotamidae were the most dominant. *Chimarra* (Philopotamidae) was very important in all rivers. *Lepidostoma* was very important (Important Species Index, ISI) in rivers other than Ruok River, while *Ceratopsyche* was prominent in Mes and Tan Hain rivers. Although measured physico-chemical parameters had a weak influence on the abundance of Trichoptera larvae, the CCA biplot showed variation in responses of Trichoptera larvae to the physico-chemical parameters of the water. *Neophylax*, *Hydromanicus*, *Marilia* and *Lepidostoma* were positively influenced by COD, pH, TDS, conductivity and river width. *Agapetus*, *Ecnomus*, *Glossosoma*, *Ganonema* and *Ceratopsyche* associated with escalating DO and NH_3-N, while *Setodes* and *Stenopsyche* preferred less shaded habitats.

10 out of 16 families of Trichoptera larvae inhabit five microhabitats; gravel, cobbles, boulders, leaf packs and pools, commonly found in all rivers showing highest preference for the cobbles. Among four functional feeding groups (FFGs); filterer, scraper, shredder and predator recognized, filterers (Hydropsychidae, Stenopsychidae and Philopotamidae), were plentiful on cobbles, gravel and boulders. Scrapers preferred boulders, while shredders and predators concentrated in pools. The only predatory family, Ecnomidae was rare in all rivers.

The influences of abiotic (stream discharge and time) and biotic (prey-predator relationship) factors on caddisfly larvae were further investigated through their drift patterns in the rivers. A total of 3033 insects (larvae/adults) (10 orders, 36 families and 71 genera) were collected at 12 h interval (day/night) in drift nets. Trichoptera dominated the drift communities with 59.45% (daytime) and 52.73% (nighttime) of all taxa collected. *Lepidostoma* (Trichoptera) was active both during the day (40.18%) and at night (31.98%). Few Coleoptera, Lepidoptera, Diptera, Odonata and Blattodea were collected at both intervals (<10% of total). Day and night drift abundances were significantly different (Mann-Whitney test, $z = -4.405$, $p<0.05$), with markedly higher density at night although their diversity was almost similar (day: $H'=2.39$), night: $H'=2.49$). Preys were actively drifting at all times. Only *Lepidostoma*, *Ceratopsyche* and *Potamomusa* were significantly affected by the amount of water discharged by the river.

CHAPTER 1

INTRODUCTION

Water from rivers and streams are widely used for irrigation, industry, households and public supply in Malaysia as well as in other countries (Chan, 2006). Accordingly, numerous dams and weirs were built for these purposes. These activities have altered river ecosystem, hence affecting the aquatic flora and fauna including fish and insects (Shieh and Yang, 1999; Thompson *et al.*, 2009).

Trichoptera, commonly known as caddisfly is one of the largest groups of aquatic insects (Wiggins *et al.*, 1994; Wiggins and Currie, 2008). These insects are successful inhabitants of the upstream rivers where the water current is fast and water temperature is low (Lenat, 1993). The larvae are widely distributed and their relative abundances vary across regions (Morse *et al.*, 1994; Merritt and Cummins, 1996; Wiggins, 1996, Dudgeon, 2008).

It has been well documented that distribution of caddisfly in headwater ecosystems are influenced by several physical and chemical parameters such as canopy covers, stability of banks, submerged vegetations, water temperature, dissolved oxygen, pH, water velocity and even width and depth of the river (Compin and Céréghino, 2003; Bonada *et al.*, 2004; Bispo *et al.*, 2006; Che Salmah *et al.*, 2007). Naturally, the water temperature can determine the distribution and abundance of aquatic macroinvertebrates including caddisflies because the temperature influences the physiological processes of growth, size and body mass of the aquatic insects (Wagner *et al.*, 2006; Bispo *et al.*, 2006). Dissolved oxygen and water current plays important roles in the distribution of aquatic insects, especially to sedentary caddisfly larvae (Allan, 1995). Physical and chemical changes that occur in the river ecosystems may alter the diversity and composition of caddisfly communities (Driscoll *et al.,* 2003) because caddisflies as well as other macroinvertebrates respond to a wide variety of pollutants in the water (Azrina *et al.,* 2006 and Maloney and Feminella, 2005).

In an ideal situation, all physical, chemical and biological parameters of running water should be assessed to provide a complete spectrum of information for appropriate water management (Iliopoulou-Georgudaki *et al.,* 2003). Currently, biomonitoring is widely used in temperate streams (Iliopoulou-Georgudaki *et al.,* 2003; Cao *et al.,* 1997; Buss and Salles, 2007), but according to Dudgeon (2008), tropical countries have made only limited use of biomonitoring to assess stream conditions or water quality. As an important component of aquatic insect community, Trichoptera have been proven useful as biological indicators because of their sensitivity and responses to physical and chemical changes in aquatic ecosystems (Sjøbakk *et al*., 1997; Wiggins, 1998; McGavin, 2001, Yule, 2004; Bispo *et al.,* 2006; Jacobsen *et al.,* 2008 and Dudgeon, 2008). Different types of environmental stress produce different groups of Trichoptera assemblages. Therefore, the quality of water can be assessed by observation on presence-absence of some Trichoptera species (McGavin, 2001; Šporka *et al.,* 2006), in addition to related ecological and biological indices.

Other than physical and chemical parameters, the stability and availability of suitable microhabitats affects the abundance and succession of caddisflies in river ecosystems (Allan, 1995; Death and Winterbourn, 1995; Merritt and Cummins, 1996). The substrates types and its' stability together with the presence of organic detritus can influence the caddisfly larval distribution either directly or indirectly (Allan, 1995). Several studies found that stable substrates produce numerically higher densities of caddisfly larvae (Cobb and Flannagan, 1990; Gregory, 2005; Silveira *et al.,* 2006). Usually, similar caddisfly taxa are associated with particular microhabitats (intraspecific aggregation) (Murphy *et al.,* 1998) which corresponds to their functional feeding groups (Hynes, 1970; Gregory, 2005). For example, the collector-filterers that feed mainly on fine particulate organic matter (FPOM) are associated with different sizes of stones with flowing current to obtain their food, while the collector-gatherer are mostly found in slower and stagnant water like in pools (Cummins *et al.,* 1989; Yule, 2004).

Other than physico-chemical parameters and microhabitat availability, the movement of caddisfly larvae as well as other aquatic insects influence their diversity and distribution pattern. According to Waters (1972), aquatic insects will drift when the population has reached a carrying capacity at the site. However, this assumption likely assumes that there is no movement when the densities of insects are low in that particular area. During their recent experimental study, Pachepsky *et al.* (2005) found that when the per capita local growth rate of a small population on the benthos is higher than the per capita rate at which individuals drift, the population will always persist at the area irrespective of the carrying capacity.

Besides the carrying capacity of a particular area, the abiotic factors such as sediment inputs, stream temperature, disturbances, diel periodicity, water flow and discharge also influence the drift propensity of aquatic insects (Runde and Hellenthal 2000; Svendsen *et al.,* 2004; Dewson *et al.,* 2007a; Dewson *et al.,* 2007b). Changes in water flow and discharge can alter the availability and suitability of instream habitat for aquatic insect, thus induce them to move to a stable place (Dewson *et al.,* 2007b). Drift would be expected to increase with increase in water flow because the insects could be washed from their substrates. In contrast, James *et al.* (2009) found that the drift density of several taxa increased significantly after flow reduction because the response of drift density to flow changes varied with taxa (Dewson *et al.,* 2007b), size as well as depth of the river (James *et al.,* 2009). Moreover, Pennuto (2003) reported that the aquatic insect movement in the rivers was also influenced by seasons of the year.

Matzinger and Bass (1995) and Flecker (1992) found that the time of day (diel periodicity) influenced the activity and movement of aquatic insects. Some aquatic insect taxa such as *Baetis* sp. drift in greater density in the darkness (Casey, 1987; Flecker, 1992) and avoid movement during the day when they are easily spotted by predators like fish and other predatory macroinvertebrates. The presence of predators significantly influenced the drift density of preys (Lancaster, 1990; Forrester, 1994). However, availability of variety of preys in water column reduces the chances of a particular insect being preyed (Pennuto, 2003).

The diversity of aquatic insects including caddsifly larvae and other information such as factors and pattern of distribution and life cycle are intensively investigated in the last four decades (Merritt *et al.*, 2008) and well documented in temperate regions (Grafius and Anderson, 1980; Myers and Resh, 2002; Wood and Sites, 2002; Jacobsen, 2005). In the tropics, especially Malaysia, information on this group of insect is very scarce (Che Salmah *et al.*, 2001; Yule and Yong, 2004; Jacobsen *et al.*, 2008; Dudgeon, 2008). The influences of variety of microhabitats on the caddisfly larval assemblages in Malaysian rivers are not well understood. Their drift pattern and factors that may influence the movement of aquatic insects in rivers had never been studied in rivers of Royal Belum State Park.

To narrow the gap in knowledge of Trichoptera in Malaysia, this research was undertaken in the rivers of Royal Belum State Park (RBSP) in Perak to fulfill the following objectives:

i. To investigate the diversity and abundance of caddisfly larvae in Royal Belum State Park, Perak with reference to habitats suitability.
ii. To determine the caddisfly larval assemblages with respect to their functional feeding group (FFG) within different microhabitats; gravels, cobble, boulder, leaf pack and pool.
iii. To study the effect of physico-chemical parameters (pH, dissolved oxygen, velocity, temperature, river width and depth) and water quality (WQI) on the cadissfly larval assemblages.
iv. To investigate the influence of stream discharge and time, presence and absence of predators factors on the drift pattern of caddisfly larvae.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Trichoptera is commonly known as caddisfly. The name Trichoptera is derived from the Greek word *Trichos* means 'hair' and *pteron* means 'wing', referring to the adult hairy wings (Wiggins, 1998). Some of the larvae live in cases while many genera are caseless (Fig. 2.1). It is closely related to the Lepidoptera (moth), where the adult caddisflies generally resemble like the adult moths, except the hairy wing rather being covered by scales (Morse, 2004). The derivation of common name (caddisfly) is related to the silk secretion by the larvae as 'cadace' refers to a commercial grade of silk (Ward, 1992). Triochptera are holometabolous as they are fully aquatic in immature stage and terrestrial during the adult stage (Wiggins *et al.,* 1994; Ward, 1992).

Generally, the caddisfly life cycle consists of eggs, larvae, pupae and adults. Usually, the first three stages are fully submerged in the water and depend on oxygenated water for respiration (Morse, 2004). The larvae obtain the oxygen either by direct diffusion or through external gills located on the surface of the abdomen (McGavin, 2001). In terms of morphology, the caddisfly larvae are caterpillar-like with a strong development of the head and thorax. At the end of the larval soft abdomen, there is a pair of hooked prolegs to anchor themselves on the cases (case-bearing) or on stones (for caseless species) (McGavin, 2001). Depending on the the species and available food sources, the caddisfly larvae are herbivores, carnivores or detritivores (Merritt and Cummins, 1996; McGavin, 2001).

Caddisfly is ubiquitous and considered as one of the largest groups of aquatic insects (Wiggins *et al.*, 1994). In Peninsular Malaysia, 113 species have been described. Out of the total number of reported species, 71 species (63%) are reported as endemic species to Peninsular Malaysia, 96 species (91%) to Sabah and 33 species (82%) to Sarawak (Morse, 2004).

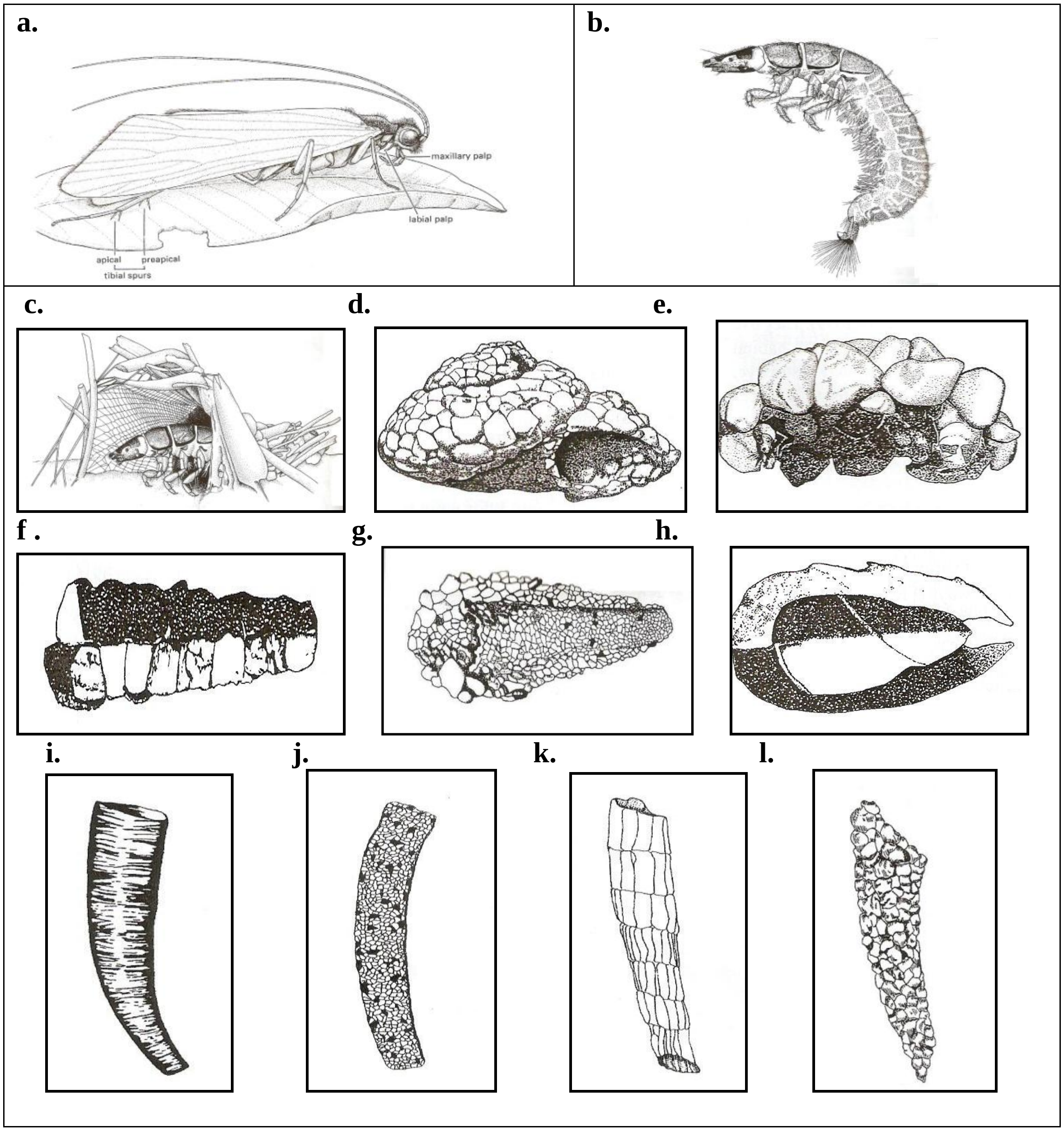

Figure 2.1 a. Adult caddisfly **b.** Larva of caddisfly (Hydropsychidae) **c.** Filter net and retreat (Hydropsychidae) **d - l** Portable cases of larvae; **d.** *Helicopsyche* sp. (Helicopsychidae); **e.** *Glossosoma* sp. (Glossosomatidae); **f.** *Lepidostoma* sp. (Lepidostomatidae); **g.** *Molanna* sp. (Molannidae); **h.** *Anisocentropus* sp. (Calamoceratidae); **i.** *Micrasema* sp. (Brachycentridae); **j.** *Gumaga* sp. (Sericostomatiade); **k.** *Triaenodes* sp. (Leptoceridae); **l.** *Ceraclea* sp. (Leptoceridae) (adapted from Yule and Yong, 2004 & Gullan and Cranston, 2005).

2.2 Environmental Factors influencing diversity and abundance of caddisfly larvae

The community structure of the aquatic macroinvertebrates and particularly aquatic insects is complicated and subjected to changes in the physical and chemical ambient environment (Schmera *et al.,* 2007; Dudgeon, 2008). It is well documented that the caddisfly larvae are abundant in oxygenated and cold running waters of temperate (Grafius and Anderson, 1980; Myers and Resh, 2002; Wood and Sites, 2002; Jacobsen, 2005) and tropical regions (Che Salmah *et al.,* 2001; Yule and Yong, 2004; Dudgeon, 2008; Jacobsen *et al.,* 2008). However, other environmental factors such as water velocity, water chemistry and river morphology are also known to influence the diversity and abundance of caddisfly larvae (Viðinskienë 2005; Schmera *et al.*, 2007). Moreover, the sensitivity of the caddisfly larvae to alterations in the physical and chemical in the aquatic habitat vary with taxa (Mihuc *et al.*, 1996).

2.2.1 Water velocity

The fluctuation of water velocity is a very important factor in the lotic ecosystems as it may affect the river morphology, habitat area and food resources and hence the behavior and assemblages of aquatic insects including the caddisfly community (Che Salmah *et al.*, 2007; Gullan and Cranston, 2005). Dewson *et al.* (2007a) found that the abundance of caddisfly and other macroinvertebrate was inconsistently fluctuated in response to low water velocity. Similarly, Katano *et al.* (2005) reported that the water velocity is an important factor in determining the reach-scale distribution of early stages of the caddisfly larvae during immigration period. Doi and Katano (2008) found that the water velocity significantly influenced the distribution of *Glossosoma* (Glossosmatidae).

Meanwhile, Wantzen and Wagner (2006) found that the distribution of *Phylloicus* (Calamoceratidae) was restricted to bank habitats with low water velocity.

The water velocity and temperature are somehow related and play important roles in the respiration and metabolism of caddisflies by controlling the availability of dissolved oxygen in the water column (Mackay and Wiggins, 1979). Water velocity can directly influence the sediment particle-size distribution and the rate of suspended food particles supply. Consequently, it influences the distribution of filter-feeder hydropsychids (Dudgeon, 1997; Brown *et al.*, 2004; Dewson *et al.,* 2007a). Viðinskienë (2005) found that the abundance of *Hydropsyche pellucidula* in Lithuanian rivers was strongly influenced by the water current. Furthermore, Mihuc *et al.* (1996) reported that filter-feeder *Hydropsyche* (Hydropsychidae) abundance increased proportionally with elevation of the water velocity.

2.2.2 Water temperature

Hydrobiologists consider the water temperature as a key factor controlling the aquatic organisms' metabolism, development and abundance. Temperature of running waters usually varies with seasonal scales and locations due to climate, elevation, extent of streamside vegetation and the relative importance of groundwater inputs (Allan, 1995). Generally, water temperature in the tropics does not vary very much and are almost constant throughout the year (Dudgeon, 2008; Allan, 1995). Water temperature affects the ability of water to reserve the oxygen, the rate of photosynthesis by aquatic plants and the metabolic rates of aquatic organisms (Dudgeon, 2008). In small rivers with less vegetation cover, the daily fluctuation in the temperature is common due to direct sunlight and changes in the air temperature (Allan, 1995).

From an ecological point of view, caddisfly larvae are ectothermic as their life history, productivity and behavioral patterns often are influenced by changes in temperature (Huryn and Harris, 2000). Usually, caddisfly larvae are highly associated in cool running waters. For instance, *Limnocentropus* (Limnecentopodidae) and *Micrasema* (Brachycentridae) preferred cool streams with high water velocity (Thamsenanupap *et al.*, 2003). However, other caddisfly species have the ability to survive in warmer streams (Blinn and Ruiter, 2009).

Thus, water temperature does not merely affect the abundance and diversity of aquatic insects including caddisfly, but it may also affect their ecological functioning. For example, Wantzen and Wagner (2006) and González and Graça (2003) found that the low water temperature may influence the effectiveness of shredders in decomposing the leaf litter.

2.2.3 Dissolved oxygen (DO)

An adequate supply of Dissolved Oxygen (DO) in the water is necessary to aquatic organisms to perform the proper and essential metabolism processes. The amount of DO in water is influence by the water temperature, salinity and water pressure (Seca *et al.*, 2011). The DO levels are often depleted in polluted ecosystems due to the presence of different organic materials as the oxygen is consumed in chemical oxidation of these materials. During the day time, the DO concentration is high due to active photosynthesis processes. However, it may decline at night times because of respiration (Dewson *et al.* 2007b).

According Elzinga (2004), the amount of dissolved oxygen varies remarkably in the aquatic habitats following changes in the chemical constitutions. Generally, the dissolved oxygen changes under several conditions:

1) Cold water has a higher DO saturation level compared to warm water
2) The DO level is higher during the day than at night
3) In stagnant water bodies, the main source of DO in water is the ambient atmosphere, thus deeper the water is corresponded with lower DO concentrations
4) Turbulence or water current
5) The presence of high organic matter usually lead to deterioration of DO levels due to decay and respiration process
6) Salinity reduces the solubility of oxygen in the water

Oxygen is transported across the gills and other respiratory of aquatic organisms by simple diffusion. The transportation rate depends on the gradient concentration, of oxygen in the water (Allan, 1995). Sudden deterioration in DO level may affect the ability of organisms to survive (Hilsenhoff, 1987). Thus, aquatic species richness and abundance are high with sufficient amount of DO in the water (Wahizatul Afzan, 2004). Similarly, it is well known that caddisfly larval population flourish in well-oxygenated rivers (Viðinskienë, 2005)

2.2.4 pH

Generally, the river water pH ranges from 6.5 to 9.0 which is the most suitable for aquatic life (Seca *et al.*, 2011). pH is considered as an important factor controlling the abundance and diversity of aquatic macroinvertebrates (Batty, 2005). Aquatic organisms differ in tolerance to the pH. For instance, in the extremely acidic waters, only collectors, shredders and predators can be found. Most of caddisfly larvae prefer neutral pH. However, some caddisfly larvae such as *Phanocelia canadensis* (Limnephilidae) were found in pool with lower pH (Colburn and Clapp, 2006). It was suggested that *Phanocelia canadensis* may have specialized physiological mechanisms to survive in the acidic habitats.

2.2.5 River width, depth and vegetation

The physical characteristics of rivers such as width and depth may influence the diversity and abundance of caddisfly larvae. Doi and Katano (2008) found that the water depth influences the distribution of *Glossosoma* (Glossosomatidae). In addition, Mihuc *et al.* (1996) found that high abundance of three hydropsychids larvae; *Arctopsyche grandis*, *Brachycentrus* and *Hydropsyche* was associated with high depth and width of the streams. In contrary, *Parapsyche elsis* prefer shallow and narrower streams. Similarly, Viðinskienë (2005) found that the abundance of *Hydropsyche pellucidula* and *Silo pallipes* was affected by water depth.

Apart from the vegetation along the river banks, the width of the river somehow influences the amount of deposited allochthonous materials entering the river ecosystem. Usually, smaller rivers with dense canopy cover receives high amount of allochthonous materials. On the other hand, distribution of caddisfly larvae especially shredders and scrapers is indirectly affected by the vegetation cover along the river banks where there is plenty of allochthonous materials deposited in the stream (Bispo *et al.*, 2004). Li and Dudgeon (2009) reported that the canopy cover influenced the abundance of the shredders but not the other functional feeding groups (FFGs).

2.2.6 Seasonal changes and flood

The tropical Asian climate consisted of two distinctive seasons (wet and dry season). Some studies in tropics (Dudgeon, 1992; Dinakaran and Anbalagan, 2010) and temperate region (Schmera and Erős, 2004; Šporka *et al,* 2006) stated that the assemblages of caddisfly larvae were highly influenced by seasonal changes. Leberfinger and Herrmann (2010) found that the production of shredders caddisfly was strongly controlled by the seasonality variations. In general, the abundance of caddisfly larvae was higher during dry season compared to wet season (Hughes, 2006; Dudgeon, 1990; Dudgeon, 1992). Besides, the community structure of the aquatic organisms is dramatically influenced by the amount of rainfall throughout the year (Thamsenanupap *et al.,* 2003; Lytle, 2003).

The seasonal fluctuation can cause the changes of the water discharge amount together with the water level and velocity. During the wet season, heavy rainfall may cause flooding and rising the water level and velocity. However, opposite changes may be noticed during the dry season. The flooding and spates reduce the abundance of caddisfly larvae as well as other macroinvertebrates (Lancaster, 1990; Lancaster *et al.*, 1991). Lytle (2003) found that flood strongly affect the *Phylloics aeneus*

(Calamoceratidae) population. However, flooding effects are often patchy and can extremely affect biotic distribution (Kilbane and Holomuzki, 2004). The degree of seasonal effect may differ with species. Hydropsychidae and Philopotamidae demonstrated broad seasonal occurrence (Thamsenanupap *et al.,* 2003), while the abundance of *Ironoquia punctatissima* (Limnephilidae) and *Neophylax mitchelli* (Uenoidae) was reduced during wet season (Kilbane and Holomuzki, 2004).

2.2.7 Environmental disturbance

The human activities such as agriculture, mining, urbanization, industrial, recreation and logging have the potential to change the aquatic macroinvertebrates communities leading to severe declines in both diversity and abundance (Haynes, 1999; Urbanič, 2006; Thompson *et al.,* 2009). Occurrence of the disturbance (land-use, deforestation, pollution) in the aquatic ecosystems eliminates sensitive taxa of the benthic macroinvertebrates (Sage *et al.,* 2004; Lorion and Kennedy, 2009). The deforestation and poor agricultural practices cause erosion (Allan, 1995). Meanwhile, logging activities cause sedimentation and heavy load into the riverine system (Douglas *et al.,* 1992). Consequently, increasing in erosion of sediments reduces the diversity and abundance of aquatic macroinvertebrates (Schwendel *et al.,* 2011). Similarly, Growns and Davis (1991) found that the logging activities affected the macroinvertebrate communities in streams up to 8 years after the disturbance has ceased.

Meanwhile, other human activity such as the construction of hydroelectric power plant resulted in formation of new man-made habitats such as a reservoirs, drainage ditches and canals which in turn influenced the composition of trichopterans community as well as other macroinvertebrates (Previšić *et al.*, 2007).

2.2.8 Altitude

The altitude and elevation are believed to influence the richness and density of caddisfly larvae (Maltchik *et al.,* 2009). Blinn and Ruiter (2009) stated that the different species of caddisfly larvae collected in rivers at different altitudes. Thamsenanupap *et al.* (2003) reported that *Arctopsyche* (Hydropsychidae) and *Himalopsyche* (Rhyacophilidae) inhabits in the highland and cold streams. Some caddisfly species are restricted to live in headwater streams. For instance, Dinakaran and Anbalagan (2010) found that *Georgium* and *Helicopsyche* (Hydropsychidae) were only found at the headwater stream, while *Hydropsyche* (Hydropsychidae) distributed in wider stream reaches.

Table 2.1 Various caddisfly species assemblages in rivers at different elevation (adapted from Blinn and Ruiter, 2009)

	Elevation (m)	
< 1000	1000-2000	> 2000
Hydroptilidae	Hydropsychidae	Brachycentridae
Hydroptila ajax	*Cheumatopsyche enonis*	*Brachycentrus americanus*
Hydroptila arctia	*Hydropsyche auricolor*	*Brachycentrus occidentalis*
Ochrotrichia logana	*Hydropsyche occidentalis*	Hydropsychidae
Oxyethira Arizona	*Smicridea disper*	*Ceratopsyche oslari*
Hydropsychidae	*Smicridea signata*	*Ceratopsyche venada*

Smicridea fasciatella	Hydroptilidae	*Sericostomatidae*
	Hydroptila arctia	*Gumaga griseola*
		Hydroptilidae
		Hydroptila arctia
		Ithytrichia mexicana
		Lepidostomatidae
		Lepidostoma unicolor
		Uenoidae
		Oligophlebodes minutus
		Polycentropodidae
		Polycentropus arizonensis
		Polycentropus gertschi

2.3 Spatial distribution of Trichoptera

Although the vast progress in ecological research, the spatial distribution of caddisflies still not completely understood (Mackay and Wiggins, 1979). Spatial distribution of caddisfly is as affected by different factors such as habitat structure and heterogeneity (Urbanič, 2006; Dudgeon, 2008; Dinakaran and Anbalagan, 2010). Generally, caddisflies larvae inhabit most types of freshwater habitats including rivers, lakes, marshes, temporary pool, spring streams and seepage areas (Wiggins *et al.,* 1994; Huryn and Harris, 2000). However, their abundance and diversity are significantly higher in lotic environments such as rivers and streams (Canton and Chadwick, 1983; Ward, 1992; Katano *et al.,* 2005). Streams and rivers with cool and running water appeared to be ideal habitats for several aquatic insects including caddisflies (Elzinga, 2004; Allan, 1995). Moreover, the riverine system provides various microhabitats such as stones and submerged and riparian vegetations for caddisfly larvae community as well as other macroinvertebrates. Therefore, different aquatic insects have different preference to microhabitats.For example, Bo *et al.* (2010) found that microhabitat preference of some preying larvae may change up on presence of the predators. The information of spatial distribution and habitat requirements for caddisfly larvae and other aquatic insects are useful for biological monitoring and establishing efficient conservation plans (Bispo *et al.*, 2004).

2.3.1 Types of microhabitat

The river ecosystem provides variety of microhabitats for caddisfly larvae as well as other macroinvertebrates. Therefore, riverine microhabitats consist of pool and riffles with combinations of rapid current and cascades of stones (Gullan and Cranston, 2005). Hughes (2006) found that the *Hydropsyche instabilis* (Hydropsychidae) belong to a group of species occurring in rapid water whilst *Polycentropus flavomaculatus* (Polycentropodidae) belonged to a group of species more readily associated with pool. Several studies found that the highest total richness and abundance of caddisfly larvae occurred at the riffle habitat (Gregory, 2005; Silveira *et al.*, 2006).

The riverbed morphology and substrate types had a significant effect on the caddisfly assemblages (Schmera and Erős, 2004; Viðinskienë, 2005). According to Allan (1995), the main categories of organic substrate are fine particles, dead leaves, submerged wood, moss and the surfaces of higher plant. According to Death and Winterbourn (1995), rocky streambed areas supported higher macroinverterbtes including caddisfly larvae. However, the various types and sizes of substrate may serve as microhabitats for different caddisfly taxa (Orth and Maughan, 1983; Gullan and Cranston, 2004). The *Glossosoma* (Glssosomatidae) were found in higher abundance among the cobbles with strong water current (Doi and Katano, 2008). Meanwhile, Kilbane and Holomuzki (2004) found that the abundance *Neophylax mitchelli* (Uenoidae) was very high in bedrocks and cobbles.

Besides, caddisflies larvae have different preference to microhabitats depending on size, characteristics and texture of stone surfaces. Cavanaugh *et al.* (2004) compared the efficiency of grazing *Glossosoma intermedium* (Glossosomatidae) on smooth and rough surfaces of substrates concluded that the substrate texture affects algal grazer dynamic. However, Morris *et al.* (2011) found that the *Glossosoma* spp. abundance was negatively correlated with streambed relative roughness. Moreover, the stability of the substrates are factor controlling the caddisfly species preferences (Schwendel *et al.*, 2011). Two of the most abundant species in mountain lakes; *Polycentropus flavomaculatus* (Polycentropodidae) dominated the stable stony riverbed. Similarly, Takao *et al.* (2006) recorded that the abundance of *Stenopsyche marmorata* (Stenopsychidae) was very high on the stable stones. However, *Limnephilus nigriceps* (Limnephilidae) live on unstable stony substrates (Ward, 1992). Meanwhile, several literature reported that the abundance of the caddisfly larvae was very low in pools and sandy substrates reflecting their less preference to those microhabitats (Allan, 1995; Ferro and Sites, 2007). Generally, sandy habitats are considered to be less favourable habitats for several macroinvertebrates including caddisfly larvae probably due to its instability (Allan, 1995; Edyta Serafin, 2004; Ailenei, 2005).

The microhabitat preference of caddisfly larvae may be related to the utilization of resources (Bispo *et al*, 2004). Usually, the species that inhabit the leaf packs are case-making caddisflies. Davies and Boulton (2009) found that the toughness of the leaf blades and their resistance to microbial decay contribute greatly to the quality of case-building material for *Anisocentropus* (Calamoceratidae). Meanwhile, *Tinodes* (Psychomyiidae) larvae (Hughes, 2006) and *Ironoquia punctatissima* (Limnephilidae) (Kilbane and Holomuzki, 2004) are common species in the leaf litter since the decomposed leaf provide food and shelter for caddisfly larvae (Dobson and Hildrew, 1992).

Furthermore, the composition, abundance and distribution of aquatic plants remarkably influence the aquatic insect communities (Ward, 1992). The submerged vegetation and moss on stone surfaces are favorable habitats for caddisflies. Colburn and Clapp (2006) found that the *Phanocelia canadensis* (Limnephilidae) was successfully associated with moss (*Sphagnum sp.*). Similarly, Wood and Sites (2002) found that *Oxyethira* (Hydroptilidae), *Oecetis* and *Triaenodes* (Leptoceridae) were associated with rootmats.

However, a particular habitat may only support a certain population numbers, which is known as ‘carrying capacity’. In a particular habitat, the higher density increases the competition for space and food. According to Holomuzki *et al.* (2010), competition can be apparent where real competition occurs directly through interference competition or indirectly through resource exploitation. Nakano *et al.* (2007) found that the case aggregation of grazer *Geora japonica* (Georidae) in cobbles decreased the abundance of another grazer species of *Glossosoma* sp. (Glossosomatidae) due to competition for food sources. Cavanaugh *et al.* (2004) found that *Glossosoma intermedium* (Glossosomatidae) expand foraging strategies or seek new patches with alternative food sources when they encounter competition in their niches. However, other biotic interaction such as predation can also determine the size and structure of the caddisfly community (Nakano *et al.,* 2007). Surprisingly, Wissinger *et al.* (2004) found that the caddisfly species of *Asynarchus nigriculus*, *Hesperophylax occidentalis*, *Limnephilus externus*, *Limnephilus picturatus* and *Limnephilus secludens* that live in temporary wetland habitats were extremely aggressive and showed cannibalism behaviour when they were caseless due to limited food sources. Meanwhile, those species with cases were less vulnerable to predation.

2.3.2 Functional Feeding Groups (FFGs)

The amount of benthic organic matter (BOM) which is one of the food sources in river ecosystem is known to influence the community structure of functional feeding groups (FFGs) (Yamamuro and Lamberti, 2007). Benthic invertebrates including caddisfly larvae have evolved a diverse array of morphological and behavioural mechanisms for exploiting the available food resources (Wallace and Webster, 1996). The spatial distribution of caddisfly larvae in riverine ecosystems is somehow related to their feeding habits (Hynes, 1970; Mackay and Wiggins, 1979). Generally, functional feeding groups of caddisfly larvae are divided into five categories; scraper, collector-filterer, collector-gatherer, shredder and predator (Morse and Holzenthal, 2008).

Gullan and Cranston (2005) and Wallace and Webster (1996) defined scrapers as animals which were adapted to graze or scrape materials such as periphyton and attached algae from minerals and organic substrates. Meanwhile, Holomuzki *et al.*, (2010) defined the scraper as organisms that wholly or partially eat multiple live producers such as photosynthetic bacteria, algae or plant over their lifetime.

The distribution of the scrapers may differ depending on the type of the habitat. For example, Buffagni and Comin (2000) found that the scrapers were in high numbers in riffles. However, Katano *et al.* (2005) found that the aggregation of grazing *Micrasema quadriloba* (Brachycentridae) was associated with the periphyton. Similarly, the grazing caddisfly species of *Glossosoma* (Glossosomatidae) was found scraping periphyton from the upper surfaces of rocks in lotic waters (Ward, 1992). Whilst, grazing larvae of *Ceraclea* (Leptoceridae) was found on rocky surfaces of lenthic habitat (Mackay and Wiggins, 1979). Morris *et al.* (2011) reported that *Glossosma* spp. larvae were the most dominant grazers in lotic food webs with high capability of suppressing the stream periphyton.

Shredder is defined as the organisms that comminute primarily large pieces of decomposing vascular plant tissue (> 1 mm diameter) along with the associated microflora and fauna, feed directly on vascular macrophytes, or gouge decomposing wood (Wallace and Webster 1996; Gullan and Cranston, 2005). Generally, upper stream catchments in forested areas receive a large portion of their energy input as coarse particulate organic matter (CPOM) from terrestrial litter input (Wallace and Webster, 1996), thus can support a rich shredding caddisfly such as calamoceratid and certain leptocerid caddisfly (Boyero *et al.,* 2009). The shredders play an important role in carbon cycle in the aquatic ecosystems and sustain sufficient organic food sources for other organism. Leberfinger and Herrmann (2010) observed that the shredder production was positively correlated with amount of organic matter. The larvae of the shredding *Phylloicus* sp. (Calamoceratidae) (Wantzen and Wagner, 2006) and *Sericostoma vittanum* (Sericostomatidae) (González and Graça, 2003) were collected from lateral pools with high woody debris accumulation. Similar findings were reported by Buffagni and Comin (2000) as they found that the shredders were abundant in pool. Yule *et al.*, (2009) suggested that the diversity and richness of the shredder depend on characteristic of the riparian vegetation along altitudinal gradients, elevation, water temperature as well as variation in water chemistry at local scales.

Wallace and Webster (1996) defined collector-gatherer as a group of animals that feed on fine particulate organic matter (FPOM; <1 mm diameter) deposited in the stream. Collector-filterer are equipped with specialized anatomical structure such as setae, fans, mouth brushes or silk secretions that act as sieves to capture suspended FPOM in the water column (Wallace and Webster, 1996). Net-spinning caddisfly larvae especially members of the family Hydropsychidae are an important group of filter-feeders in terms of biomass and production in many streams (Edler and Georgian, 2004). Canton and Chadwick (1983) observed that the filter-feeder species of *Brachycentrus americanus* (Brachycentridae) and *Arctopsyche grandis* (Hydropsychidae) were abundant in upper streams, while *Hydropsyche* (Hydropsychidae) were abundant in middle reach rivers. The filtering net is considered an important structure for filter-feeders in the aquatic ecosystems. The filter net meshes varied according to instar and species (Runde and Hellenthal, 2000).

Predators are organisms that feed primarily on animal tissue by either engulfing their prey or piercing prey and sucking the body fluids (Wallace and Webster, 1996; Gullan and Cranston, 2005). The free-living *Rhyacophilla* (Rhyacophilidae) is one of the predatory caddisfly (Ward, 1992). The predacious *Oecetis* were found to live on rocky surfaces in lentic habitat (Mackay and Wiggins, 1979). Although there is an ecological balance between number of both preys and predators, predator abundance can limit the abundance of benthic prey and affect prey size, behaviour and morphology which in turn will lead to remarkable alterations in food web and ecosystem (Wallace and Webster, 1996; Holomuzki *et al.*, 2010).

2.4 Importance and ecological function of Trichoptera

2.4.1 Bioindication of aquatic ecosystem health

Generally, the macroinvertebrates including caddisfly larvae differ in their environmental tolerance and habitat requirement (Dewson *et al.,* 2007b). Caddisfly larvae are known to inhabit clean and unpolluted rivers. Most of them are intolerant to physical and chemical disturbance in the aquatic ecosystem (Urbanič, 2006). Thus, they serve as valuable indicators for water condition and can reflect the subtle changes in water quality and riverine ecosystems (McGavin, 2001; Viðinskienë, 2005). It is well established that caddisfly larvae have the potential to be useful and reliable bioindicators for water quality and river conditions (Šporka *et al.,* 2006; Dinakaran and Anbalagan, 2007). Specifically, some trichopteran species can be used to reveal the presence of heavy metals in the aquatic ecosystem (Sjøbakk *et al.*, 1997). Similarly, Bonada *et al.*

(2004) reported that the caddisfly larvae from the families of Limnephilidae, Psychomyiidae, Rhyacophilidae are very sensitive to any possible contamination with sulphates and chloride. However, philopotamid larvae are intolerant to eutrophication and toxicity. In general, the various caddisfly species respond differently to the physical and chemical changes in the water bodies. For instance, hydropsychid larvae especially *Hydropsyche exocellata* are very tolerant to chemical and/or physical pollution. Moreover, Bonada *et al.* (2004) reported that the glossosomatids are tolerant to salinity. On the other hand, leptocerids have the ability to survive in streams with extreme concentrations of sulphate (up to 638 mg/l) and chloride (up to 176 mg/l). Similarly, philopotamids endure high concentrations of suspended solids (up to 96 mg/l) and sulphates (up to 791 mg/l).

In the last decades there is a fast and strong development and improvement of application the aquatic macroinvertebrates including caddisfly as bioindicators for ecosystem health and integrity. According to Barbour *et al.* (1999), there are several advantages in using macroinvertebrates in biomonitoring programs to assess the water quality and river conditions:

- Macroinvertebrate assemblages are good indicators of localized conditions because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, they are particular well-suited for assessing site-specific impacts
- Macroinvertebrates are capable in integrating the effects of short-term environmental variations. Most species have a complex life cycle of