CHAPTER 2

LITERATURE REVIEW

An early limnological study (Bishop, 1973) comprehensively reported on the aquatic fauna, particularly the benthos, in a Malaysian stream. Towards much later, several ecological studies (Ho & Tan, 1997; Zakaria-Ismail & Aishah, 1997; Yap, 1997; Yap *et al.*, 1997) devoted to the relationships between riverine fauna and environmental factors and water quality classification.

2.1 RIVER CONTINUUM CONCEPT

Relationships between riverine fauna and environmental factors were historically based on the classification of rivers into zones or district units from headwaters to mouth (Hawkes, 1975). In such longitudinal gradient or river continuum concept models (Vannote *et al.*, 1980), macroinvertebrates have been the commonly studied biota within a similar set of drainage basins. These models predict that invertebrate assemblages will change along the lengths of rivers and may be used to relate the spatial distributional patterns of family-based insects associated with a series of physical gradients along rivers. Cummins *et al.* (1989) illustrated an association between feeding groups of aquatic insects and riparian vegetation along the length of rivers. However, deviations from the stream ecosystem model and exceptions can be found in nature too and, have been reported and explained by variations in climate, riparian vegetation and tributaries (Minshall *et al.*, 1985) and changes in water quality. Therefore, it is important to consider and differentiate natural longitudinal changes from changes in water quality or changes due to other environmental variability.

2.2 ECOLOGY OF AQUATIC INSECTS

The emphasis for aquatic insect studies has been mainly from ecological perspective, beginning from its relevance in sport fishery-related accounts of the '30s and '40s, and through growing interest in bioindicators for water quality studies of the '50s and '60s. Of relevance to this study is a large amount information on the ecology and geographical distribution of aquatic insects. Ecological data have been organised in three categories (Cummins & Merritt, 1994) and are summarised as below.

2.2.1 Habitat Affiliation, Habit and Distributional Pattern

Aquatic nymphs and larvae adapt to two basic distinct habitat types: (1) lotic (running waters e.g. streams and rivers) and (2) lentic (standing waters e.g. ponds and lakes) environments. However, the habitat affiliation is determined by the physical-chemical conditions and substrate differences prevailing among erosional (stream ripples and along rocky, wave-swept lakeshores or splash and seepage zone of waterfall), depositional (pools of stream-river, soft sediments of lake bottoms), and semi-aquatic zones. Dictated by the prevailing conditions, often the same genera may occur in both erosional and depositional habitats. As examples, snail-case caddisfly *Helicopsyche borealis* (Helicopsychidae, Trichoptera) is reported to inhabit cobble substrates in both lotic and lentic habitats of North America. Similar co-occurrence of aquatic biota can also be found in semi-aquatic habitats. Within a given habitat, nymphs and larvae adopt habits and modes of maintaining their habitat location (live as a clingers to surfaces in fast-flowing waters e.g: Heptageniidae & Hydropsychidae; climbers/sprawlers on vascular hydrophytes and riparian vegetation e.g: Aeshnidae & Libellulidae; or as burrowers in soft sediments e.g: most

Chironominae) or have morpho-behavioral means (move as surface skaters e.g: Gerridae or swimmers/divers e.g: Leptophlebiidae & Corixidae).

Habitat affiliations of aquatic insects are generally useful in partitioning aquatic insect genera and elucidate on the taxonomic resolution of co-existing genera (or even species). The habitat affiliations and selection gives rise to a characteristic distribution pattern (random, uniform, patchy and aggregate) resulting from the optimal overlap between physical-chemical environmental aspects of the habitat (flow, turbulence and substrate) and faunal habit/adaptation mode of existence. Other contributing factor to distribution pattern is food resource category and availability. Thus, the patchy distribution pattern of an aquatic population is the result of interplay among three factors: habitat (water flow, sediment particle size and detrital debris), organism's habit or mode and food resource availability (Cummins & Merritt, 1994; Pringle *et al.*, 1988).

2.2.2 Aquatic Insect Orders – Ephemeroptera, Plecoptera and Trichoptera (EPT) Group vs Odonata as Water Quality Indicator Taxon

Among the lotic macroinvertebrates, three insect orders comprising Ephemeroptera, Plecoptera and Trichoptera (EPT) have been used for monitoring water quality in hilly pristine running waters (Lenat, 1988; 1993). This indicating assemblage has also been used in Malaysian streams (Che Salmah *et al.*, 2001; Yap, 2004). In lentic environment, Odonata, both Zygoptera and Anisoptera sub-orders are proposed to be a suitable water quality indicator; like in the freshwater swamp lake, Tasik Bera, Malaysia (Norma-Rashid *et al.*, 2001).

The diversity, compositional and distributional patterns of EPT is influenced by their tolerance to a set of physical-chemical variables, types and availability of fast-flowing, cooling microhabitats; and can be affected locally by changes in water quality (Che Salmah *et al.*, *op. cit.*). Indirectly, an assessment on the EPT taxa richness, abundance and tolerance levels allows limnologists to determine rapidly the status of water quality in the habitats of these indicator taxa. The information on EPT taxa richness can also be based on for water quality classification in mountains and hilly pristine areas (Lenat, 1993).

2.3 WATER QUALITY CLASSIFICATION USING EPT METRIC AND MACROINVERTEBRATE-BASED BIOTIC INDICES

It is assumed that the EPT taxa richness, abundance and distribution is site-specific and indicative of their preference and tolerance towards the specific conditions of the microhabitats. Using this assumption, Lenat (1993) had proposed using EPT taxa richness as a biotic criterion for assigning or rating a water quality classification separately for mountains, hill country and coastal plain. The classification includes excellent, good, good-fair, fair and poor classes. However, the EPT taxa richness data when used must consider variation arising from seasonal changes, changes in number of taxa associated with nutrient enrichment and effect of stream size and current speed.

Biotic indices based on grouping of macroinvertebrates are recent (Chutter, 1972; Hilsenhoff, 1982), after the Pantle and Buck index, which was probably the first macroinvertebrate-based index for pollution rating (Pantle & Buck, 1955 cited in Yap, 1997). Recently, Hilsenhoff (1988), Lenat (1988) and Biological Monitoring

Working Party (BMWP) of Europe (Chapman *et al.*, 1996) have developed the popular family- and genus-level biotic indices that have been widely used for determining water resource quality. As compared with other local fauna in aquatic ecosystem, the macroinvertebrate usage has considerably made the community-based approach easier, and can be readily applied into the regulatory culture in any country, especially in a tropical country like Malaysia (Che Salmah *et al.*, 2001; Yap, 2003).

2.4 WATER QUALITY

The term "water quality" is used to express the suitability of water for various uses or processes (Bhargave, 1985). Water quality can be defined by a range of variables and guidelines set by authorities. Without sacrificing the basic requirements of the guidelines set by water authorities, efforts to enhance or maintain the water quality often compromise between the quantity and quality because of varying demands for different uses.

2.4.1 Natural Factors Influencing Water Quality of Pristine River

Water quality is influenced by both the natural and human factors. In water quality management of natural flowing water, it is essential to identify those natural factors that either individually or jointly, affect the quality of water (Reinert & Hroncich, 1990; Meybeck *et al.*, 1996). The degree of influence by these factors varies depending on the characteristics of the watershed and drainage basin. Again, the vulnerability of the water to eutrophication and contamination also varies depending on the size and type of water bodies, such as a hilly fast-flowing river compared with lowland meandering river.

The free flowing river can restore itself more rapidly than standing water through seasonal and short-term runoff cycles. With the free flowing water, it is also self-aerated and able to replenish its oxygen content more rapidly. Seasonal change in weather patterns, such as prolonged drought or rainy seasons, will have a direct effect on river water quality.

Certain natural factors can degrade water quality and affect the water quality to fall below recommended standards required for protection of nature reserve. Natural factors cannot be easily controlled and may have a significant impact on the water quality. Natural events may include climate, watershed characteristics, topography, flora and fauna, geology as well as microbiological growth. (Reinert & Hroncich, 1990; Meybeck *et al.*, 1996).

(a) Climate

Variations in weather patterns have direct effect on the water quality. The main effect by the weather conditions on water quality is the precipitation process (Reinert & Hroncich, 1990). Wet climates such as torrential rainfall and hurricanes lead to high rates of runoff, soil erosion and landslides. All these will result in high content of suspended matters, which in turn cause increases in turbidity, colour, metals and other contaminants. The flushing effect of heavy precipitation on watersheds can lead to the accumulation of organic compounds and other contaminants through runoff, with deleterious effects on water quality. Prolonged dry weather will lead to low rates of runoff and stagnation of water, which promotes the microbiological activity and algal growth. Another climatological factor that has effect on water quality is temperature. It can affect the rate of biological activity, oxygen saturation and mass transfer of water with little or no dissolved oxygen to the surface.

(b) *Watershed Characteristics*

The different types of natural characteristics of a watershed can have a significant effect on water quality. Topography of the surrounding area is an important factor, which affects the flow rates. Steep slopes may result in erosion of topsoil, which lead to increases in turbidity, colour, poor clarity, nutrient loading, metals and other contaminants. Topography also has effect on the residence time where the residence time affects water quality through its effect on sedimentation and biological activity (Reinert & Hroncich, 1990).

The surrounding flora and fauna can affect water quality in a few ways. Vegetative cover provides a natural filtering system for runoff and a buffer to human activities. On the other hand, decomposition of vegetative materials will cause colouration and release of humic compounds (Reinert & Hroncich, 1990). Wildlife found in the watershed area affects water quality through their droppings and pathogens carried by some of the warm-blooded animals. Local geology has direct impact on the quality of surface water (Meybeck *et al.*, 1996). Soils play a significant role in water quality, acting as buffering zone for acidic precipitation. Higher acidity of runoff have adverse effect on biological activities in the watershed.

(c) *Microbiological Growth*

The state of a water body depends on nutrient levels and microbiological activity. The natural life cycle of a water body consists of three stages known as trophic levels. The three stages are oligotrophic with low nutrient and minimal microbiological activity, mesotrophic with moderate nutrient and microbiological activity and lastly eutrophic with high nutrient and high microbiological activity (Reinert & Hroncich, 1990). Sudden increase in microbiological activity will lead to depletion of oxygen levels, high turbidity and dense colour, and the formation of trihalomethane (THM) precursors. All these result in problem with the aesthetic and other water quality problems such as water clarity (Mono, 1991).

2.4.2 Human-Induced Factors Influencing Water Quality of Pristine River

Human activities, which may have subtle effects on natural running waters, are tourism and recreation, livestock, land development and deforestation. Human activities related to low-density tourism, have impact on water quality and are usually categorised into point and non-point sources. Point sources are those contamination sources characterised by a single or discrete source. Non-point sources involve large and diffuse sources of contamination such as lavatory runoff. Non-point sources of contamination are more complex and difficult to control than point sources' contamination. Recreational activities such as swimming, boating, and camping in watersheds can degrade surface water quality. Although the significance and extent of the impact caused by recreational activities on water quality are not clearly defined, there are results indicating the adverse effects. Several studies show that coliform counts in recreational areas are about 10 fold higher than those in a similar watershed but without any recreational activities (Reinert & Hroncich, 1990).

The presence of livestock in watershed areas contributes bacterial contamination to water sources. Nutrients such as nitrates from the feedlots also create adverse effects on water quality. Uncontrolled or over-grazing cause increased soil erosion during surface runoff, which leads to high sediment loading, turbidity and colour.

Large scale of land development due to illegal logging in the protected area contributes directly to contamination of water source. Land development, deforestation and forest fire decrease the buffer zones of natural vegetative cover that filter runoff and prevent soil erosion. Erosion of the soil causes soil particles and nutrients to be carried by surface water runoff, and also increases the sediment loading and creates adverse effects such as increased in turbidity, colour and eutrophication of water sources.

Earlier published works (Aiken & Leigh, 1984; Kiew *et al.*, 1987) on Endau-Rompin Forest Reserve, indicated that human-induced factors have yet influenced significantly on the water quality of the hilly and fast-flowing rivers.

2.5 ENDAU-ROMPIN FOREST RESERVE

The Endau-Rompin National Park is situated at the border between Johore and Pahang states covering more than 80,000 hectares, in the south of Peninsular Malaysia (Figure 1). The Endau-Rompin National Park was gazetted as a national park in 1993 (http://www.bernama.com./johor/eco.htm, 2003). The National Park is an area defined by topography and remaining forest cover, rather than by administrative boundaries. It includes parts of the Labis Forest Reserve and Endau-Mas Forest Reserve in Johore and the Lesong Forest Reserve in Pahang (Davison, 1989). It covers the whole upper part of the Endau River basin and headwaters of the Pukin River, a tributary of the Rompin River (Aiken & Leigh, 1984). The Endau River basin is fed by five main sub-basins comprising Kinchin, Kemapan, Jemai, Kemidak and Selai Rivers. The Kemidak-Selai Rivers join at the southern border of the protected area to form Semborong River, which then flows southeasterly to drain into Endau River. A number of waterfalls and tributaries feed the Selai River. The major waterfalls are the Takah Pandan, Selor and Air Batu Dinding, which are located above 300 – 500 m, forming the headwaters of the Selai River.

Endau-Rompin National Park is rich in natural features such as hills, rocks, cliffs and waterfalls. The hills around Endau-Rompin area which form remarkable landmarks around the surrounding park area of Pahang and Johor are mainly made up of ignimbrite, a volcanic rock, and granite (Davison, 1989). Gunung Besar, the highest peak in the region, is 1036 m above sea level. At the Kemidak-Selai Rivers sub-basin, the highest peak, Gunung Tiong, rises to 800 m above sea level.

The Endau-Rompin National Park contains a wide range and fascinating collection of tropical lowland and hilly rain forest with pristine rivers, interesting flora and fauna. It is also the home to some of the highly endangered and rarest animal, such as the Sumatran rhinoceros *Dicerorhinus sumatrensis*, and others like the seladang or Malayan gaur *Bos gaurus hubbacki* and the tiger *Panthera tigris* (Aiken & Leigh, 1984; Kiew *et al.*, 1987; Davison, 1989).

The Endau-Rompin Forest Reserve area is traditionally used by the aboriginal people (the *Jakun* or *Orang Hulu* people), who depend heavily on the biodiversity of wildlife and pristine rivers as source of protein and potable water (Mabberley, 1983). The *Jakun* or *Orang Hulu* people rely very much on the rivers for food and transportation. They spend a lot of their time fishing and catching other aquatic animals such as turtles, terrapin and prawn, which are important food source to them. Narrow boats that are made from planking, dug-out boats from tree trunks and light canoes made from bark sheets stripped from trees are used for fishing and travelling from one place to another (Davison, 1989).

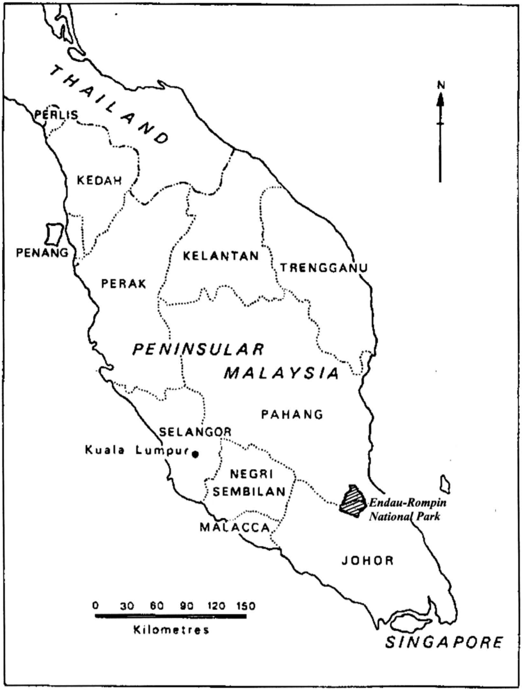

Figure 1. Peninsular Malaysia: Location of Endau-Rompin National Park (Source: Aiken & Leigh, 1984)

2.6 ECOLOGY OF TRICHOPTERA (CADDISFLIES)

Trichoptera, or caddisflies, comprise one of the major aquatic insect orders. The name Trichoptera, derived from the Greek words "*trichos*" meaning hair and "*ptera*" meaning wings, refer to the long and silky hairs that cover most of the adult's body and wings.

The case making behaviour of some species at larval stage may contribute for the common name known as caddisfly. Although, the origin of the word is obscure, it has been suggested to derive from "cadaz", which is meant for cotton or silk used as a padding back in 1400. Forty years later, with the same meaning, it was spelt as "caddace" (caddys), a word of variable spelling used in Shakespearean times to refer to a ribbon made from a certain kind of yarn sold by traveling vendors, who because of this were sometimes called "caddice men". Caddice men would often pin samples of their wares to their clothing, a habit which may have suggested the name caddisfly or caddisworm for the larvae of caddisflies, who exhibit the analogous behaviour of attaching bits of leaves and twigs onto the outside of their cases (Hickin, 1967).

2.6.1 The Life Cycle and History of Trichoptera

All caddisfly larvae live in aquatic environments. They may be herbivores, scavengers or predators. In most cases, the predatory species are usually free-living or spin silken structures similar to webs or tunnels in the water to trap their prey. Meanwhile, the herbivore and scavenger species will usually live within the protective cases built by them from their own silk, stones, twigs, leaf fragments or other natural materials. The design and construction of the case is distinctive for each different family or genus of caddisfly. The case is usually portable and can be dragged around like a snail shell as the insect moves. A pair of hooked prolegs at the tip of the larval abdomen is used to hold its case in position. Most of the species have thread-like abdominal gills and get oxygen from the water that circulates inside their case. All larval growth and development, which also including the pupation stage, occurs within the case.

The adults, when compared to the larvae, are terrestrial and look like drab, fragile moths. They are often found in large amount by the lakeside or stream-side habitats. The adults are mostly nocturnal, weak flying insects that are attracted to lights. During the day, they hide in cool and moist environments such as dense vegetation found along the riverbanks (http://www.cals.ncsu.edu/course/ent425/compendium/caddis~1.html, 2003). Most caddisflies especially in temperate latitudes complete one generation every year, passing through generally five larval instars, a pupal stage and lastly, a winged adult stage although life cycles of six and seven larval instars were recorded for a European species (Wiggins, 1977).

(a) The Egg Stage

Caddisflies lay their eggs either in water or areas near to it. In some species, the female caddisflies will enter into the water and lay their eggs before cemented the eggs on to the surface of rocks or aquatic vegetation. Other species of caddisflies lay their eggs in an oval or irregularly shaped mass and are enveloped in gelatinous material. The egg masses will then released into the water by dipping their tails against the pulling current of the stream. Once in contact with water, these egg masses will swell up and become very glutinous in order to stick to any rough surfaces that come into contact while travelling downstream (Hickin, 1967).

(b) The Larva

The larvae of Trichoptera have a primitive structure with an elongated body. Its body is well segmented into head, thorax and abdomen. It has a sclerotized prothorax, followed with less sclerotized or membraneous meso- and metathorax. Like most holometabolous larvae, the mouthparts are well developed with the mouth more or less facing forward and downward (Lepneva, 1964). They have well-developed thoracic legs but abdominal prolegs are absent except for a pair of anal prolegs on the last abdominal segment, bearing a strong anal claw (Morse *et al.*, 1994).

Caddisflies larvae can be found in different type of habitats ranging from fast flowing to still waters. They construct a case or retreat, except for a few free-living families. The larvae are mostly aquatic in the immature stages. They spend their whole larval state in aquatic habitat with the ability to extract oxygen directly from the water through either gills of various types or cuticles, depending on type of species.

The larvae of Trichoptera are generally subdivided into three distinct groups: the eruciform, suberuciform and campodeiform larvae (Hickin, 1967). The eruciform larva has a whitish and/ or greenish cylindrical abdomen. It constructs and stays in cases made of various materials like sand particles and pieces of vegetation. It has shallow intersegmental grooves in the abdomen, hypognathous head and furnished with protuberance at first abdominal segment. The suberuciform larva also constructs cases and has coloured abdomen with distinct patterns. This type has deep intersegmental grooves in the abdomen with a head in between hypognathous and prognathous type. The third group is the campodeiform larvae where it differs completely from thė earlier two groups in having a prognathous head, distinctly defined abdominal and thoracic segments and with long anal legs. Usually these larvae do not construct any cases and free-living or they live in movable cases. Some spin net-liked structures and cement to the underneath of stones or aquatic plants. These larvae use these nets to trap smaller aquatic animals and detritus for food (Lepneva, 1964; Hickin, 1967).

A life cycle of 5 – 7 larval instar was recorded and in some cases diapause was demonstrated, usually at the last larval instar stage, until the conditions in its habitat are more favourable (Wiggins, 1977). The final stage of larval is the prepupal stage where remarkable changes on the morphology and functionally more towards of a pupa.

(c) The Pupa

The caddisfly pupae are also aquatic and have dectitious mandibles in most families (http://www.cals.ncsu.edu/course/ent425/compendium/caddis ~1.html, 2003). The pupa of Trichoptera is protected by a cocoon, where it is usually made from the larval case, by concealing both the front and rear entrances. The cocoon is attached to submerged stones, aquatic plants or woods. During the pupal stage, the pupa moves very little except at the end of pupal stage. These small undulating movements are to ensure that the fresh water with oxygen will enter into the case by creating a current from the front to the rear of the case. Through this method, oxygen is being extracted from the fresh water as it baths the abdomen and gills. After hatching, the pupa will emerge from the cocoon, swims for some time before crawling out of the water by clinging onto plants or stones.

2.6.2 General Description of External Morphology

Trichoptera are closely related to the order Lepidoptera due to this similarity of having "dressed-up wings", which referring to dense clothing of scales or hairs on the wings (Kristensen, 1984; Morse *et al.*, 1994). Trichoptera possesses the more primitive character of having hairs rather than scales on the wings. Adult caddisflies have a number of characteristic features. The adult mouthparts are reduced or vestigial, but the maxillary and labial palps are prominent. Most species have filamentous or filiform antennae that are about as long as their body, but they can be several times longer than the body in some families. They have well-developed compound eyes, and not all species have the ocelli. Tibial spurs on the legs are conspicuous (Lepneva, 1964; Hickin, 1967; http://www.cals.ncsu.edu/course/ent425/compendium/caddis~1.html, 2003). As defined above, the body and wings of the adult are covered with long and silky hairs or setae, which is a distinctive characteristic of the order.

2.6.3 Movement, Feeding and Respiration

(a) Movement

Generally, most of the larvae of Trichoptera move slowly on the bottom or on plant surfaces. They use their anal legs to cling onto substrates for better holding when crawling from one place to another. Some free-living larvae especially predators can travel quite rapidly on the bottom as they have strong and almost equal size legs. For young caddisfly larvae, swimming is quite common as a means of moving around but become uncommon in the later stages of development (Lepneva, 1964).

(b) Feeding

Caddisfly larvae are highly diversified groups and they demonstrate little selectivity on food (Lepneva, 1964; Morse *et al.*, 1994). They feed on a wide range of organic matters that are found in the flowing water or on the bottom. The feeding habits of caddisfly larvae are influenced by the structures or retreat built by them (Wiggins, 1977). Some larvae build net-liked retreats that also act as a filter that capture food particles of appropriate size from the flowing water. Their food consists of plant and animal materials. These animals obtaining food through this way are regarded as filter feeders (Wiggins, *op. cit.*; Morse *et al.*, 1994). Meanwhile, for those free-living ones, many of them are predators.

(c) Respiration

Similar to other aquatic insects, the larvae of Trichoptera have closed tracheal system (Lepneva, 1964; Hickin, 1967). In the early development stages, oxygen is absorbed through the whole body but respiratory organs such as tracheal gills or cuticles that are developed in later stages will be the main respiratory areas (Lepneva, *op. cit.*). The gills are differentiated mainly into filiform and compound gills. The former may vary in length and shape where it ranges from short finger-liked processes to long filaments longer than the length of the abdomen. The compound gills comprise tufts of small gills arising from a common or different stalk. The gills occur in longitudinal series with dorsal, lateral and ventral rows where generally, all gills are directed posteriorly. Usually abdominal gills are found only at 2^{nd} to 8^{th} abdominal segments and very seldom they occur at the 1^{st} and 9^{th} abdominal segments (Hickin, 1967).

Larvae with portablė tube-liked cases have higher efficiency of respiratory rates. Dorsal-ventral abdominal undulating movement can create an artificial current of fresh water flowing from the anterior entrance and out at the posterior opening of the cases and dissolved oxygen are absorbed from the water bathing their bodies and gills (Lepneva, 1964; Hickin, 1967; Wiggins, 1977; Morse *et al.*, 1994). Free-living larvae without cases depend on the fast-flowing current for respiration.

2.6.4 The Economic Importance of Trichoptera

Although caddisflies are not generally considered to be of great economic importance, they are important components in the diet of freshwater fish. The benthic larvae of Trichoptera are one of the food sources of bottom-feeding fish in various freshwater bodies (Lepneva, 1964; Hickin, 1967). Certain predatory young fish sometimes also feed on Trichoptera larvae and adult. The most useful food for the fish is the macro-caddisfly which appears in great numbers such as various species of Limnephilinae (Lepneva, 1964). Some fishes such as trout feed on larvae and adults of Trichoptera and other insects. These fish jump out of the water to catch the adults or catch them from the water surface when these insects hatch or lay eggs. Besides the fish, birds, bats and other insectivorous animals also consume large amount of the adult stage of caddisflies. Swallows and bats are found to be flying over rivers or lakes, looking for caddisflies in the late summer evenings. Caddisflies form part of the food of terrestrial and wild aquatic birds, some mammals, especially when they fly in great numbers. Some of the reptiles such as frogs, snakes, lizards and even mammals like bears feed on these insects when they are at rest on trees and stones (Lepneva, 1964; Hickin, 1967).

The larval stage of caddisflies plays an important role in cleaning up their aquatic environment. The case-making caddisflies, cut up vegetation for the construction of their cases, thus indirectly clearing organic debris found in the habitats and niche they occupy. They feed on almost all forms of organic matter, living or dead, found in the water bodies. The herbivorous species feed on vegetation only while the carnivorous species feed on a wide range of freshwater animals, and also show cannibalism among their own species.

Caddisflies are often found in extraordinary large numbers, yet they are usually go unnoticed. They are hardly regarded as pests and only occasionally they caused considerably minute economic damages to the local community. In the larval stage, the species *Limnephilus lunatus* and some other species, cause damage to some of the water plants such as watercress beds by chewing the stalks and shoots for food and to construct their retreats. A few species have been recorded as pests in the rice fields as they cause damage to the newly transplanted rice plant (Hickin, 1967).

During the nuptial flight, caddisflies shed their pupal exuviae. These exuviae float on the water and may eventually, lead to clogging of filters of municipal water pipes. The canal's walls of reservoirs and hydroelectric power stations provide new habitats to some species of Hydropsychidae. These species have been recorded to settle on the walls of canals, where larval cases, nets and pupal shelter are built. The larval and pupal shelters, which consist of solidly glued sand grains and gravel, form scaling and thus, narrowing the canal and often reducing the output of the power stations by 10 – 20 % (Lepneva, 1964). In order to prevent thickening of scale on the wall, periodic scraping of the canal wall or other methods such as using cuprous oxide paint are recommended but all these will lead to higher maintenance cost.

2.6.5 Potential Use of Trichoptera as Water Pollution Indicator

Caddisflies have the potential to be used as water pollution indicator as they are represented by a large and diversified group (Wiggins, 1977). Although caddisfly larvae occur mainly in cool and lotic habitats, they can be found in warm and lentic conditions too. They are not site specific and certain groups have the ability to adapt to a harsher environment. Through these adaptations, the available niches in the habitats can be exploited more efficiently.

Caddisfly larvae are known for their ability to construct nets, retreats and portable tubes or cases. These case making behaviours are closely related to their diverse roles in the surrounding environment. Besides serving as shelter, the cases also assist the larvae to capture or obtain food particles from the current through the nets. Portable cases enable the larvae to travel from one place to another for food and they also increase the efficiency of the larvae's respiration through artificial current created by the larvae rather than depending on natural current (Wiggins, 1977; Morse *et al.*, 1994).

It is common that caddisflies are found to be more abundant in species and biologically more diversified in any given habitat. Therefore, through the adaptation on different type of habitats and case making abilities, the caddisfly larvae have the potential to become one of the reliable water pollution indicators (Nielsen, 1974).

2.6.6 Habitat Affiliation, Distribution and Seasonal Abundance of Trichoptera

Habitat affiliations of Trichoptera are generally related to their habits in constructing of retreats and food acquisition. Although the habitat preference, compositional and distributional patterns, and seasonal abundance of Trichoptera could not be studied in this short-term study, some published information on these ecological aspects were briefly provided for the families that are found along Selai River, based on the works by Merritt & Cummins (1984), Morse *et al.* (1994) and Wiggins *et al.* (1994). The larvae of Ecnomidae (*Ecnomus* sp.), Psychomyiidae (*Psychomyia* & *Tinodes* spp) and Glossosomatidae (*Agapetus* sp.) families are clingers and their habitats are of lotic-erosional type. The Ecnomidae and Psychomyiidae families construct silk-tube retreats while the Glossosomatidae constructs turtle shell case, which is laterally compressed and they are generally collectors, gatherers or scrapers. As reviewed in sub-section 2.2.1, the helicopsychid larva (*Helicopsyche* sp.) is also a clinger but generally found in lotic and lentic-erosional habitat, and the larva is mostly scraper and builds snail shell-shaped case from fine sand and minerals.

The Hydropsychidae (*Diplectrona*, *Ceratopsyche*, *Cheumatopsyche*, *Hydropsyche*, *Potamyia* & *Amphipsyche* spp), Polycentropodidae (*Nyctiophylax* sp.), Stenopsychidae (*Stenopsyche* sp.) and Philopotamidae (*Chimarra*, *Dolophilodes* & *Wormaldia* spp) larvae are clingers whereby the first three families are net spinning fixed-retreat makers while the Philopotamidae builds sac-like silk net as its home. Most of the four families are found in lotic-erosional environment and through the net they filter food particles from the current. The larvae of Hydroptilidae (*Orthotrichia*, *Oxyethira*, *Stactobia* & *Ugandatrichia* spp) are mostly collector-gatherers and some as piercers. They are clingers or climbers, living in lotic and lentic-erosional habitat, and they consume mainly on plant material such as algae. Both the larvae of Leptoceridae (*Leptocerus* sp.) and Limnephilidae (*Arctopora* & *Dicosmoecus* spp) families are generally swimmers-climbers-sprawlers and their habitats are of lotic and lentic-erosional type. The former constructs silk-tube retreats while the latter makes cases from plant material or minerals though both are shredders or scrapers. The wide distribution pattern of caddisfly population is the result of interplay among habitats, habit or mode of existence and food availability. This adaptation explains partially the fact that caddisflies are one of the largest groups of aquatic insects (Morse *et al.*, 1994) inhabiting aquatic ecosystem from moderately poor to good water quality.