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Full Length Research Paper

Stoneflies (Insecta: Plecoptera) in Malaysian tropical rivers: Diversity and seasonality

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Adult stoneflies (Plecoptera) were light-trapped monthl from January to December 2008 in Tupah River, Kedah, Malaysia. Two families of Plecoptera, Perlidae and Nemouridae were represented with nine species. More Plecoptera was collected in the wet seasons especially for the family Nemouridae. *Neoperla* asperata was a common species that occurred throughout the year. *Neoperla fallax* was equally common but this species was absent during early part of the year. The percentage of females was higher than male for all species of Plecoptera collected.

Key words: Upstream river, Plecoptera, season, sex ratio, peninsular Malaysia.

INTRODUCTION

Plecoptera are primitive group of insects also known as stoneflies or salmonflies. The diversity of Plecoptera declines rapidly from temperate Asian latitudes (nine families) to tropical latitudes (four or fewer families). The only diverse stonefly family in the Malaysian region is the Perlidae. Comparative to their temperate counterparts, tropical stoneflies are incompletely understood (Sheldon and Theischinger, 2009) although these regions have the highest diversity of stoneflies (Zwick, 2000). Asian stoneflies diversity is much greater than that of Europe or North America but the knowledge of the enduring Asiatic areas is extremely poor (Fochetti and Tierno de Figueroa, 2008). In Malaysia, no systematic work on Plecoptera has been undertaken. Sivec and Yang (2001) estimated there are approximately 350 Plecoptera species in countries forming the Oriental Region except for Southern China. One reason for the paucity of ecological studies of tropical river Plecoptera in the international literature is the fact that identification of tropical species is difficult for non-specialist. Many lower taxa (especially genera and species) have received limited study and relevant literature is scarce (Boyero, 2002).

Plecoptera provides a valuable food source for a wide variety of vertebrates. Nymph and adult stages are eaten by many species of fish and amphibians (Petersen et al., 1999). Actively dispersing adults' Plecoptera are a valued and plentiful food source for bats and birds that feed at dusk on flying insects (Fochetti and Tierno de Figueroa 2008). Moreover, according to Sweeney (1993), mammals such as shrews and raccoons also eat on Plecoptera nymphs as well as emerging adults.

Aquatic insect emergence is strongly influenced by season. Based on Gopal (2002), most of the Asian countries are affected by the monsoon and seasonal rainfall where monsoon behavior is nearly unpredictable. Most tropical rivers have an annual cycle, which like so many features of the river is dictated by the pattern of rainfall (Payne, 1986). Precipitation plays a major role in changing the benthic community (Robinson and Minshall, 1986) in the tropical rivers (Silveira et al., 2006). In this study, the diversity and seasonal distribution of stoneflies of a water catchment in a tropical river of northern peninsular Malaysia were described. Previously, studies by Che Salmah et al. (2001; 2007) emphasize functional roles of immature plecopterans. In the present study adults were identified to the species level and their species richness evaluated for conservation value in Tupah River. Factors that could influence the temporal distribution of adults were investigated.

MATERIALS AND METHODS

Sampling of adult Plectopera

The sampling was carried out in Tupah River located at N5°45' E100°26' in Kuala Muda district. It is situated within the Gunung

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Table 1. Succession of adult Plecoptera (stoneflies) at Tupah River.

Taxon	DS							WS				DS
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N. asperata												
N. fallax												
N. hamata												
K. trang												
K. jariyae												
K. curriei												
E. nigrogeniculatum												
P. malayana												
Indonemoura spp.												
Total	4	8	16	100	20	34	6	25	13	5	26	42

Key: DS – Dry season; WS – Wet season.

Jerai catchment area, a virgin forest reserve. The 5.6 km long, 0.32 ± 0.05 meter mean depth with mean width 4.14 ± 0.28 meter river enters Merbok River, which flows, into the Straits of Malacca. Tupah River has fast flow of 0.56 ± 0.16 m/s. The water pH in the Tupah River ranges from 5.03 to 6.66 whiles the yearly mean water temperature ranged from 22.8 to 25.7 ºC. Tupah River passes through a low land Dipterocarp Forest at 100-200 meters above sea level. Tree species, such as *Shorea leprosula*, *Shorea ovata*, *Dipterocarpus sp.*, *Dillenia sp.*, *Pometia pinnata, Pongamia pinnata, Dolichandrone spathacea* and *Sindora sp.* are dominant in the area. River substrates are predominantly cobble and gravel (65%), and the other 35% of river sediment is made up of boulder.

Light trap was used to collect adults Plecoptera in this study. Two white sheets (1.7 m long x 1.2 m wide) were hung adjacent to each other at right angle (90°). They were placed 5 m from the river edge. Mercury light bulb (250 watt) powered by portable generator (EM650Z) was provided between the sheets. White mercury light was used for the trap because it consisted of a combination of all the visible wavelengths (Ward, 1965). All adults landed on the sheets were collected either with forceps or by hands and placed them in an empty vial. All methods followed Bispo et al. (2002). On each sampling occasions, the light trap was deployed for 5 hours from 1830-2330 h. This duration was found to be an active flying period for the adults based on preliminary observations prior to the sampling. The collection was terminated at 0000 hr because no Plecoptera was found after that time. Number of trap, frequency of trapping and duration time of sampling was proposed by Bowden (1982). Samples were not separated on hourly basis because the total adults captured was small showing no clear pattern of Plecoptera composition. Adults were collected one day in a month for 12 months from January to December 2008. All collected specimens in one night were considered as one sample for that particular month. Sampling was done on a clear sky night, avoiding the full moon that might interrupt light trap catches.

In the laboratory, adult Plecoptera were placed in a universal bottle filled with 75% ethanol. They were identified using keys of Merritt and Cummins (1996), Wang and McCafferty (2004) and Triplehorn and Johnson (2005), counted and placed in the corresponding species. Species identifications were verified species by Prof. Ignec Sivec (Slovenian Museum of Natural History) and Prof. Bill P. Stark from Mississippi College, Mississippi, USA.

Data analysis

Independent samples t-test analysis was used to determine seasonal influence on Plecoptera abundance and diversity while the sex ratio was determined using the chi-square test for goodness of fit. The differences of adult Plecoptera abundance among months of sampling were determined using the Kruskal-Wallis test for non-normally distributed data. All analysis were tested using the SPSS software version 14®.

Monthly means of temperature and precipitation for Kuala Muda district were obtained from the Malaysian Meteorological Department headquarters in Kuala Lumpur. According to the department's database, annual precipitation in Kuala Muda district for the year 2008 was 2301.3 mm. Dry seasons was determined when mean monthly precipitation was less than 200 mm. The wet season was identified when mean monthly precipitation was more than 200 mm. Based on the amount of precipitation in the area, the dry season commenced from January to July and December, whereas the wet season started from August until November 2008.

RESULTS

Diversity and succession of adult Plecoptera (stoneflies) in Tupah River

In this study, the diversity of adult Plecoptera varied widely over the months. The result showed 299 individuals of Plecoptera belonging to two families, five genera and at least nine species were identified (Table 1). This assemblage represented large number of individuals considering the collection was made from a small area of low elevation and only single trap was operated. Out of four plecopteran families occurring in peninsular Malaysia (Yule and Yong 2004), two families (Perlidae and Nemouridae) were obtained from Tupah River. No representative of adults Peltoperlidae and Leuctridae was caught throughout the sampling period although Peltoperlidae nymphs were collected from the river.

Adult stoneflies were present at all times of the year in Tupah River. The largest abundance of perlid adults were collected in April (33.4 ± 1.10) while the lowest was recorded in January (1.33 ± 0.21) (Figure 1). Two main species of *Neoperla* were commonly collected in this

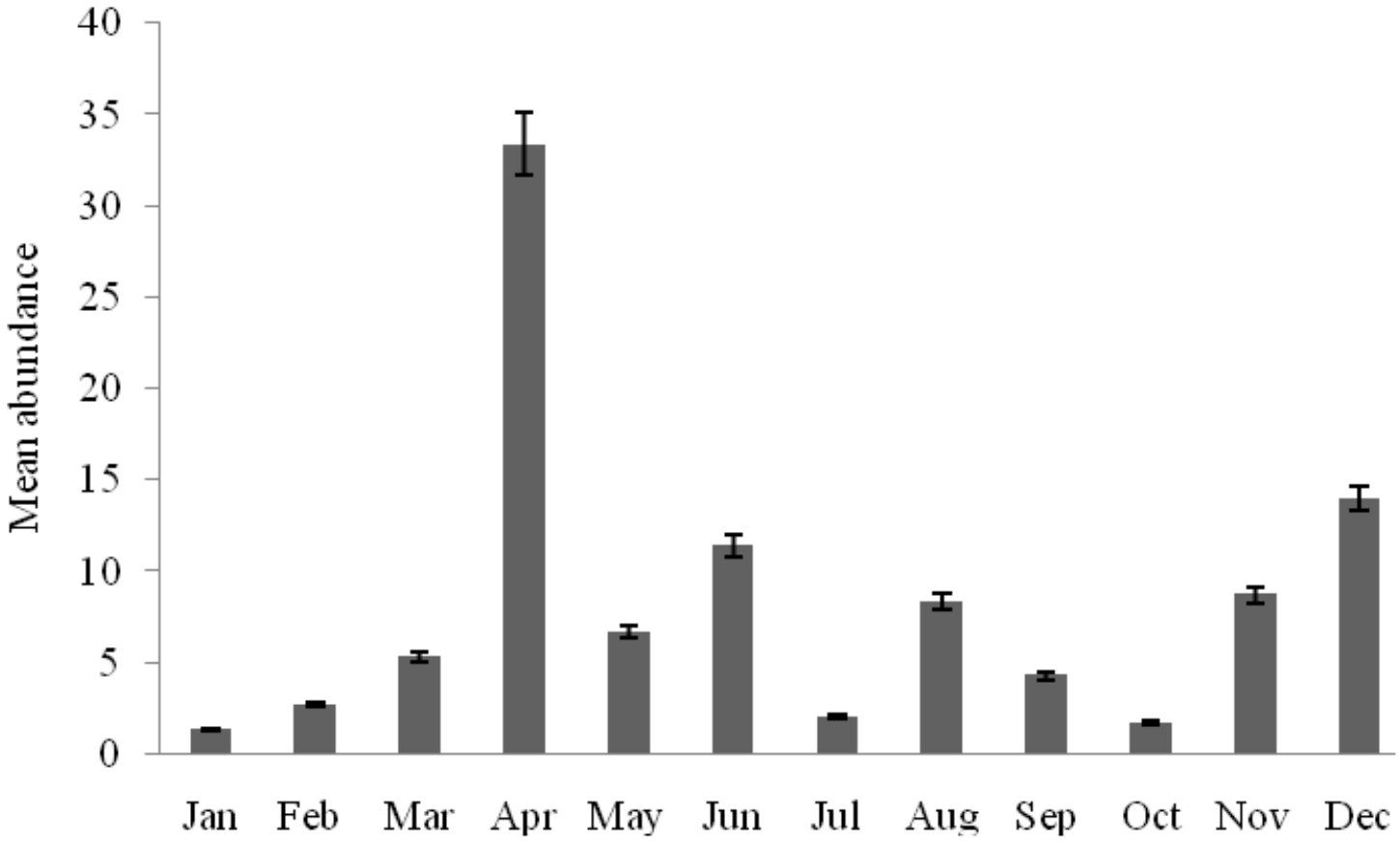

Figure 1. Mean abundance (±SE) of adult Plecoptera collected in Tupah River in the year 2008.

area. *Neoperla asperata* were found in all months of the year while *N. fallax* was found in most of the months especially in January, February and July 2008. *Phanoperla malayana* was spotted in April 2008 (dry season) in Tupah River. In November 2008, all three species of *Kamimuria* (*K. trang*, *K. jariyae* and *K. curriei*) were present. *Indonemuoura* spp. appeared in January, March and December 2008. The Kruskal-Wallis test indicated that there was no significant difference in number of individual Plecoptera among months of sampling ($X^2 = 3.255$, $P > 0.05$).

The highest diversity (seven species) of adult Plecoptera was recorded in April 2008 whiles the lowest number of species occurred in July 2008 (one species) (Figure 2). Relatively few species were present from May to August 2008 but species number began to increase in September until December 2008. There was no significant difference in diversity of adult Plecoptera among sampling months ($X^2 = 1.373$, $P > 0.05$).

Succession among plecopteran species in Tupah River is depicted in Table 1. Most species were absent at sometimes in a year. However, *N. asperata* was a common species that occurred throughout the year. *N eoperla fallax* was equally common although this species was absent during early part of the year in February and June. Occurrence of other species were scattered in some months in the year. *Kamimuria trang* was more common than *K. jariyae* that was only found in January and November. Except for *N. asperata*, the distribution of adult plecopterans in general was rather restricted to certain time of months in either dry or wet seasons.

Perlid *P.malayana* and nemouridaes were present only in the dry season (January, March and December 2008). Other perlid species were present at least during part of both seasons. The lowest number of adults Plecoptera were collected in the months with mean rainfall less than 150 mm. The Mann-Whitney U test revealed that there was no significant difference in abundance of adult Plecoptera in both seasons ($z=-0.444$, $P=0.657$).

Distribution of male and female plecopteran adults varied during their flight period and more females were collected than males (Figure 3). The result of Chi-square test for goodness of fit revealed that there was a significant difference in the frequency of occurrence of males and females. Females were more abundant than males, X^2 (1, N = 309) = 79.77, $P<0.05$. However, the sex ratio remained 1:1. Throughout the sampling, only males *K. jariyae* and females *P.malayana* were collected but

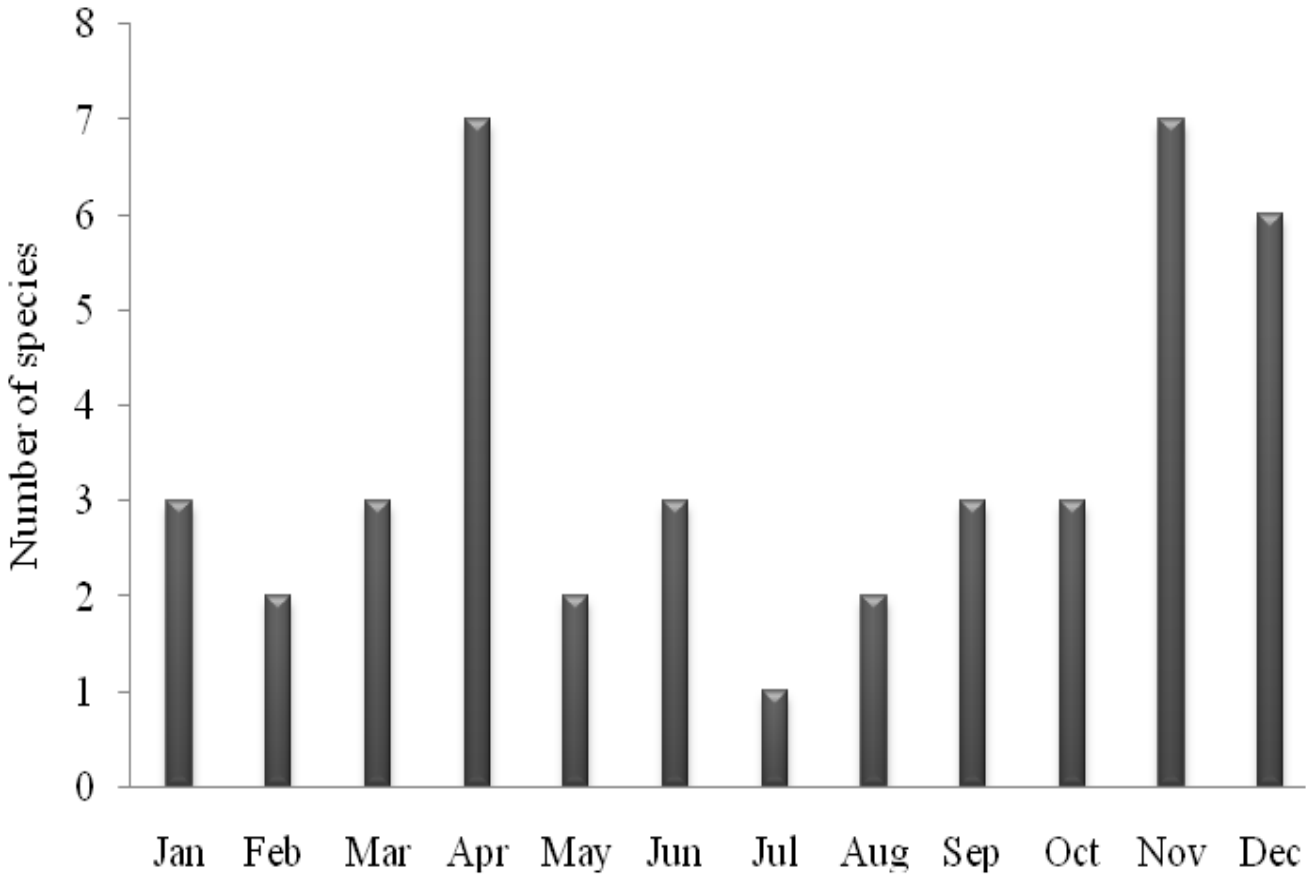

Figure 2. Monthly diversity of adult Plecoptera species collected Tupah River in 2008.

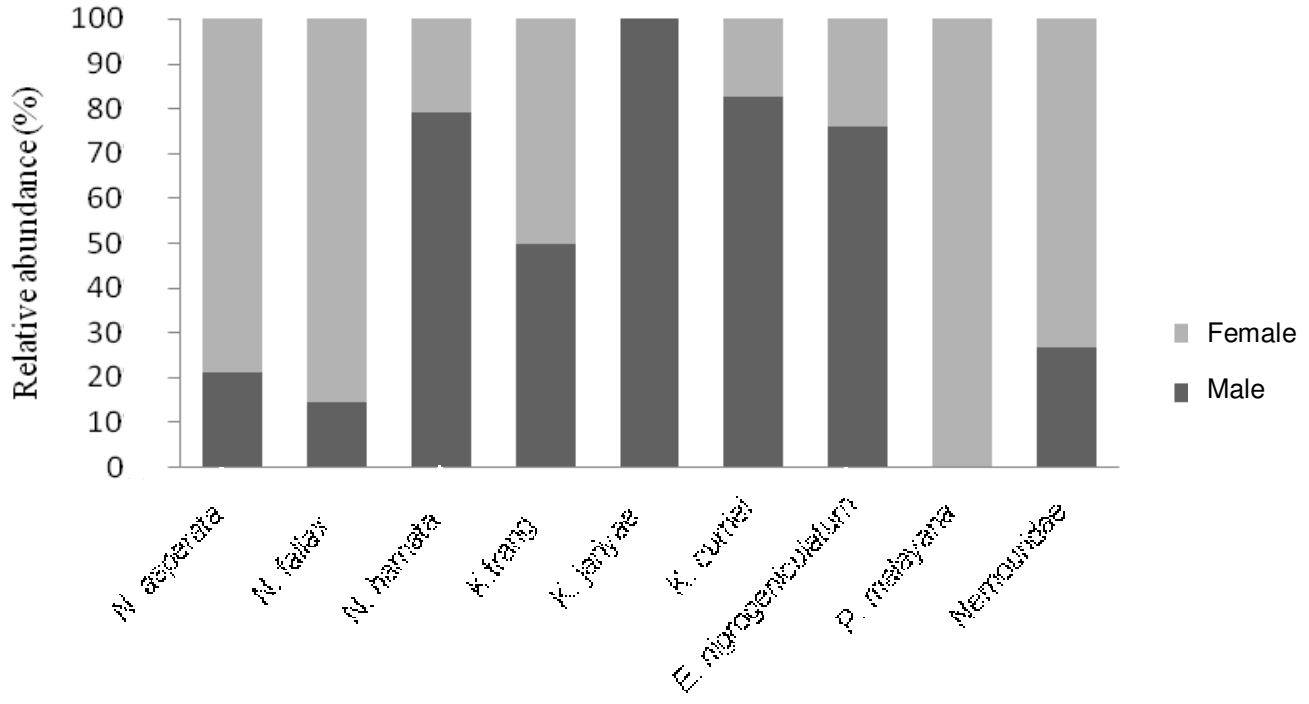

Figure 3. Relative abundance (percentage) of males and females of plecopterans species caught in light traps in Tupah River.

both sexes were represented in other species.

DISCUSSION

Naturally, the stoneflies are poorly represented in the tropics (Sivec and Yule, 2004). Different plecopteran species are active at different times of the day (Triplehorn and Johnson, 2005). Plecoptera caught in this study are nocturnal since the samplings were done at night. Study by Vaught and Stewart (1974) has confirmed the nocturnal emergence of *Neoperla clymene*. Meanwhile, Nemouridae is a diurnal stonefly as Hitchcock (1974) found at least two species of *Nemoura* emerged in the morning.

Petersen et al. (1999) suggest that differences in riparian vegetation may affect the distribution of adult Plecoptera. Sweeney (1993) supported Petersen's claim when he found many plecopteran species actively choose different streamside trees as preferred site to rest or mate. For instance, Nemouridae show high preference over deciduous trees and shrubs (Harper, 1973). In their studies, Sweeney (1993) and Baas and Mennen (1996) reported that loss of riparian trees can increase predation pressure. In Tupah River, the unshaded water surface led to higher water temperature thus decreased the abundance of plecopteran nymphs because stoneflies reach their maximum richness in cool, riffle area streams (Hynes, 2000). Apart from having naturally low population in tropical streams, the habitats of Tupah River may have been less suitable for this order of insects.

In Tupah River the substrate was dominated with boulders and cobbles that was not suitable for families such as Leuctridae (Pescador et al., 2000; Stewart and Stark, 2002). Moreover, fewer gravel substrates (5%) which were optimally embedded in the sand in Tupah River were less suitable for many plecopteran nymphs.

According to Duffield and Nelson (1990), the flight period of aquatic insect adults depends on the duration of the adult life. Furthermore, adult Nemouridae can live for a few days while the life span of Perlidae last for four weeks (Lees and Ward, 1987). Hynes (1976) reported that Nemouridae may be found lesser in the tropics but numerous in Western Europe than in North America. The reason behind this varied abundance is based on a speculation that Atlantic climate of Europe is milder, thus providing suitable temperature for flight activity (Hynes, 1976).

Many authors reported that the emergence pattern of Plecoptera corresponds to weather conditions. Most emergences occur during sunny days and cease during cloudy days (Flannagan and Lawler, 1972; Masteller and Buzby, 1993; Collier et al., 1997). In New Zealand, the peak emergence that generally occurs in summer and their flight activity is related to air temperature (Collier et al. 1997). Seasonal precipitation has been suggested as a factor influencing composition and temporal abundance of aquatic insect in Puerto Rico (Masteller and Buzby, 1993). In addition, DeWalt and Donald (1998) confirms that lower richness of adult Plecoptera is related to lower air and water temperature.

In this study, Plecoptera population was naturally low in both seasons especially in the wet season. Predation and behavior of the stoneflies could also contribute to the paucity of the population. Bird and Hynes (1980) found that most of plecopterans especially Capniidae move away from the water towards the woods. Collier and Scarsbrook (2000) reported that many Plecoptera emerge on land and because of this, they are prone to carabid (Coleoptera) predation. In their study in Isar River, Germany, Hering and Plachter (1997) found large proportion of recognizable Plecoptera preys in the guts of *Nebria picicornis* (Carabidae), More Plecoptera species can be seen during the dry season especially in April (seven species). The diversity began to decrease in July at the onset of the wet season. Bottorff and Bottorff (2007) found that colder temperatures have delayed stonefly emergence in Sagehan Creek but warmer temperatures hastened stonefly emergence in Irish Gulch Creek, California.

In this study, two most dominant species, *N. asperata* and *N. fallax* showed non-seasonal emergence. Similarly, in southeastern Brazil (subtropical areas) by Froehlich and Oliveira (1997) have found *Macrogynoplax* sp. (Perlidae) flew throughout the year. *Anacroneuria* sp. (Perlidae) in the tropics of Pedregulho, Sao Paulo State, Brazil fly all year round in high abundance (Bispo et al., 2002).

Both males and females were found in the plecopteran population in the Tupah River. The percentage of females was higher than males for *N. hamata, K. jariyae, K. curriei* and *E. nigrogeniculatum*. Only females *P. malayana* were caught in this study probably because the females live longer than males (Hynes 1976; Smith and Collier, 2005). Long-lived female plecopterans are important for reproduction and species dispersal. Those females may be important in colonization of new areas (Bunn and Hughes, 1997). In contrast to *P. malayana*, only males *K. jariyae* were caught in Tupah River. According to Hynes (1976), normally the males emergence is ahead of the females although they could overlap. Consequently, more males were caught at certain period of time. In contrast, Petersen et al. (1999) collected more females than males Plecoptera because many females may disperse inland to mate and rest. They later move back to the stream to oviposit whereas the males do not. However, this study was very preliminary. Conclusion on the plecopteran sex ratio must remain tentative. More sampling variations could be explored, for example variation in time of the day and collection using various sampling gears.

Conclusion

Plecoptera were only represented by two families,

Perlidae and Nemouridae in the study area. The low number of plecopteran population may have caused by the terrestrial taxon-specific predation either by riparian arthropods or riparian birds. Furthermore, few plecopteran individuals belonging to two families which reported in the Tupah River is confirming the statement of their rarity in the tropical streams.

Abundance of Plecoptera was more affected in the wet seasons especially for the family Nemouridae. *Neoperla aspearata* (Perlidae) was the most common species of Plecoptera found in Tupah River and based on sample collections; the abundance of this species may not have seasonal variation. This study also revealed only males *Kamimuria jariyae* and females *Phanoperla malayana* were represented in light traps. The main reason for the low stonefly numbers and richness reported in this study could be related to the collection technique.

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