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AQUATIC INSECT EMERGENCE COLLECTIONS OF RIVERS IN THE ST. PAUL NATIONAL PARK, PALAWAN, PHILIPPINES AND METHODOLOGICAL IMPLICATIONS FOR ECOLOGICAL AND BIODIVERSITY STUDIES

Hendrik Freitag
Phyllodrom Leipzig, Museum and Institute for Rainforest Ecology,
DelitzscherLandstrasse 38, D-04158 Leipzig, Germany
hendrik.freitag@gmx.de

ABSTRACT

Aquatic insect emergence was sampled along two 4^{th} order streams (Cabayugan River and Panaguman River) at the St. Paul's Subterranean River National Park, Palawan from September 2000 to August 2001. These data are the first emergence trap samples from streams in the Philippines and Greater Sunda. High abundances in Coleoptera and Diptera, particularly in Chironomidae and Ceratopogonidae were found compared to other emergence studies in tropical and temperate latitudes. Affected by the variability of physical and chemical characters, Ephemeroptera abundance in the two rivers varied distinctly. In contrast, Trichoptera displayed more stable proportions to the emergences by tolerating a wider range of environmental conditions. The collections included various taxa not defined as 'emergence' or 'aquatic' in the strict sense likely to be strengthened by the large littoral strip included by the traps used. Hydrological and technical features are questioned with regard to the efficiency of emergence traps, indicated by the present longitudinal emergence data and those of other studies. The Palawan collections obtained with emergence traps, which were modified for the tropics, displayed high species richness for most insect orders, especially aquatic Coleoptera. This fact and general characteristics of emergence trap samples suggest a high potential of this method for qualitative-ecological, taxonomic, and biodiversity studies in the tropics.

Key words: Biodiversity study, Trichoptera, Ephemeroptera, Diptera, Coleoptera, Odonata, macroinvertebrates, entomological method, Southeast Asia.

INTRODUCTION

Emergence (lat.: emergere – to emerge) collection is an entomological method used for ecological or faunistic studies (e.g. Davies, 1984). It is based on the fact that most insects found in freshwater undergo a transition from their aquatic larval habitat to a terrestrial environment where the adults live, disperse and reproduce (Müller, 1982). Emergence traps are characterized by continuously accumulative sampling. They sample predominantly mature adults, which are easier to identify. Samples usually include rare species, overlooked by other methods (Brehm and Meijering, 1996). The use of emergence traps allows a selective habitat choice. However, they are complex and sensitive equipment, which require daily checking if specimens are collected manually or weekly if preserving collectors are used. Furthermore, fluctuations in water level affect sampling efficiency namely at streams of higher order and estuaries and in the humid tropics (Freitag, 2004a).

Data on emerging aquatic insects from tropical streams in Southeast Asia and longitudinal patterns of aquatic insect emergences from headwaters to estuaries have been unknown until this study. Generally, there are very few emergence studies from the tropics (see Tab. 1), namely from Central Africa (Böttger, 1975), Columbia (Wolf et al., 1989) and Puerto Rico (Masteller, 1993).

By comparing the results from Palawan with other emergence studies, potentials as well as limitations of the method are demonstrated.

MATERIALS AND METHODS

Aquatic insect emergence was studied in the St. Paul's Subterranean River National Park in Puerto Princesa City, Palawan, the Philippines (Fig. 1). Because of the narrow distance from coast to coast of Palawan, the rivers studied reach the sea already as 4th order streams. All of the sites studied had low altitude. However, the catchment was surrounded by steep mountain ranges (up to 1028m). The uppermost site CR1 (Cabayugan River 1; 10°09'46''N; 118°49'29''E) was located at a second order creek a few hundred meters down the spring, in hilly terrain with predominating secondary forest and bamboo shrubs at 80m a.s.l.. The river bed had mainly coarse stony substrates, while the trap was situated in a small depositional pool section with temporary CPOM accumulations on loamy ground. The next site (CR2; 37m a.s.l.; 10°09'47''N; 118°50'37''E) was installed where the stream entered flatter areas with similar vegetation. The river showed a wide variety in hydraulics and substrates there. The emergence trap was put into an inlet enriched with CPOM and FPOM three meters downstream of a larger riffle section. Site CR3 (28m a.s.l.; 10°09'16''N; 118°52'30''E) was situated in a part of the river crossing a rice field plain. Its river bed was dug into the ground level at 2-3m. Most parts of the river within this section were about 1m deep (medium water level) and had loamy substrates with a thin covering of gravel. Before the Cabayugan River enters a subterranean course it passes primary forest alongside the limestone cliffs of Mt. Saint Paul. Here site CR4 (28m a.s.l.; 10°09'28''N; 118°53'26''E) was fixed. Heterogeneity in substrates and hydraulic features increased again here. The trap was established in a deeper slow-moving section similar to CR3. A small tributary, running directly out of the rocks in the vicinity was also included in the study (LS4; 28m a.s.l.; 10°09'29'' N; 118°53'30''E). The trap completely spanned the width of the brook including a larger section of the bank. This spring brook had substrates of sand and silt supplemented by CPOM in patches. Behind the riverine cave the most downstream site (UR6; sea level; 10°12'08''N; 118°55'30''E) was located at the estuary in the tidal zone of the same stream, called Underground River there. Fine sand and limestone boulders dominated the place of the trap, while loamy silt was predominant in neighboring parts.

For comparative purposes the Panaguman River, a running water of a similar size was sampled. Due to its hydraulic conditions marked by rapid and distinctive changes in flow and discharge (Freitag, 2004a), the river bed is widely non-shaded and temporarily scoured. One site was situated at the lower middle course in secondary forest and scrub (PR1; 8m a.s.l.; 10°15'09''N; 118°58'03''E). Substrates and river morphology varied, including distinctive riffles and pools. Sediments under the trap consisted of sand, silt, CPOM and FPOM. Another trap was set up in place at the estuary (PR2; sea level; 10°14'09''N; 118°56'56''E) which was not as strongly influenced by tidal movement as the Underground River. This river section was lined by *Nypa*-dominated vegetation and swamp forest. Sediments comprised loamy silt to sand and some CPOM as were also found under the trap. Further information on the study area is provided in Freitag (2004b).

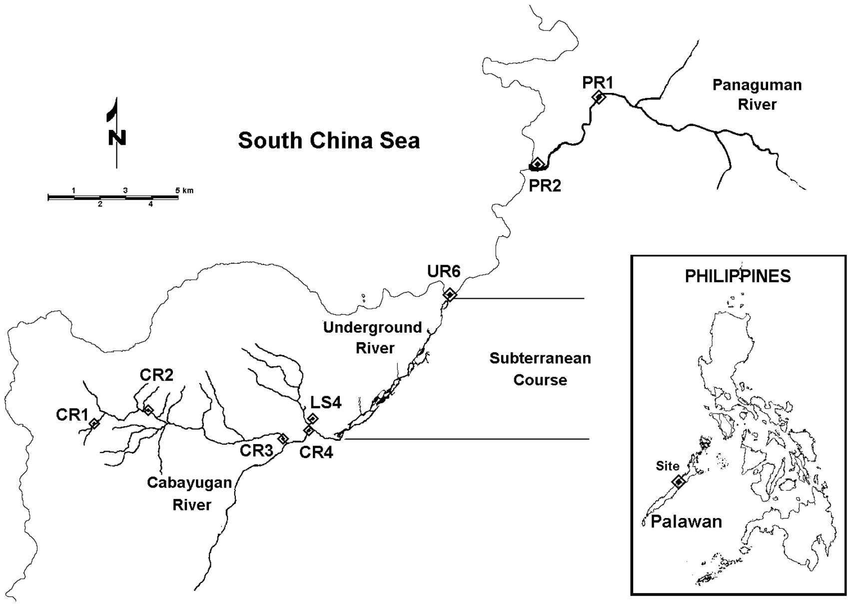

Figure 1. Locality of the study area showing the coastline, the rivers sampled and the emergence trap sites (left), the position of the study area in Palawan and the location of Palawan Island in the Philippine Archipelago (right).

The emergence traps used (Plate 1) were modified from the model of the Max-Planck-Institute for Limnology (MPIL) in Schlitz (Hesse, Germany). They were equipped with collectors made of UV-light-permeable acrylic glass which contained a bowl filled with 3% formalin solution and few drops of detergent. The screens were removable Nylon tents (80 mesh/cm) sewn of a single piece of fabric which covered a sampling area of about 1m² including a wide littoral strip. Detailed instructions for construction and use of the traps are given in Freitag (2004a).

The trap locations were restricted to pool sections close to upstream riffles to minimize sample loss due to floods and enabling riffle dwelling species to enter the trap by drift. Samples were collected in two-week intervals from September 2000 to August 2001. Since some samples were lost due to flooding, data analysis is limited to one data set per month (excluding January and February 2001) and site, usually extending over a period of approx. two weeks. To obtain consistent standards for comparison with similar studies, specimen numbers were extrapolated to annual data per square meter. Numbers of organisms caught in this study and those of comparable studies were divided by days of sampling and multiplied by 365d. In the same way, river areas covered by traps were extrapolated to a theoretical size of 1m².

Plate 1. The emergence trap at the site CR2 exposed to fluctuations in water level.

Heteroptera, Lepidoptera, Thysanoptera, Acari and *Brachyura*, which were sporadically trapped were not included in the analyses as they are not usually considered in emergence studies, even if some of them might meet emergence terms such as genera of *Nymphulinae (Pyralidae, Lepidoptera*) (Dudgeon, 1999).

Measurements of electrical conductivity, pH, water temperature, dissolved oxygen (DO) and biochemical oxygen demand (BOD) by WTW professional meters and emergence sampling were done simultaneously. The BOD was determined as BOD_{2+5} according to the European Standard (EN 1899-2) used with alternative incubation according to Annex A (CEN, 1998) which allowed the samples to be stored at 0-1°C in ice water during field work for the first two days.

RESULTS

The temperature of the freshwater sites sampled ranged from 23.0°C to 29.4°C, while estuarine sites varied from 25.7°C to 30.4°C. The waters were well supplied with oxygen. The mean DO saturation was between 80% and 90% at all sites, except for site CR1 (94%), and site LS4 (77%). The lowest reading was taken at the latter site in March 2001 (distinct dry season). The averaged BOD amounted to values between 1.08mg/l and 1.21mg/l at all sites, except for CR3 where the average (2.02mg/l) was slightly higher (Fig. 2).

PH values ranged between 7.39 and 8.45 in the Cabayugan River. The Panaguman River displayed more acidic pH values between 6.32 and 7.02. Electrical conductivity was distinctly higher at estuarine sites UR6 (max. 25,300µS/cm) and PR2 (max. 3,450µS/cm), due to their brackish water (Fig. 2). At freshwater sites conductivity values were found between 60µS/cm and 743µS/cm.

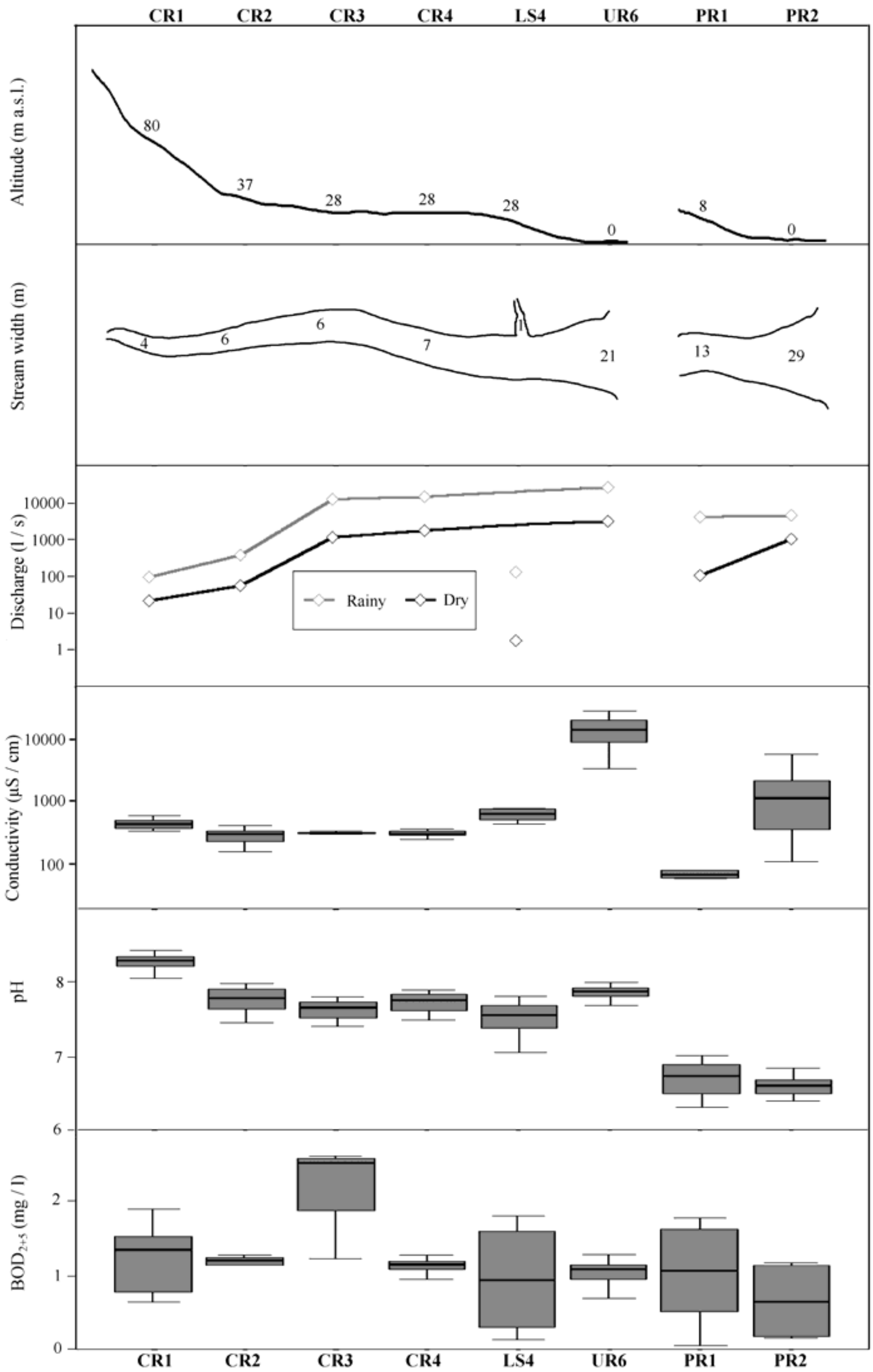

Figure 2. Selected environmental variables measured during the emergence sampling program at the river sites of the St. Paul's National Park.

Of all taxa collected, Diptera dominated with 86% of the total catch, followed by the orders Hymenoptera (dominantly Formicidae), Coleoptera , Trichoptera and Ephemeroptera (Fig. 3).

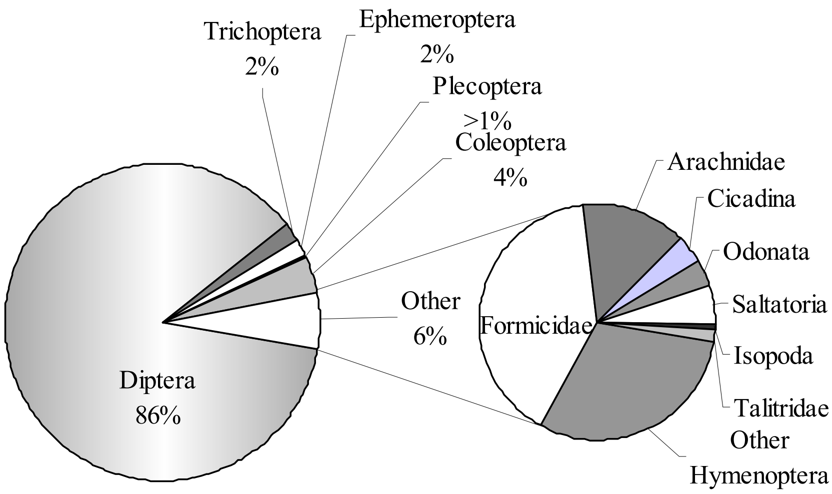

Figure 3. Composition of the total catch (specimens) of the emergence traps in St. Paul's National Park (modified after Freitag, 2004b).

Out of 34,478 specimens collected, 28,093 were emergent aquatic insects. Numbers of those ranged from 770 (126d of sampling, PR2) to 10,181 (141d of sampling, CR1). A decline of total emergence towards estuaries was observed, affecting all major orders (Figs. 4, 5). Diptera was the best represented group at all sites, including estuaries. Sixty-seven percent of these were Chironomidae, other aquatic families followed as sorted by decreasing abundance: Ceratopogonidae, Psychodidae, Culicidae, Tipulidae, Dolichopodidae, Empididae s.l., Dixidae, Chaoboridae, Ephydridae, Simuliidae. Families, which generally have no aquatic larvae, contributed more than 10% to the Diptera fraction. By far, the largest numbers among them were Cecidomyidae, followed by Phoridae, Sciaridae, Mycetophiliidae, Drosophilidae, Rhagionidae, Scatopsidae and other Brachycera.

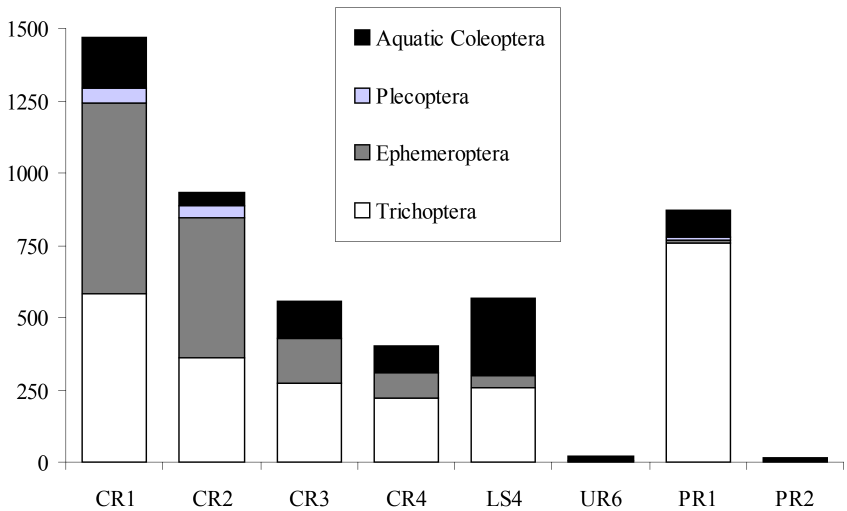

Figure 4. Extrapolated annual emergence (n/yr/m²) of selected aquatic insect orders at the river sites sampled in St. Paul's National Park (modified after Freitag, 2004b).

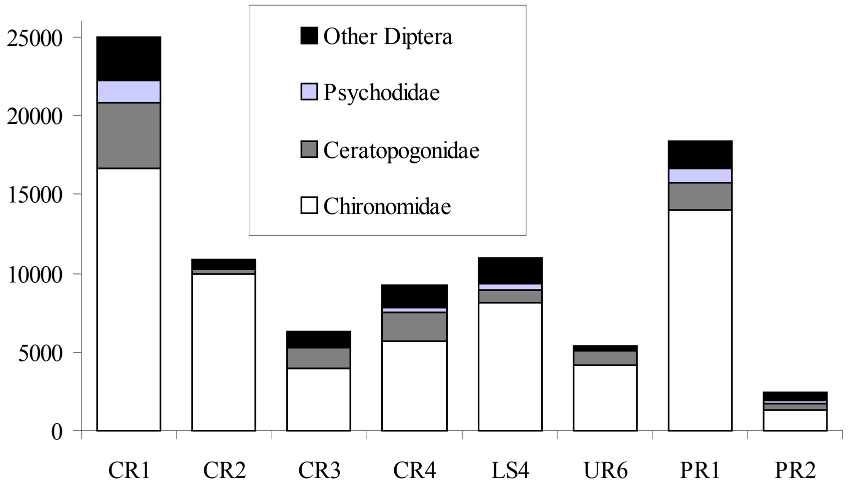

Figure 5. Extrapolated annual emergence (n/yr/m²) of selected aquatic Diptera families at the river sites sampled in St. Paul's National Park (modified after Freitag, 2004b).

Coleoptera were the second largest order, but only 16% out of the overall 4% were aquatic including mainly Psephenidae, Hydraenidae, Scirtidae, Dryopidae, Elmidae, and Lampyridae. Remaining fractions were riparicol beetles (Limnichidae (dominantly), Staphylinidae, Pselaphidae, Ptiliidae, Scydmaenidae, Carabidae, Scaphidiidae, Georyssidae, Curculionidae) and terrestrial beetles (Chrysomelidae (dominantly), Coccinellidae, Scolytidae, Orthoperidae, Pedilidae).

Ephemeroptera (20 species) were most abundant at CR1 and CR2 but rare at the PR sites. Trichoptera (56 species) showed quite stable proportions in freshwater sites between 2.2% and 4.5% of the aquatic insect fraction. Six species of Plecoptera were rarely found in upstream-sites (CR1, CR2, PR1). Species richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) declined distinctly downstream along Cabayugan River from CR1 to CR3 and slightly increased again at site CR4 (CR1: 46; CR2: 33; CR3: 16; CR4: 18). Odonata (3 species) occurred in low numbers.

DISCUSSION

Emergence patterns are neither spatially nor directionally uniform (Williams, 1982; Davies, 1984; Malicky, 2002). Results seem to depend on different trap construction and size (Malicky, 2002; Flannagan and Cobb, 1994; Davies, 1984; LeSage and Harrison, 1979; Morgan, 1971; Kimerle and Anderson, 1967). Collecting frequency affects collection efficiency, particularly in manually operated traps under high temperature conditions (Sandrock, 1978; Boerger, 1981; Davies, 1984). The extrapolated numbers of total aquatic insects emergence expressed as specimens per year and square meter (n/yr/m²) are very high in the present study, likely due to the use of a suitable trap equipped with a collector. The data from site CR1 are most compatible with other studies as these are also on headwaters. In temperate latitude, Joost et al. (1986) collected emergences in streams of Thuringia, Germany. In that study, the total emergence from April to October in 1975-1977 caught by a trap covering 5.1m² stream was 19,436 specimens. Extrapolated to an annual emergence per square meter this comes to 1270n/yr/m². Illies (1972) found 138,486 specimens in Breitenbach (11.1m² trap area) and 70,849 specimens in Rohrwiesenbach (7.5m² trap area). These studies from Hesse, Germany resulted theoretically in 12,476n/yr/m² and 9,447n/yr/m² insects emerging, respectively. Masteller (1977) collected a total of 16,223 specimens in one year with a trap installed at Six Mile Creek (Pennsylvania) covering a stream and stream bank area of about 15.8m². This amounts to 1027n/yr/m² of aquatic insect emergence including EPT and aquatic Diptera. Emergence numbers of studies from tropical rivers are presented in table 1. Comparing all these studies, those traps revealed highest numbers of emerging insects, which were equipped with a collector (present study; Wolf et al., 1989) or were collected manually in short (daily) intervals (Illies,1972; Böttger 1975). The comparably low numbers of total insect emergence obtained by Masteller (1993) might be caused by methodological aspects. The traps he used had a mesh size of 0.5mm. It has already been confirmed by Morgan (1971) that Ceratopogonidae, Orthocladiinae, and further small taxa escape through wide-meshed screens. Therefore, LeSage and Harrison (1979) strictly recommended net mesh less than 300µm. Considering that some Diptera have very small sizes, in particular among tropical taxa, an inadequate sampling of such taxa might have occurred in Puerto Rico. As a consequence larger taxa might appear to be accounting for a greater proportion of the emergence, although their numbers have not actually increased. This seems likely as the total annual numbers of Ephemeroptera and Trichoptera per area are similar in site CR1 and the survey by Masteller (1993).

Table 1. Total numbers of aquatic insects and species richness of selected insect orders collected by emergence traps at lotic waters.

Study	Palawan			Central Africa	Puerto Rico	Columbia		
	present study[1]			Böttger (1975); Kopelke (1981); Zwick (1976); Statzner (1976)	Flint & Masteller (1993); Masteller (1993)	Wolf *et al.* (1989); Flint (1991)		
	CR1	LS4	PR1			A	B	C
Total aquatic insect emergence (n / yr / m²)*	26355	10500	18217	14192	2684	4563	4493	12500
Total aquatic Diptera emergence (n / yr / m²)*	24874	9925	17249	9515	1213	3873	3813	11940
Species of aqu. Coleoptera	20	9	4	3	0	0	0	0
Species of Ephemeroptera	11	3	1	21	7	1	3	2
Species of Trichoptera	30	15	23	27	15	31	27	23
Species of Plecoptera	5	0	2	5	0	1	0	0
Species of Odonata	3	1	2	5	0	1	4	3
Total species of all orders above-mentioned	**69**	**29**	**32**	**61**	**22**	**34**	**34**	**28**

There appears to be a general trend for aquatic insect emergence in streams irrespective of latitude, faunal province, and altitude where Diptera and Chironomidae in particular are dominant components (Böttger et al., 1987; Illies, 1983; Joost, et al., 1986). Their sub-families have adapted to various aquatic environments (Coffman, 1995). The present study showed that the dominance of Chironomidae is even independent of stream order, longitudinal zones, salinity, and substrates.

In Central Africa (Böttger, 1975) and Puerto Rico (Masteller, 1993; Pescador et al., 1993) Ephemeroptera constituted more than 20% or 30% of stream emergences. The present study as well as data from Columbia (Wolf et al., 1989) display lower and highly varying proportions and total numbers. Comparing these and additionally studies (e.g. Illies, 1972; Masteller and Flint, 1980; Waringer, 1996), no consistent trend of Ephemeroptera abundances occurs considering distance from source, stream order, discharge or zoogeographic region conversely to pH values (Freitag, 2004b).

In contrast to Ephemeroptera, Trichoptera numbers displayed lower variations, both inter-regionally and locally, but displayed partly reversal tendency in abundance patterns (this study; Wolf et al., 1989; Waringer, 1996). This might indicate that Trichoptera can tolerate a wider range of environmental conditions and they are consequently able to fill further niches where Ephemeroptera are scarce.

The qualitative aspect of emergence collection is very promising for biodiversity studies as high numbers of species are detected (Steffan, 1997; Brehm and Meijering, 1996). This applies generally to the EPT and aquatic Diptera (Tab. 1; Joost et al., 1986; Waringer, 1996; Böttger et al., 1987) For certain orders (Trichoptera, Coleoptera) the Palawan rivers had some of the highest species richness ever obtained in emergence collections (Tab. 1, Tanida and Takemon, 1993). However, the qualitative efficiency of the method varies among orders and families sampled.

Coleoptera display various adaptations to the riverine environment (Jäch, 1998). Comparing the entire water beetle fauna of emergence trap samples with data of drift, benthic colonization and manual collections, the method was less effective in total numbers of species detected and in ratios of species numbers per total individuals collected (Freitag, 2003; personal data). However, adult "**false water beetles**" (Jäch, 1998) such as Psephenidae (see Lee et al., 2005), Scirtidae and Lampyridae have been predominantly yielded by emergence sampling. Surprisingly, "**true water beetles**" with aquatic adults (Jäch, 1998) have been collected frequently. They belonged to the families Hydraenidae, Elmidae, Hydrophilidae, Dryopidae, Dytiscidae, and Noteridae. These individuals have likely left their adult's aquatic habitat for dispersal or mating. The large fraction of riparicol beetles represented species dwelling at the semi-aquatic littoral but distinctive riverine habitat. The terrestrial beetles collected might have incidentally entered the trap.

The traps used in Palawan (Freitag, 2004a) covered a wide littoral strip. This was regarded as one of the main causes for high numbers of non-aquatic organisms in the emergence. For instance, Cecidomyidae, a generally non-aquatic family (Oosterbroek, 1998), was the third largest group. Lestremiinae are small, non-aquatic Nematocera with fungivorous larvae (Oosterbroek, 1998), and therefore abundant in wet bank habitats. In LS4 with the largest riparian fringe under a trap they had the highest proportions. Similar niches along streams are inhabited by further insects which contribute to the catch (Sciaridae, Mycetophilidae, Scatopsidae, Rhagionidae, Phoridae and other Brachycera, Cicadina). This also applies to some other groups, which do not belong to the emergent fauna e.g. Blattodea, Saltatoria, Heteroptera (Fig. 3). Some of them are even aquatic or semi-aquatic and of interest for river ecologists: e.g. Tetrigidae (Saltatoria), amphibious cockroaches (Blattodea: Epilamprinae), or neustic Hydrometridae and the benthic Nepidae Cercotmetus asiaticus Amyot and Serville, 1843 (Heteroptera).

Hymenoptera were most likely terrestrial. Formicidae and Araneae within the samples were neither semi-aquatic nor emergent but may be important as predators (LeSage and Harrison, 1979; Davies, 1984). They colonize or temporarily enter the screen, prey on the catch and reduce the amount of emergence recovered. Preserved predators of these groups were found frequently in the collection tray, but the extent of undesired predation remains unknown (proportional or selective predation). Due to their size (up to 3cm) they might have a higher impact than judging solely from their abundance.

It was assumed that terrestrial insects in the emergence samples are less disturbing because the most frequent groups could be assigned to the larval habitat, at the family level. The frequent occurrence of terrestrial Empididae, Mycetophilidae or Syrphidae particularly in greenhouse-like emergence traps was considered a common phenomenon, but with debatable effects (Malicky, 2002; Straka and Samietz, 1992; Caspers, 1984; Löhr, 1987). Böttger (1975) successfully eliminated terrestrial and semi-terrestrial taxa by excluding the littoral zone from the trap. Statzner and Resh (1993) regarded the inclusion of terrestrial taxa in the catches as a disadvantage. On the other hand, bank areas provide important emergence sites for specimens crawling out of the water for ecdysis, like Plecoptera or Odonata (Davies, 1984; Corbet, 1999). Thus, the inclusion of a wide river fringe was advisable considering reports on movements to and aggregations on bank-sides of late instar nymphs preparing for emergence (e. g. Hendricks et al., 1969; Ulfstrand, 1968; Williams, 1982). However, conventional emergence traps may not display a representative spectrum of species dwelling in the waters concerned, namely in Odonata, when soft and flexible trap screens are the only pathway for nymphs crawling out of the water because many Odonata species select specific emergence supports (Corbet, 1999). Different observations of relations to solar aspects in spatial emergence patterns of

Odonata have been reported (Lavoie-Dornik and Pilon, 1987; Beynon, 1995; Jödicke and Jödicke, 1996). There are indications that some species actively select sunny places for emerging (Corbet, 1999), which could result in a lower acceptance of locations covered by traps. In Odonata the emergence data could not confirm records of further taxa found in benthic samples from the two Palawan rivers (personal data, unpubl.).

Anthropogenic impacts, indicated by BOD at site CR3 likely affected some groups in abundances (Diptera) and in species richness (EPT) as were observed already for decapod assemblages at site CR3 (Freitag, 2005).

A downstream decline in macroinvertebrate abundances due to lower current and lower altitude was already reported by Stahrmühlner (1984), who studied longitudinal patterns in streams of Sri Lanka. This is supported by the emergence data of Palawan. However, as similar parallel trends were observed for the frequency of inundation (Freitag, 2004a) one might question whether or not downstream traps were sampled with the same efficiency. Although only samples neither affected by floods nor by damaged screens were compared, traps were differently exposed to fluctuations of the water level. Conceivably, nymphs, subimagoes, and adults crawling up the net might have been washed away to certain, downstream-increasing extent.

In conclusion, the qualitative faunistic side should be underlined as a major aspect for the application of this method to the tropics, as quantitative comparability of classical emergence samples is still controversially interpreted (Malicky, 2002; Steffan, 1997; Statzner and Resh, 1993; Illies, 1983). Most complete lists of taxa collected might be retrieved from headwaters only. High collecting frequency (manual collection: daily; collector: weekly) and close-meshed collecting screens (mesh size <300μm) are most important for successful sampling. Thus, the method appears to be very suitable to collect identifiable adults of aquatic Diptera, EPT, and „**false water beetles**“. By including the littoral zone large spectra of riparicol taxa, namely Diptera and Coleoptera can be trapped which are often overlooked in riverine studies. In contrast, Odonata species are under-represented among the emergent fauna, as are non-emergent neustic, benthic or planktonic macroinvertebrates in general.

Provided that one bears in mind the variable efficiency of the method in taxa collected and regarding ways of trap operation, emergence sampling should be paid more attention to in qualitative-ecological, taxonomic, and biodiversity studies in the tropics. High numbers of taxa can be collected by comparably little effort allowing selective macro-habitat choice and relation to environmental variables.

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