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Dry mass estimates of some tropical aquatic insects

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Abstract: Relationships of body mass and head capsule width were developed for *Thraulodes* sp., *Haplohyphes* sp. (Ephemeroptera), *Leptonema* sp., *Phylloicus* sp. *Nectopsyche* sp. (Trichoptera), and *Anacroneuria* sp. (Plecoptera). The organisms were collected with a Surber net (0.1296 m^2 and 0.286 mm mesh size) on the Orituco river, Venezuela. The number of specimens used in the analysis for the species studied, was different (from 84 to 103 specimens). Regression analysis indicated that all relationships were best expressed by a power function rather than by linear or exponential equation. Analyses of the relationships reveal interspecific differences among insects of the same order. Species-specific relationships are recommended to be used whenever possible since, depending on the species, the underestimation of mass could be as much as 56%.

Key words: Biomass, length-mass relationships, aquatic insects, tropics.

It is recognized that biomass estimates are an essential methodological aspect in order to determine growth rate and/or production of aquatic macroinvertebrates as well as to understand life histories and trophic relationships between functional feeding groups (Benke 1996). However, benthic biomass could also be used in studies of colonization rates or in the quantification of the role that macroinvertebrates play in the decomposition of leaves. In any of these studies, two main problems are encountered. First, the high number of samples that must be taken to overcome spatial heterogeneity, when sampling a river, precludes the attempt to separate, identify and weight animals while still alive (Cressa 1986). Secondly, when studying decomposition rates where shredders with cases are numerous, they have to be separated from their cases to determine their biomass. This is a time consuming process and the manipulation error (breaking of body structures) is high due to the fragility of these organisms. Thus, to overcome these problems it is necessary to make indirect dry biomass determinations, of which the simplest method is to measure live biomass (Parma 1971). Nevertheless, this is not a suitable method, since differences on live mass of aquatic organisms might reflect not only differences in biomass, but differences on water retention (Dermott & Paterson 1974, Schema *et al*. 1981, Traina & Von Ende 1992, Dumont & Balvay 1979). Therefore, direct determination of dry mass is recommended in order to obtain reliable estimates of biomass (Donald & Paterson 1977, Sudgen 1967, Slack 1967, Stanford 1973, Mason *et al*. 1983, Meyer 1989).

Measuring any body structure of an insect is less time-consuming than to weight all the organisms collected. Since fundamental relationships do exist between linear body measurements (body length, head width, head length) and biomass (Gould 1966, Peters 1983), they have been used in order to obtain indirect biomass estimates. Wenzel *et al.* (1990) indicated that a difference of 20% could be expected between actual and theoretical biomass.

Even though the importance of length-dry mass relationships is well known, few data are available for aquatic macroinvertebrates living in temperate habitats (Clifford 1970, Cianciara 1980, Meyer 1989, Smock 1980, Wenzel *et al.* 1990, Burgherr & Meyer 1997) and even fewer for aquatic as well as terrestrial tropical insects (Lewis 1975, Cressa & Lewis 1984, Cressa 1986, López et al. 1996-1997). Furthermore, the data available suggest the need to use taxa-specific regressions since they are more accurate (Schoener 1980, Smock 1980, Cressa 1986, Gowing & Recher 1985). The objective of this work is to increase this knowledge providing length-specific mass relationship for some common species of tropical insects: two species of Ephemeroptera (*Thraulodes* sp. and *Haplohyphes* sp.), three of Trichoptera (*Leptonema* sp. *Phylloicus* sp. and *Nectopsyche* sp.) as well as a species of Plecoptera (*Anacroneuria* sp.).

MATERIALS AND METHODS

The basic data sets used for calculation were derived from a study on community structure, standing crop and secondary production of macroinvertebrates in the Orituco River, Venezuela (9°57 -10°1’ N, 66°24’ - 66°26’ W). A description of the river as well as its physicochemical characteristics is given in Cressa & Senior (1987).

The taxa chosen for this study are among the most important representatives of the benthos community in rivers of Venezuela (Cosme 1985, Cressa 1994, 1997, Rincón 1996). In this particular stream, they comprise 64.2 % of the macroinvertebrate community. On the other hand, species were selected because they were the most abundant at the order level (Cressa 1994).

Larvae were collected with a Surber net (0.1296 m2 and 0.286 mm mesh size), anesthetized in the field with CO_2 and placed in a cooler for transportation to the laboratory where they were kept at -5°C. Samples were examined within 48 h after collection and dry mass was determined individually on animals that had been anesthetized but not preserved, as it is known that preservation causes losses of dry mass by leaching (Dermott & Paterson 1974, Donald & Paterson 1977, Mason *et al.* 1983, Benke 1996).

In the laboratory the larvae were cleared of attached detritus particles, identified and head capsule width determined to the nearest 10 µm with a stereomicroscope fitted with an ocular micrometer. Head capsule width was measured as the distance across the widest portion of the head. Subsequently, the animals were dried at 60°C during 24 hours. After cooling in a desiccator for 24 h, they were weighed to the nearest 10 µg with an electrobalance. Individual animals were weighed one at the time except for the smallest size of *Nectopsyche* sp. and *Haplohyphes* sp. For these taxa animals with same head capsule width were pooled (2-3), and the mean weight determined. The data reported represents actual number of animals used for the statistical analysis (Table 1).

Some authors have indicated that body length is a better predictor to estimate biomass than head capsule width (Smock 1980, Meyer 1989, Burgherr & Meyer 1997). However, since the objective of this study was to develop a fast and reliable method to estimate biomass, body length was not used because among other reasons the head capsule is a heavily sclerotized structure, not subject to distortion or breakage under manipulation as is body length.

Trichoptera are usually collected with their cases and it was thought that it would be interesting to determine if some relationship exists between some dimensions of the case and body weight. Therefore, the width (widest part at the opening) and weight of the case

TABLE 1

Number of individuals (n), ranges, mean ($\bar{x}$) and standard deviation (s) for head capsule width (µm) and dry mass (µg) for several species of aquatic insects

		Head capsule width (µm)				Dry weight (µg)			
Taxon	n	Range	$\bar{x}$	s	cv	Range	$\bar{x}$	s	cv
Ephemeroptera									
Thraulodes sp.	98	108.0 - 2450	818.62	515.18	62.93	5.10 - 8962.69	1694.78	2086.06	123.09
Haplohyphes sp.	94	66.5 - 962	393.80	217.10	55.13	12.00 - 836.02	208.59	168.75	80.90
Trichoptera									
Leptonema sp.	85	152.0 - 1875	723.69	345.60	47.76	9.10 - 16443.84	1689.26	3166.66	187.46
Nectopsyche sp.	103	72.0 - 705	301.23	131.71	43.72	15.81 - 383.24	108.25	72.54	67.01
Phylloicus sp.	87	238.7 - 1258	703.75	327.12	46.48	6.63 - 10167.00	2857.21	3339.42	116.88
Plecoptera									
Anacroneuria sp.	84	375.0 - 2812	1060.86	527.82	49.74	131.80 - 11071.22	1406.41	2055.06	120.14

cv = coefficient of variation in %: (s / $\bar{x}$) x 100 were determined for *Phylloicus* sp. and *Nectopsyche* sp. If the resulting relationship is as good as the relationship between head capsule width and body mass it would allow easier determination of growth rate in the laboratory or field experiment since manipulation could be minimized.

Regression analyses were used to determine the relationship between linear measurements (head capsule width) and dry weight. The data were fitted to the following models in order to determine which best described the width-weight relationship of the various species: power (y = axb), exponential (y = aebx) and linear (y = a + bx) models, where y is weight (µg), x is head capsule width (µm) and a and b are regression constants. The analyses were performed on logarithmic transformed data (log10), to express the exponential and power equations in linear form.

RESULTS

In general, the range of weight is higher than that of head capsule width among the different species, with *Leptonema* sp., *Thraulodes* sp. and *Phylloicus* sp. showing the highest coefficients of variation (Table 1).

Head capsule width and weight were highly correlated for all species (Table 2, $p < 0.001$), with the power model best describing this relationship. This assertion was corroborated with the analysis of residuals for each equation using studentized residual plots, which indicated that none of the regression model assumptions were violated. Similar results have been found for terrestrial (Roger *et al.* 1976, Gowing & Recher 1984) and for aquatic insects (Smock 1980, Wenzel *et al.* 1990, Meyer 1989, Burgherr & Meyer 1997). Since *Nectopsyche* sp. was the only species where the coefficient of determination for the linear equation (0.852) was almost the same than for the power equation (0.871), the data were analyzed using the power equation and the results are summarized in Table 2.

The values of b are lower than the expected value of 3 predicted by the surface law (Hill 1976, Gould 1966, Smock 1980, Wenzel *et al.* 1990), with the exception of *Phylloicus* sp. (4.49, Table 2), which has the highest value. The equations indicate a high difference in intercepts for the different species, reflecting their different average sizes (Table 1). Change in body weight per unit change in head capsule width differs greatly among species from the same insect order. Unplanned comparison of the regression coefficients for the different species (GT2, $p < 0.01$, Sokal & Rohlf 1981) indicates that all slopes were significantly different from each other with the exception of the comparison between *Haplohyphes* sp. and *Nectopsyche* sp. (GT2, $p > 0.05$, Sokal & Rohlf 1981).

Predictive equations for each insect order was calculated from pooled data for individuals in that particular order and are also given in Table 2. All relationships were highly significant ($p < 0.001$) but the fit at order level is poorer than at a lower taxonomic level (Table 2). Pairwise comparison of these resulting slopes indicated a nonsignificant difference between Plecoptera and Ephemeroptera (GT2, $p > 0.05$, Sokal & Rohlf 1981), suggesting a similar relationship between body mass and head capsule width for these taxa. When *Phylloicus* sp. is not considered in the pooled data of Trichoptera, the pairwise comparison of the slopes for the three orders are nonsignificant different from each other.

A predictive general equation was also obtained by pooling data from all individuals measured in this study (Table 2) which will be used for comparison with published data (Table 3).

Case width and dry mass of caddisfly larvae were highly correlated ($p < 0.001$) for *Nectopsyche* sp. and *Phylloicus* sp. even though their coefficients of determination were lower than when using body measurements (Table 2). Comparison of slopes for *Nectopsyche* sp. indicates a nonsignificant difference (GT2, $p > 0.05$, Sokal & Rohlf 1981), suggesting that changes in body weight

TABLE 2

Parameters of the linear regression $\log_{10} W = \log_{10} a + b \log_{10} L$ for the relationship between a linear measurement (head capsule width or case width, in µm) and dry mass (µg) for various taxa of tropical aquatic insects.

Taxon	$\log_{10}$ a ± SE	b ± SE	r^2
Ephemeroptera			
Thraulodes sp.	-4.456 ± 0.137	2.550 ± 0.048	0.966
Haplohyphes sp.	-1.814 ± 0.107	1.570 ± 0.014	0.938
Ephemeroptera general	-3.129 ± 0.116	2.083 ± 0.043	0.922
Trichoptera			
Leptonema sp.	-5.304 ± 0.223	2.877 ± 0.079	0.940
Nectopsyche sp.	-1.347 ± 0.105	1.350 ± 0.042	0.871
Nectopsyche sp.	-1.782 ± 0.243*	1.342 ± 0.085	0.767
Phylloicus sp.	-9.787 ± 0.294	4.495 ± 0.104	0.953
Phylloicus sp.	-7.881 ± 0.413[a]	3.083 ± 0.118	0.889
Trichoptera general	-4.321 ± 0.172	2.550 ± 0.064	0.827
Plecoptera			
Anacroneuria sp.	-3.541 ± 0.201	2.194 ± 0.067	0.927
All taxa	-3.566 ± 0.101	2.249 ± 0.037	0.859

* Regression equation for the relationship between case width (m) and dry mass (g)
a, b = regression constants, SE = standard error of the estimate, r^2 = coefficient of determination.

TABLE 3

General log-log equations relating dry mass (mg) to head capsule width (mm), according to insect order from several sources.

Taxon	Intercept	Slope	r[a]
Ephemeroptera			
Habrophlebia lauta[d]	-0.06	3.17	0.68
Habrophlebia lauta[e]	-0.33	3.29	0.94
Habroleptophlebia confusa[e]	-0.26	2.88	0.91
Ephemera (E.) spilosa[f]	-1.89	1.52	0.98
Campsurus[c]	-6.84	3.23	0.96
Non-Heptageniidae[b]	0.33	3.57	0.91
Non-Heptageniidae[e]	-0.16	3.47	0.94
Heptageniidae[b]	-0.87	3.56	0.90
Heptageniidae[e]	-0.83	2.88	0.93
Leptophlebiidae[g]	-0.36	4.25	0.93
Trichoptera[b]	0.43	2.77	0.79
Trichoptera[e]	0.17	2.73	0.91
Plecoptera[b]	-0.04	2.45	0.96
Plecoptera[e]	-0.35	2.71	0.95

[a]correlation coefficient
[b]Smock (1980)
[c]Cressa (1986) Weight in µg and head width in µm
[d]Wenzel *et al*. (1990)
[e]Meyer (1989)
[f]Dudgeon (1996)
[g]Burgherr & Meyer (1997)

per unit change in case width or head capsule width is similar. On the other hand, comparison of slopes for *Phylloicus* sp. indicate a significant difference (GT2, $p < 0.05$, Sokal & Rohlf 1981), suggesting that changes in body weight per unit change in case width are smaller than changes in body weight per unit change of head capsule width.

DISCUSSION

The length-mass relationships are useful since they allow a fast determination of biomass when processing a high number of samples. The data presented here, although based on a few taxa, reinforce the notion that in tropical aquatic insects the constant b falls short of the expected value of 3. The underlying assumption for this value is that body mass of insects is more influenced by surface than by volume (Engelmann 1961). Thus, it is possible that tropical aquatic insects could have longer thinner bodies than those in temperate habitats, as was suggested by

TABLE 4

Dry mass of individual organisms ($\hat{W}$, g dry mass) calculated from the species-specific equations, order-specific equations and general equations. The 95% confidence intervals (CI) are also presented.

Taxon	Head Capsule Width (µm)	Species-Specific Equation $\hat{W}$ (µg)	95 % (µg)	CI (µg)	Order-Specific Equation $\hat{W}$ (µg)	95 % (µg)	CI (µg)	General Equation W (µg)	95% (µg)	CI (µg)
Thraulodes sp.	818	938.33	874.58	1006.72	869.57	811.51	931.79	1074.91	1015.80	1137.46
Haplohyphes sp.	337	142.71	134.47	151.47	137.05	126.14	148.91	134.55	125.35	144.42
Leptonema sp.	1480	6551.22	5751.86	7461.66	8809.58	7521.59	10318.13	4313.43	3970.38	4686.11
Nectopsyche sp.	325	110.79	105.87	115.94	125.80	113.41	139.54	123.59	114.93	132.89
Phylloicus sp.	950	8274.65	2375.85	28819.16	2542.83	2270.70	2847.57	1526.25	1435.53	1622.71
Anacroneuria sp.	2000	5015.07	4479.47	5614.71				8735.09	7894.88	9664.73

Schoener (1980) when working with terrestrial tropical insects. Since *Phylloicus* sp. was the only species whose slope is higher than 3, it will be interesting to compare body length-dry mass relationship of this species from temperate habitats with tropical ones. Furthermore, it is possible that in this genus volume could influence body mass more than surface as is suggested by the data when. *Phylloicus* sp. and *Leptonema* sp. are compared (see Table 1) since the former is wider and shorter than the latter.

On the other hand, Trichoptera seems a particularly interesting order for further comparisons since the difference in slopes among species was the greatest. Even though the number of species analyzed here are few, the range in slope values is also higher (Table 2) than the one shown by Meyer (1989) with a bigger data set (2.86 – 3.64, head capsule width and dry mass relationships).

Only few comparable results are available which might serve as a basis for evaluating the information presented here. Thus, a summary of the data already published is presented in Table 3. The values indicate that head capsule width-dry mass relationships are similar at the order level for insects from North American and Central Europe. For the tropical species analyzed in this study, with the exception of *Phylloicus* sp., as well as for *Ephemera (E.) spilosa* (Dudgeon 1996), the data indicates that changes in weight are smaller than in head width. However, since there are few data available, it is impossible to indicate if tropical insects in general will have lower slopes ($b < 3$) than temperate ones. This hypothesis should be supported by further studies comprising a higher number of taxa.

A relationship between weight and case width was expected, since a change in case dimensions is needed as animals grow. Surprisingly though, this correlation was as high as for the relationship between weight and head capsule width. This result will be useful in growth rate studies because of the following advantages: (i) the same animal could be subject to measurements throughout the experiment, (ii) it will eliminate data extrapolation since measurements will belong to the same individual and (iii) it will avoid the use of a high number of experimental animals, since samples would not have to be subdivided, and therefore lost, in order to determine biomass at particular intervals.

The regression equations and relationships presented here are suitable for investigations into production biology since the results of several samples are used to estimate total biomass of the species under study.

Furthermore, the data also illustrate the need to use species-specific equations since their predictive capability is higher than when using equations based on data grouped at higher taxonomic levels. In order to illustrate this, I have computed the predicted weight of an individual of each one of the species studied from three different equations: (i) general (all data pooled), (ii) order-specific and (iii) species-specific. The linear measurements from which the weight predictions are made represent the midpoint of the range for the species. The predicted weights are shown in Table 4, from which it is evident that errors associated with substitution of the species-specific equations for the general or order-specific equations may lead to underestimation of biomass from 5.7 % to as much as 82%, with *Phylloicus* sp. being the species most affected. On the other hand, the overestimation of weight by using the order specific or the general equation was not as high (12% - 43%). The highest overestimation of mass was for *Anacroneuria* sp. when using the general equation.

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RESUMEN

Se calcularon las relaciones entre la masa del cuerpo y el ancho de la capsula cefálica para *Thraulodes* sp., *Haplohyphes* sp. (Ephemeroptera), *Leptonema* sp., *Phylloicus* sp., *Nectopsyche* sp. (Trichoptera), y *Anacroneuria* sp. (Plecoptera). Los análisis de regresión indicaron que todas las relaciones se expresan adecuadamente mediante la función potencial en vez de la función exponencial o linear. El análisis de las relaciones obtenidas revela diferencias entre los insectos pertenecientes a un mismo Orden. Se recomienda el uso de relaciones específicas para cada especie siempre y cuando sea posible, debido a que, dependiendo de la especie, la subestimación de la masa puede llegar a ser hasta de un 56%.

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