Population density is used in many ecological studies as a measure of ecological importance. However, coexisting species may differ in body size and thus have different levels of ecological importance with respect to a particular ecosystem function (WOODWARD et al. 2005). For this reason, biomass determination can be very important in ecological studies. Aquatic invertebrate biomass has been used in ecological studies to determine secondary production, transference of energy in the food chain, life history and growth rate (BENKE 1996, BURGHERR & MEYER 1997). Biomass can also be used to assess the preponderance of functional groups in different portions of an environmental gradient (e.g., the River Continuum Concept, VANNOTE et al. 1980) and in studies that aim to detect human disturbances and leaf breakdown (MASON JR et al. 1983, LIGEIRO et al. 2010).

Although biomass is important to several ecological processes, it is not easy to measure (RADEKE & WILLIAMSON 2005). Biomass can be determined directly by weighing individuals, or indirectly by determining their biovolume or the relationship between body dimensions and mass (BENKE et al. 1999). Biomass estimation based on body dimensions is faster and more accurate than biovolume and direct methods, especially in the case of small invertebrates (BURGHERR & MEYER 1997, BRADY & NOSKE 2006). Moreover, unlike biovolume and direct weighting, which require that the entire sample is dried out, samples used for biomass estimation can also be used in additional studies (e.g., molecular analyses; TOWERS et al. 1994).

When determining biomass directly, problems may arise as a result of the sampling method, sample handling, drying, period of collecting and method of preservation (MASON JR et al. 1983, LEUVEN et al. 1985, WETZEL et al. 2005). Moreover, the regression models for body dimensions and biomass are generally taxon-specific. They are also dependent on the genetic makeup of individuals and the environmental conditions of the geographical area studied, (BENKE et al. 1999), and for that reason caution should be taken when extrapolating these regressions from one place to another (BURGHERR & MEYER 1997).

Phylloicus caddisflies (Trichoptera) are important leaf shredders in Neotropical streams. Their behavior, and their role in leaf breakdown, has been subjected to several laboratory studies (GRAÇA et al. 2001, RINCÓN & MARTÍNEZ 2006, MORETTI et

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**Estimation of dry mass of caddisflies Phylloicus elektoros (Trichoptera: Calamoceratidae) in a Central Amazon stream**

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In the Neotropical region, the biomass of species of Phylloicus has only been estimated for areas in Venezuela (Cressa 1999a) and Southeastern Brazil (Becker et al. 2009). In the Amazon region, there have been no studies estimating the biomass of Phylloicus from the dimensions of the body or case. To fill this gap, we analyze this relationship for Phylloicus elektoros Prather, 2003, collected from a stream in Central Amazonia using linear, exponential and power regressions. The predictive power of the fitted models was assessed by cross-validation. We also evaluate whether the relationship between body dimensions and biomass are specific to the studied population. To this end, we tested the predictive power of regression models published for Phylloicus sp. from another region of Brazil by using them to estimate the biomass of our samples.

**MATERIAL AND METHODS**

Larvae of *P. elektoros* with different body sizes were collected in September 2012 (dry season) from the Barro Branco stream, at the Duke Reserve (02°55’ and 03°01’S, 59°53’ and 59°59’W), ca 50 km from the city of Manaus, AM, Central Amazonia, Brazil. This reserve has about 10,000 ha of preserved upland (“terra firme”) forest (Ribiero et al. 1999). The Barro Branco stream has dense riparian vegetation and closed canopy, acidic water (pH = 4.63 ± 0.08), high dissolved oxygen (6.62 ± 0.06 mg/l), low electrical conductivity (10.71 ± 0.41 µS/cm) and average temperatures of 24.52 ± 0.52°C. The abiotic variables were measured on the day larvae were collected.

A total of 152 larvae with cases were located (principally in pool areas), collected manually in a single day and transported to the laboratory. There, individuals were removed from their cases, individualized in containers, and preserved in 80% alcohol in a 20°C freezer for two months before analyses. The larval cases were also preserved in 80% alcohol at -20°C in the same vials containing their larvae. We opted for alcohol preservation because it takes a long time to measure all individuals and because the material was also being used for another study. We used four body dimensions as predictors of biomass: body length, head capsule width, intraocular distance and pronotum length. Body length was measured as the distance between the anterior portion of the head and the posterior portion of the abdomen. Head capsule width was the distance across the widest section of the head. Intraocular distance was measured as the minimum distance between the eyes. Pronotum length was measured along the mid-dorsal ec dysial line. These body dimension measurements followed Becker (2005) and Becker et al. (2009). We also used case length (ventral portion) and width (widest part at the opening) to estimate biomass because individuals of Phylloicus are usually collected with their cases (Cressa 1999a). The dimensions of the cases and the bodies of the larvae were measured using Leica M165 stereo-microscope im-

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Table I. Range, mean, standard deviation (SD), coefficient of variation (CV = (SD/mean)*100, in%) and number of observations (N) for body mass and body and case dimensions of *Phylloicus elektoros* larvae from a Central Amazonian stream.

| Body dimensions | Range      | Mean      | SD      | CV     | N  |
|-----------------|------------|-----------|---------|--------|----|
| Body length (mm) | 5.17-18.79 | 12.62     | 3.22    | 25.52  | 150|
| Head capsule width (mm) | 0.43-1.28 | 0.96      | 0.21    | 21.64  | 150|
| Intercocular distance (mm) | 0.19-0.80 | 0.58      | 0.14    | 23.84  | 150|
| Pronotum length (mm) | 0.38-1.29 | 0.89      | 0.21    | 24.12  | 150|
| Case dimensions  |            |           |         |        |    |
| Case length (mm) | 7.98-36.38 | 19.67     | 6.84    | 34.74  | 45 |
| Case width (mm)  | 2.79-9.52  | 6.17      | 1.86    | 30.10  | 45 |
| Body mass        |            |           |         |        |    |
| Dry mass (mg)    | 0.80-125.70| 26.69     | 23.17   | 86.80  | 152|

All regression models used to estimate the biomass of *P. elektoros* were significant (p < 0.001, Table II). The best fit between body mass and case or larval dimensions was provided by the power models, followed by the exponential and the linear models. For the three model classes, case width fit biomass better than case length. Body length yielded the best biomass predictions of all model classes (Table II).

We recorded significant differences in the biomass predicted using the models proposed by Becker et al. (2009), our cross-validated models, and the observed biomass (Table III). The predicted biomass using power and exponential models in our cross-validation study was approximately 20% higher than the observed biomass (Table III). On the other hand, the predicted biomass using the models proposed by Becker et al. (2009) was 75% lower than the observed values.

As expected, the coefficients of determination using predicted values (i.e., cross-validation) were lower (Table III) than those estimated using the same data set (Table II). Cross-validated coefficients of determination for body dimensions were similar for power and exponential models. However, power models using case dimensions performed much better than exponential models. Biomass predictions using models for *Phylloicus* sp. developed by Becker et al. (2009) were not only strongly negatively biased but were also not better than the predictions of a model composed of a single constant (the mean; in all cases R² = 0).

**DISCUSSION**

The best model for body dimensions was the one for body length, which explained up to 68% of the biomass variation. Previous studies have shown that body length provides good estimates of the biomass of several aquatic insect larvae (Smocek 1980, Benke et al. 1999, Genke-Kato & Miyasaka 2007). Body length was also the best predictor of biomass for a population of *Phylloicus* sp. in Southeast Brazil (Becker et al. 2009). In caddisflies the abdomen is usually less sclerotized than the pronotum or the head capsule, and grows continuously through the different instars, allowing for best fit with biomass (Benke et al. 1999).

Intraocular distance and head capsule width also provided high coefficients of determination. These body dimensions were highlighted by Cressa (1999a) and Becker et al. (2009) as good predictors of biomass for *Phylloicus* sp. Sclerotized structures are considered more reliable than body length to estimate the biomass of preserved organisms because they are less subject to breakage and deformation (Johnston & Cunjak 1999). However, our fitted regressions using sclerotized structures provided lower fit than did body length. According to Note (1990), the use of 70% ethanol to preserve Chironomidae has little effect on larval shape. In our study, we did not observe great alterations in the shape of the body of *P. elektoros*. Moreover, all specimens were individualized before alcohol preservation. This procedure is supposed to reduce specimen breakage, which could impact biomass determination (Radtko & Williamson 2005).

Preservation of invertebrates in alcohol is often necessary due to the large volume of material collected and the time...
Table III. Predictive performance of cross-validation models and the models developed by Becker et al. (2009) to estimate biomass of Phylloicus elektoros from a Central Amazonian stream. Difference indicates percentage of difference between predicted and observed data. Positive differences indicate that the predicted values were higher than the observed ones. F and p refers to tests between observed and predicted values. For cases in which models by Becker et al. (2009) are available, a one-way blocked analysis of variance was performed. For the remaining cases a paired t-test was performed. In both analyses, larvae were considered in blocks (or pairs). Values refer to averages obtained from predictions and tests repeated 100 times (see Methods). (DM) Dry mass, (BL) body length, (HW) head capsule width, (ID) interocular distance, (PL) pronotum length, (CL) case length, (CW) case width.

| Model          | Body and case dimensions | Difference (%) | r²          | Analysis of variance |
|----------------|--------------------------|---------------|------------|---------------------|
|                | Test data                | Becker et al. (2009) |             |                     |
| Exponential    | BL                       | 19.29         | -75.54     | 0.38 0.00 66.31 2,148 0.001
|                | HW                       | 23.20         | -75.01     | 0.38 0.00 71.22 2,148 0.001
|                | ID                       | 21.50         | -87.57     | 0.39 0.00 82.49 2,148 0.001
|                | PL                       | 26.74         | –          | 0.31 – 5.44 1,740 0.136
|                | CL                       | 43.08         | –          | 0.18 – 2.71 1,220 0.348
|                | CW                       | 26.54         | –          | 0.00 – 3.72 1,220 0.289
| Power          | BL                       | 17.10         | -77.08     | 0.42 0.00 71.05 2,148 0.001
|                | HW                       | 22.16         | -77.16     | 0.38 0.00 74.60 2,148 0.001
|                | ID                       | 20.87         | -90.85     | 0.37 0.00 87.10 2,148 0.001
|                | PL                       | 28.89         | –          | 0.31 – 5.69 1,740 0.155
|                | CL                       | 35.27         | –          | 0.51 – 3.35 1,220 0.304
|                | CW                       | 17.50         | –          | 0.45 – 3.26 1,220 0.344

needed to process samples (Leuven et al. 1985, Nolte 1990). However, insect preservation in alcohol could result in more than 50% weight loss (Hollowell 1972). This generally results from the dissolution of large amounts of lipids that are present in the larval body (Wetzel et al. 2005), but can be prevented by storing the insect in low temperatures (-20°C). According to Leuven et al. (1985), storage of the Gastropod Radix peregra (Müller, 1774) in 70% alcohol at -15°C during four months resulted in less than 5% mass loss. Additionally, Methot et al. (2012) assessed the relative importance of storage period, preservation method, continent, investigator, and taxonomic level to determine invertebrate biomass, and observed that the effects of preservation were small and represented less than 3% of the total variation in the estimated biomass.

We observed that the dimensions (length and width) of the case provided good biomass estimates for P. elektoros. Other studies have used case dimensions efficiently to predict the biomass of other Trichoptera species (Grauis & Anderson 1980, Cressa 1999a, Campos & González 2009). According to Cressa (1999a), the relationship between case dimensions and biomass are predictable because changes in case size closely follow individual growth. The high fit of case dimension models provides a way to measure the same individual on several occasions and thus allows longitudinal studies to be performed (Cressa 1999a).

Power models provided the best fits for P. elektoros biomass and body and case dimensions, although exponential models performed only slightly more poorly than power models. According to Wenzel et al. (1990), differences in biomass predicted using different regression models tend to be low, and to decrease when more specimens are used. The power model is the most frequently used in the literature to estimate invertebrate biomass (e.g., Smock 1980, Towers et al. 1994, Burgherr & Meyer 1997). However, we emphasize that the exponential model may provide satisfactory results for the relationship between body mass and body dimensions (González et al. 2002, Becker et al. 2009).

According to Cool et al. (1987), regression models do not provide good fit and show high predictive power in all cases. In our study, the coefficients of determination of models using cross-validation (test data) were very low compared to models estimated from sample data. This indicates that the difference between predicted and observed biomass may be important, and thus that biomass predictions may not be very reliable. Although we observed a good fit between body and case dimensions and biomass for P. elektoros, the predictive power of these models was low.

A perfect cubic relationship between body mass and body dimensions is obtained when the slope value (b) of the power model is 3 (Stoffels et al. 2003). According to Cressa (1999a), the relationships for most tropical aquatic insects show slopes lower than 3, usually between 1.34 in Nectopsyche sp. and 2.88 in Leptonema sp. The only exception seems to be a species of Phylloicus studied by Cressa (1999a), who found a slope of 4.50 for populations in Venezuela, and Becker et al. (2009), who reported coefficient values higher than 3 for Phylloicus sp. in
Southeast Brazil. In our study, slope values were high but were usually lower than 3, except for head capsule width (b = 3.32). Slope values close to 3 indicate that biomass is more influenced by body volume than by body surface area (Engelmann 1961, Benke et al. 1999). Thus changes in the biomass of *Phylloicus elektoros* are more pronounced than changes in body and case dimensions (Cressa, 1999a).

According to Wenzel et al. (1990) differences between observed and estimated biomass produced by a good model should be lower than 20%. Using the exponential and power models obtained in our study (test data), the difference between estimated and observed biomasses was slightly lower than 20%. On the other hand, literature models (Becker et al. 2009) for *Phylloicus* sp. from Southeastern Brazil underestimated biomass by 75% in relation to the observed data. This agrees with previous studies in which relationships between mass and body dimensions of insects collected in a given area usually are not efficient to make predictions based on other regions (Johnston & Cunak 1999, Misere_nding 2001). This may be the result of possible differences in species identity, environmental variables, food availability or population genetics (Basset & Glazier 1995, Burgherr & Meyer 1997, Benke et al. 1999, Baumgartner & Rothhaupt 2003).

We conclude that the power model provided the best fit between body and case dimensions and biomass. However, the exponential model also provided good biomass estimates. Our cross-validation study showed that our models do not predict the biomass of *P. elektoros* well. Additionally, we found that the predictive ability of models built for other regions performed even worse. Accordingly, literature models should not be used for regions other than the ones on which they were based. We suggest that, in order to attain more reliable predictions, the size-mass relationship should be based on the target population.

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