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Length–mass relationships for macroinvertebrates in freshwater environments of Patagonia (Argentina)

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ABSTRACT. Mass–length equations were obtained for aquatic macroinvertebrates collected in different streams and rivers of Patagonia, Argentina. Thirty six taxa were studied: Plecoptera (10 species), Ephemeroptera (3 species, 3 genera), Trichoptera (4 species, 1 genus), Diptera (6 genera), Coleoptera (1 species, 1 genus) Anisoptera (1 genus), Crustacea (2 species), Oligochaeta (1 genus, 1 family), Gasteropoda (1 species) and Turbellaria (1 genus). Additional relationships were obtained at the order level for Plecoptera, Ephemeroptera, Trichoptera and Diptera. Mass-length relationships were estimated by fitting the model $Y = aX^b$ linearized by logarithmic transformation) to data of dry mass vs. body length of preserved specimens. The regressions were highly significant and explained a high proportion of variation of the dependent variable, as expressed by the Coefficient of Determination (R^2 = 0.58–0.98). The equations obtained allow the estimation of biomass of invertebrates in Patagonian running waters from measurements of linear dimensions, facilitating calculations of benthic standing crop and of secondary production.

RESUMEN. Relaciones longitud–peso para macroinvertebrados de ambientes dulceacuícolas de Patagonia (Argentina): Se obtuvieron ecuaciones para estimar el peso seco a partir de medidas del largo del cuerpo, para 36 taxa de macroinvertebrados acuáticos de diferentes ríos y arroyos de Patagonia. Se estudiaron los siguientes taxa: Plecoptera (10 especies), Ephemeroptera (3 especies, 3 géneros), Trichoptera (4 especies, 1 género), Diptera (6 géneros), Coleoptera (1 especie, 1 género) Anisoptera (1 género), Crustacea (2 especies), Oligochaeta (1 género, 1 familia), Gasteropoda (1 especie) y Turbellaria (1 género). Se obtuvieron ecuaciones a nivel de orden para Plecoptera, Ephemeroptera, Trichoptera y Diptera. Las relaciones longitud–peso fueron estimadas por ajuste del modelo $Y = aX^b$ (en su expresión linear mediante transformación logarítmica) para datos de peso seco vs. largo del cuerpo de especímenes preservados. Las regresiones obtenidas fueron altamente significativas y explicaron una alta proporción de la varianza, expresada en el Coeficiente de Determinación (R^2 = 0.58–0.98). Los modelos obtenidos permiten estimar la biomasa de invertebrados de aguas corrientes de Patagonia a partir de mediciones del largo del cuerpo, facilitando cálculos de biomasa béntica y de producción secundaria.

INTRODUCTION

Many ecological questions at the organism, population, community and ecosystem levels of organization can be understood using biomass data. Biomass determinations are based on direct weighing of fresh, frozen, or preserved animals, biovolume determination, and length–dry mass conversion (Benke et al. 1999). Length–mass conversion has several advantages over direct weighing (Rogers et al. 1976; Meyer 1989) and has been widely used for biomass determination of terrestrial, benthic and planktonic invertebrates (Smock 1980; Meyer 1989; Nolte 1990).

Length–mass relationships obtained for macroinvertebrates in a specific area are not generally transferable to other study sites (Meyer 1989). Studies on length–mass relationships for macroinvertebrates from Patagonian streams in Argentina are scarce (Albariño & Balseiro 1998). The purpose of this work is to provide equations to estimate biomass from length measurements, for macroinvertebrates of running waters from Patagonia.

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METHODS

Macroinvertebrates were collected from 1991 to 1996 in different basins situated between 41°53' and 50°25'S, and between 71°29' and 72°27'W, Argentina. Sites description and characterization of water conditions can be found in other papers (Miserendino & Pizzolón 2000, in press). Samples were collected using a Surber net (250 µm mesh size). Animals were fixed in 4% formalin and preserved in 70% ethanol.

The length of those specimens having the entire body parts was measured to the near-

Table 1. Values for the constants ln *a* and *b*, obtained from dry mass (*DM*, mg) and body length (*L*, mm), according to macroinvertebrate taxa from Patagonian rivers. All determination coefficients are highly significant ($P < 0.001$). Also shown are length range (mm) and the number of individuals used to calculate each regression (*n*).

Tabla 1. Valores para las constantes ln *a* y *b*, obtenidos del peso seco (*DM*, mg) y longitud del cuerpo (*L*, mm) para los taxa de macroinvertebrados de ríos de Patagonia. Todos los coeficientes de determinación son altamente significativos ($P < 0.001$). Se muestran también el rango (mm) de individuos medidos y el número de individuos usados para calcular cada regresión (*n*).

Taxa	Regression constants				Length
	ln *a*	*b*	R^2	*n*	range
PLECOPTERA					
Austroperlidae					
Klapopteryx kuscheli	-5.16 ± 0.24	2.53 ± 0.10	0.94	39	4.5–25
Perlidae					
Pictetoperla gayi	-4.41 ± 0.24	2.66 ± 0.11	0.96	23	2–20
Kempnyela genualis	-4.83 ± 0.36	2.74 ± 0.16	0.94	17	3–19
Gripopterygidae					
Notoperla archiplatae	-5.46 ± 0.39	3.15 ± 0.10	0.85	39	2–16
Notoperlopsis femina	-6.29 ± 0.47	2.94 ± 0.22	0.86	31	3–15
Antarctoperla michaelseni	-3.49 ± 0.33	1.61 ± 0.20	0.74	22	2–9
Limnoperla jaffueli	-5.17 ± 0.69	2.34 ± 0.42	0.54	26	3–8
Aubertoperla illiesi	-5.28 ± 0.29	2.78 ± 0.22	0.87	23	2–5.5
Potamoperla myrmidon	-2.81 ± 0.49	1.38 ± 0.26	0.63	17	3–9.5
Senzilloides panguipulli	-4.69 ± 0.26	2.70 ± 0.14	0.93	27	2–17
EPHEMEROPTERA					
Leptophlebiidae					
Penaphlebia chilensis	-4.71 ± 0.40	2.29 ± 0.25	0.87	13	3–7
Meridialaris spp.	-9.95 ± 0.53	4.84 ± 0.29	0.87	39	2.5–11
Nousia bella	-4.90 ± 0.83	2.34 ± 0.43	0.69	14	5–9
Siphlonuridae					
Metamonius sp.	-6.36 ± 0.41	3.26 ± 0.19	0.88	41	5–11.5
Ameletopsidae					
Chiloporter eatoni	-4.83 ± 0.65	2.67 ± 0.28	0.87	14	6–15
Baetidae					
Baetis spp.	-5.25 ± 0.35	2.73 ± 0.26	0.84	21	2–6
TRICHOPTERA					
Sericostomatidae					
Parasericostoma ovale	-2.97 ± 0.31	1.45 ± 0.27	0.58	21	1.5–5
Hydropsychidae					
Smicridea spp.	-4.77 ± 0.31	2.79 ± 0.15	0.88	44	3–16
Hydrobiosidae					
Neoatopsyche sp.	-5.56 ± 0.27	2.51 ± 0.14	0.95	17	3–13
Cailloma sp.	-4.65 ± 0.32	2.47 ± 0.18	0.89	24	3.5–13
Rheochorema sp.	-4.70 ± 0.16	2.37 ± 0.09	0.99	7	2–7.5

est 0.5 mm under stereomicroscope. Body length in insects included the distance between the anterior part of the head and the posterior part of the last abdominal segment. Length of *Girardia* sp. was measured in relaxed specimens. *Chilina patagonica* was always measured and dried with the shell, and the size parameter used was the length of the shell. *Hyalella curvispina* body length was determined with the dead animals in their natural curved position as in Meyer (1989).

For dry mass determinations, each specimen was individually transferred into aluminum foils. Drying was performed at 105 °C for up

Table 1. Continuation.
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Taxa	Regression constants ln *a*	*b*	R^2	*n*	Length range
DIPTERA					
Chironomidae					
Paratrichocladius spp.	-6.38 ± 0.37	3.23 ± 0.25	0.90	17	3–7
Muscidae					
Lispoides sp.	-8.03 ± 1.27	3.55 ± 0.57	0.88	6	6.5–13.5
Athericidae					
Dasyoma sp.	-4.59 ± 0.21	2.04 ± 0.10	0.93	31	3–14
Blephariceridae					
Edwardsina (edwardsina) sp.	-5.01 ± 0.11	2.85 ± 0.05	0.98	31	2–15.5
Simuliidae					
Simulium spp.	-3.79 ± 0.21	1.78 ± 0.15	0.81	31	2–7
Tipulidae					
Hexatoma sp.	-7.74 ± 0.80	3.29 ± 0.35	0.84	18	6.5–23
COLEOPTERA					
Elmidae					
Austrelmis sp.?	-5.14 ± 0.56	2.11 ± 0.33	0.72	16	3–7
Hidrophilidae					
Tropisternus setiger	-6.03 ± 0.92	2.20 ± 0.56	0.82	7	3–8
ANISOPTERA					
Aeshna sp.	-6.04 ± 0.64	3.18 ± 0.28	0.91	13	3–22
CRUSTACEA					
Aeglidae					
Aegla neuquensis?	-5.08 ± 1.49	3.76 ± 0.62	0.80	5	6–22
AMPHIPODA					
Hyalellidae					
Hyalella curvispina	-3.77 ± 0.27	2.31 ± 0.17	0.85	33	2–8.5
ANNELIDA					
Oligochaeta					
Lumbriculidae sp.	-9.19 ± 1.18	3.25 ± 0.36	0.74	28	11–40
Tubificidae					
Limnodrilus sp.	-2.58 ± 0.29	0.74 ± 0.14	0.57	20	3–12
MOLLUSCA					
Chilinidae					
Chilina patagonica	-2.49 ± 0.21	2.75 ± 0.10	0.97	16	3–15
PLATHYHELMINTHA					
Turbellaria					
Girardia sp.	-4.01 ± 0.28	1.91 ± 0.14	0.86	28	3.5–10

to 4 h (Smock 1980). Animals were weighed on an electronic balance with 0.5 mg accuracy. In some cases, when the specimens were very small (e.g., very early stars of *Limnoperla jaffuelli*, *Baetis* spp.), the animals were dried and weighed together. In these cases, the individuals were grouped (5 specimens) by length before weighting. On the whole, 822 specimens were examined and measured.

Body mass relationships were assessed assuming that weight and length are related by the general power equation $DM = aL^b$ or equivalently, $\ln DM = \ln a + b \ln L$ (where: a and b are constants, DM = dry mass, and L = length). The linearized version of the model was fitted to the log-transformed data by standard regression techniques.

RESULTS AND DISCUSSION

Predictive equations for the conversion of length into dry mass were obtained for 36 taxa (Table 1), comprising the most frequent and abundant invertebrates found in rivers and streams of Patagonia (Albariño 1997; Miserendino 1999, 2000, 2001). Lengths were in the range 1.5–40 mm and weights were between 0.05–1619 mg. Regressions obtained were highly significant and explained a high proportion of variation of the dependent variable, as expressed by the coefficient of determination ($R^2 = 0.54$–0.98). It was not possible to obtain appropriate models for the stonefly *Pelurgoperla personata* nor for *Ablabesmya* sp. (Chironomidae). This was because *P. personata* accumulates a notable amount of detritus around the body that interfered with the measurements, and because specimens of *Ablabesmya* sp. in early stages were scanty.

Four additional regression models at order level were estimated for Plecoptera, Ephemeroptera, Trichoptera, and Diptera (Table 2 and Figure 1). The mean value of b for the four orders was 2.79; individual values were within the range 2.36–3.51. There were no significant differences in b mean values among insect orders (t-test and ANOVA, $P > 0.05$ in all cases). Similar results have been obtained applying multiple comparison tests to eight orders of aquatic insects in eastern USA (Benke et al. 1999). However, another work showed differences in the curves obtained for Coleoptera and Diptera, due to the different degree of exoskeleton chitinization that these taxa present (Smock 1980). As have been showed by other authors (Smock 1980; Meyer 1989), regression models with lower taxonomic levels of resolution explain a higher proportion of dry mass variation than those at order level. For this reason, predictive equations for the lowest possible taxon should be chosen when accuracy is needed.

Length–mass relationships in decapods usually show b values larger than 3, probably because their chelipeds increase in size more rapidly than their body length (Benke et al. 1999). The b value obtained for an *Aegla* species in this work was high (3.76), but it was based on a single species and could not be used in statistical analysis.

Table 2. Values for the constants ln a and b, obtained from dry mass (DM, mg) and body length (L, mm), according to four insect orders and for the class Insecta, from Patagonian rivers. All determination coefficients are highly significant ($P < 0.001$). Also shown are length range (mm) and the number of individuals used to calculate each regression (n).

Tabla 2. Valores para las constantes ln a y b, obtenidos del peso seco (DM, mg) y longitud del cuerpo (L, mm) para cuatro órdenes de insectos y para la clase Insecta, en ríos de Patagonia. Todos los coeficientes de determinación son altamente significativos ($P < 0.001$). Se muestran también el rango (mm) de individuos medidos y el número de individuos usados para calcular cada regresión (n).

Taxa	Regression constants		R^2	n	Length
	ln a	b			range
PLECOPTERA	-4.99 ± 0.14	2.61 ± 0.07	0.82	264	2–25
EPHEMEROPTERA	-6.98 ± 0.28	3.51 ± 0.14	0.82	128	2.5–15
TRICHOPTERA	-5.04 ± 0.26	2.72 ± 0.13	0.82	92	1.5–13
DIPTERA	-4.73 ± 0.17	2.36 ± 0.09	0.84	118	2–23
INSECTA	-5.15 ± 0.10	2.62 ± 0.05	0.77	715	0.5–25

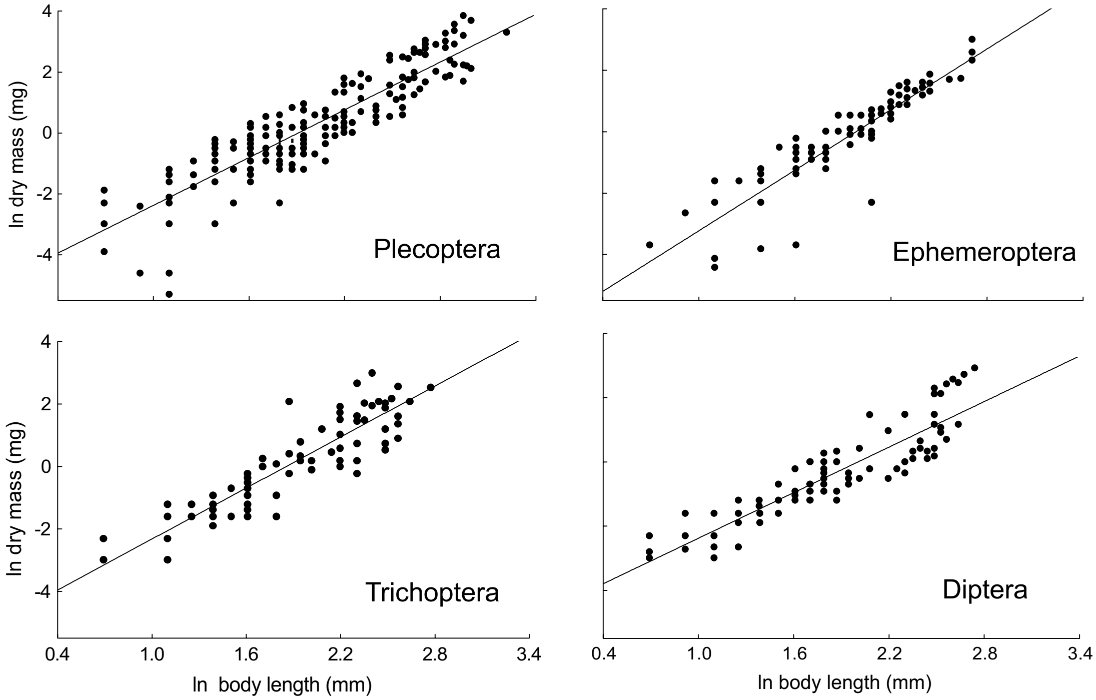

Figure 1. Length-mass curves for four orders of aquatic insects from Patagonian rivers. Regression constants, R^2 values, range, and number of measured individuals are given in Table 2.

Figura 1. Curvas de longitud-peso para cuatro órdenes de insectos acuáticos de ríos de Patagonia. Las constantes de regresión, el valor de R^2, el rango de valores y el número de individuos medidos están consignadas en la Tabla 2.

The general equation for aquatic insects obtained in this paper (a = 0.0057, b = 2.62) is very similar than those obtained for Smock (1980) (a = 0.019, b = 2.46), Benke et al. (1999) (a = 0.0059, b = 2.46), and Burgherr & Meyer (1997) (a = 0.019, b = 2.46). As has been remarked by Benke et al. (1999), all the curves for aquatic insects fall below the regression lines estimated for terrestrial insects (Rogers et al. 1976). Terrestrial insects generally gain weight, relative to increases in body length, more rapidly than most of aquatic insects. Terrestrial environments present a relatively greater number of heavily chitinized insects compared to aquatic environments, in which softer-bodied immature forms are dominant (Smock 1980).

In preserved specimens, fresh mass and dry mass are partly subject of mass losses, depending upon preservation time, preservative and taxon (Howmiller 1972). The present regressions were developed on preserved specimens because fresh material was not available. Formalin-preserved animals can provide estimations of dry mass very close to those using fresh animals (Benke et al. 1999), while ethanol-preserved animals may lose part of their dry mass through leaching (Howmiller 1972). Comparison of measurements of freshly-killed chironomid larvae with measurements taken after preservation with 70% ethanol, however, showed no change in body shape due to preservation (Nolte 1990).

Previous papers have shown the convenience of express some structural attributes of macroinvertebrate communities as biomass data. In Patagonian streams, functional feeding groups relationships are better understood using biomass than density (Miserendino & Pizzolón 2000). Various authors have suggested that regressions developed for the same taxa from different geographic regions may be significantly different, and recommended caution in their application. The predictive equations here presented apply to invertebrates from Patagonian running waters, both of the cordillera and of the plateau. These equations will be of valuable help in calculations of benthic standing crop and secondary production of these systems.

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