

Estimating the biomass of freshwater mussels (Bivalvia: Unionidae) from shell dimensions

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Keywords: Unionidae, unionid, *Quadrula quadrula*, *Quadrula pustulosa*, *Lampsilis anodontoides*, *Amblema perplicata*, biomass, model, prediction

Abstract

We have compared the convenience and accuracy of two models using 6 shell dimensions for predicting 4 biomass parameters for 4 species of southern U.S.A. unionids (*Quadrula quadrula*, *Q. pustulosa*, *Lampsilis anodontoides*, and *Amblema perplicata*). Prediction of whole wet weight, tissue wet weight, tissue dry weight, and shell dry weight as a linear function of (shell length)³ was accurate, even with extremely small sample sizes. In addition, this method is very convenient for field use because it requires one simple, unambiguous shell measurement.

Introduction

The Unionidae, when present, often dominate the biomass of the freshwater benthos (Waters, 1977). Past investigators have measured the biomass parameters whole wet weight, tissue wet weight, tissue dry weight, and shell dry weight in order to estimate standing crop biomass, growth, and net production in unionid populations (Negus 1966; Isom 1971; Cameron *et al.* 1979). However, these estimates are costly to obtain and require the destruction of large numbers of individuals, a problem when small populations are being studied. This study reports a method to estimate the biomass of unionids from rapid, nondestructive field measurements.

In general, unionids of the same species (or the same sex in sexually dimorphic species) possess the same relative shell proportions regardless of size or age. Old individuals with heavily eroded umbones may be an exception to this generalization. Therefore, we hypothesized that biomass is linearly related to the volume of each individual and therefore, biomass could be predicted from shell dimensions. We tested our hypothesis by regressing known values of whole wet weight, tissue wet

weight, tissue dry weight, and shell dry weight against various logarithmic and cubic functions of six shell dimensions. One variable, length³, provided adequate prediction of all biomass parameters for four common Texas unionids.

Materials and methods

We collected unionids from 2 locations: Buffalo Bayou below Barker Dam in Harris County, Texas (22 December, 1979) and the Little Brazos River, 1000 m downstream from F.M. 1687 in Brazos County, Texas (18 January, 1980). We collected 43 *Quadrula quadrula* (Rafinesque) 1820 and 9 *Lampsilis anodontoides* (Lea) 1834 (5 males and 4 gravid females) from Buffalo Bayou, 22 *Q. quadrula*, 23 *L. anodontoides* (15 males and 8 gravid females), 17 *Quadrula pustulosa* (Lea) 1831, and 22 *Amblema perplicata* (Conrad) 1841 from the Little Brazos River.

We scrubbed each clam to remove foreign matter from the periostracum. Then we measured whole wet weight, tissue wet weight, and shell dry weight with a beam balance (± 0.1 g). We dried the soft parts at 105 °C for 72 hours and measured tissue

dry weight with a torsion balance (± 0.005 g).

We then measured 6 external dimensions of each reassembled pair of valves. We measured shell length, height, and inflation with vernier calipers (± 0.1 mm). Length was the greatest antero-posterior distance measured parallel to the hinge ligament. Height was the greatest dorso-ventral distance measured perpendicular to the hinge ligament. Inflation was the greatest transverse distance measured perpendicular to both height and length.

We also measured 3 nonstandard shell dimensions. Shell profile, circumference, and girth were the greatest distances around the shell in the saggital, frontal and transverse planes, respectively, measured with a flexible tape (± 1.0 mm).

We performed two stepwise multiple regression analyses. We fit the sample weights (g) and 6 external dimensions (mm) to the model:

$$Y = aX^b$$

where Y is weight, X is any of the 6 linear dimensions, and 'a' and 'b' are constants by conversion of the model to the logarithmic form:

$$\ln(Y) = \ln(a) + b \ln(X)$$

We then fit a general cubic model of the form:

$$Y = aX^3$$

with Y defined as above. X^3 in this model is one of 13 variables derived from cubic combinations of shell dimensions: Length³ (L³), Height³, Inflation³, Length X Height X Inflation, Profile³, Circumference³, Girth³, Length² X Height, Length² X Inflation, Height² X Length, Height² X Inflation, Inflation² X Height, and Inflation² X Length. Therefore, each of the 6 unionid populations was analyzed for 4 weight variables, yielding 24 logarithmic regressions and an equal number of cubic regressions.

We tested for dependence of the regression coefficients on length in the L³ model by regressing the ratio, Y/L³, on length for each population (with Y defined as above).

We tested the ability of the L³ model to estimate population slopes from small samples for one biomass parameter, tissue dry weight. For each population we selected 3 groups of 3 individuals. We segregated *L. anodontoides* by sex and repeated the selection. For each group of 3 clams we regressed tissue dry weight on L³ and compared the

deviation of the slopes for each small sample from the slope obtained for the whole population.

Additionally, we analyzed length and whole wet weight data for *Amblema perplicata* from Little and Gentner (1970), Table II, in two ways. Little and Gentner sampled individuals at 2 times of the year, April and September. They also classified their individuals into arbitrary size classes. First, we performed a regression of the cubic model, whole wet weight = aL^3 , for their April and September data sets. Second, we computed the coefficient, whole wet weight/L³, for each individual and performed a 2 way analysis of variance (ANOVA) on these coefficients using time of year and size class as the classification variables. This tested the hypothesis that season, size class, or interaction of season and size class had an effect on the relationship of length to whole wet weight.

The regression analyses and ANOVA were performed using the STEPWISE/MAXR and GLM routines from the Statistical Analysis System (SAS) package (S.A.S. Institute, Inc., Raleigh, NC) as implemented on an Amdahl 470 V/6 computer.

Results

The logarithmic models showed generally good fit to be the data. The r^2 values (coefficient of determination) for the best fit models isolated by the regression program ranged from 0.722 to 0.992. Each of the 6 possible linear dimensions was selected as best predictor of a weight variable at least once. Girth, the most successful parameter, was selected best fit model 8 times. Circumference, the least successful parameter, was selected best fit in only 2 cases. No single logarithmic model was best fit for the 4 dependent biomass variables for all 6 populations.

Our estimates of 'b' in the logarithmic model for tissue dry weight and shell dry weight showed the same relationship that was obtained by Cameron *et al.* (1979); the shell weight 'b' values were all larger than the tissue dry weight values (Table 1).

The cubic models had much better overall fit than the logarithmic models. The lowest r^2 value obtained for all best fit cubic models was 0.955. Again, a variety of models was selected as best fit by the regression program. Eleven of the 13 possible parameters were selected at least once. Inflation² X

Table 1. Relationship of tissue dry weight to shell weight. Estimate of 'b' (slope) \pm one standard error for the logarithmic regressions of tissue dry weight and shell dry weight on length. BB = Buffalo Bayou populations. LB = Little Brazos populations.

	Tissue dry wt.	Shell dry wt.
<i>Q. quadrula</i> (BB)	3.155 \pm 0.582	3.615 \pm 0.140
<i>Q. quadrula</i> (LB)	2.176 \pm 0.309	3.652 \pm 0.176
<i>L. anodontooides</i> (BB)	1.981 \pm 0.281	4.096 \pm 0.284
<i>L. anodontooides</i> (LB)	3.073 \pm 0.222	3.204 \pm 0.176
<i>Q. pustulosa</i> (LB)	3.394 \pm 0.277	3.851 \pm 0.218
<i>A. perplicata</i> (LB)	2.438 \pm 0.327	3.094 \pm 0.132

Length, the most successful model, was selected best fit 5 times. L^3 , the next most successful model, was selected 4 times.

We performed stepwise regressions which included up to 5 independent variables for both the logarithmic and cubic models. In most cases we found no significant improvement (at the $P = 0.05$ level) in fit of the multivariable models over the single variable models.

Next, to choose between the single variable models, we compared the r^2 values of the best fit models to the r^2 values of the L^3 model for all 24

cases (Table 2). The L^3 model was found to be significantly different from the best fit model ($P = 0.05$) in 7 of the 24 cases.

Figures 1 and 2 illustrate the fit of the L^3 model to tissue dry weight for *Q. quadrula* from the Buffalo Bayou population. Figure 1 presents tissue dry weight vs. L^3 values defining the regression line, tissue dry weight = $(9.89 \times 10^{-6})L^3$. The r^2 value for this regression is 0.988.

We then tested the adequacy of the L^3 model in 2 additional ways. Regression of the ratio, weight variable/ L^3 , on length for each individual tested the dependence of the regression coefficients on shell length, testing the hypothesis that clams grow isomorphically. Thirteen of the 24 comparisons showed significant dependence of the regression coefficients on length. However, we found no consistent pattern of dependence with regard to a given population or biomass variable.

Secondly, the ability of the L^3 model to predict the slope of the regression lines from small samples was also taken as a measure of adequacy. We tested only one parameter, tissue dry weight. For 3 species, *Q. quadrula*, *Q. pustulosa*, and *A. perplicata*, and for female and male *L. anodontooides*, the largest percent deviation of a slope for a 3-member sample

Table 2. L^3 model regression results for each biomass parameter by population. The top value in each block is the coefficient of regression (slope), the middle value is the standard error of the coefficient of regression, and the bottom value is the coefficient of determination (r^2). LB = Little Brazos populations. BB = Buffalo Bayou populations. The asterisks denote r^2 values found to be significantly lower than the best fit model r^2 values ($p = 0.05$).

	Whole wet wt.	Tissue wet wt.	Tissue dry wt.	Shell dry wt.
<i>Q. quadrula</i> (BB)	2.36×10^{-4}	5.68×10^{-5}	9.89×10^{-6}	1.54×10^{-4}
	3.93×10^{-6}	8.90×10^{-7}	1.70×10^{-7}	3.32×10^{-5}
	0.989*	0.989	0.988	0.988*
<i>Q. quadrula</i> (LB)	2.44×10^{-4}	4.94×10^{-5}	1.20×10^{-5}	1.56×10^{-4}
	6.65×10^{-6}	1.99×10^{-6}	5.70×10^{-7}	3.36×10^{-6}
	0.985	0.967	0.953	0.988*
<i>L. anodontooides</i> (BB)	1.11×10^{-4}	3.36×10^{-5}	4.86×10^{-6}	5.57×10^{-5}
	9.35×10^{-6}	1.85×10^{-6}	3.40×10^{-7}	3.01×10^{-6}
	0.952	0.976	0.963	0.977
<i>L. anodontooides</i> (LB)	9.17×10^{-5}	3.44×10^{-5}	5.48×10^{-6}	3.71×10^{-5}
	2.84×10^{-6}	1.56×10^{-6}	2.60×10^{-7}	1.20×10^{-6}
	0.981*	0.957*	0.953	0.978
<i>Q. pustulosa</i> (LB)	3.77×10^{-4}	6.65×10^{-5}	1.51×10^{-5}	6.65×10^{-5}
	1.26×10^{-5}	2.39×10^{-6}	5.00×10^{-7}	2.39×10^{-5}
	0.982	0.980	0.983	0.980
<i>A. perplicata</i> (LB)	2.70×10^{-4}	6.04×10^{-5}	1.24×10^{-5}	1.65×10^{-5}
	8.91×10^{-6}	2.04×10^{-6}	3.70×10^{-7}	6.16×10^{-6}
	0.990*	0.989	0.978	0.980*

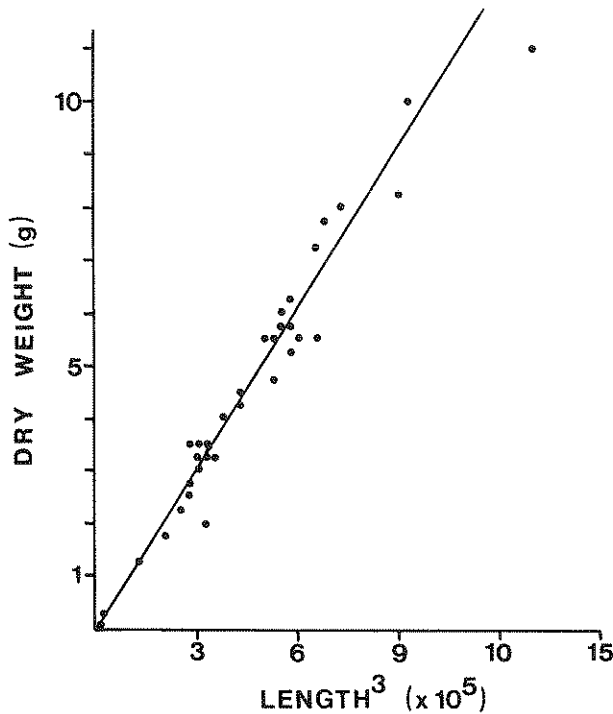


Fig. 1. Tissue dry weight regressed on $(\text{length})^3$ for *Quadrula quadrula* from Buffalo Bayou. The regression line is described in the text.

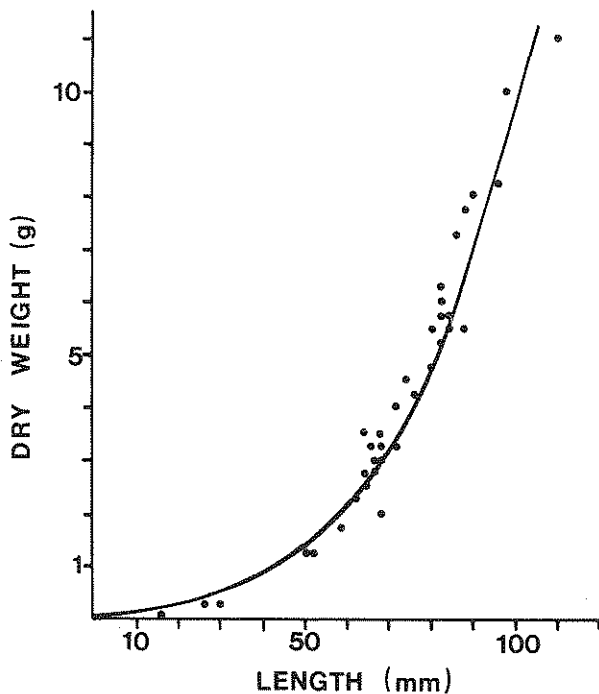


Fig. 2. Tissue dry weight regressed on length. The curve is defined by the equation: $(\text{length})^3 \times (\text{coefficient of regression})$. The coefficient of regression in this example is 9.89×10^{-6} (Table 2).

from the slope of the population was 12.2%.

The ANOVA of data from Little and Gentner (1970) for *A. perplicata* showed no significant effect of either size class, time of year, or interaction of size class and time of year on the weight/length relationship. The coefficients of regression of whole wet weight on L^3 for their data from April and September, 1966 (2.547×10^{-4} and 2.695×10^{-4} , respectively) are remarkably close to the value we obtained for *A. perplicata* 14 years later (2.692×10^{-4}).

Discussion

We propose the simple cubic model, L^3 , as an adequate and convenient predictor of the 4 biomass variables whole wet weight, tissue wet weight, tissue dry weight, and shell dry weight. The L^3 model has numerous advantages which we feel makes it the best choice for application to field studies of unionid productivity.

Logarithmic models have been used successfully to estimate biomass (Negus 1966; Coon *et al.* 1977; Cameron *et al.* 1979). However, we feel that linear cubic models are superior biomass estimators. First, the cubic model assumes an intercept of zero biomass for zero length individuals. This assumption is impossible in the logarithmic model (i.e. the $\ln(0)$ is undefined). This assumption gives the linear cubic model great facility to estimate the population coefficients from small samples. Our trial estimates of the regression coefficients for tissue dry weight using groups of 3 individuals, an unrealistically small sample size, gave coefficients very close to the population coefficients for all 4 species. Thus, very good estimates with small size samples argues for the acceptance of the L^3 model.

L^3 was not the best fit model in each case, but we feel that it is certainly adequate. Even when the r^2 values of the L^3 model were found to be significantly different from those of the best fit cubic models, the fit is sufficiently good for practical purposes (all r^2 values for the L^3 model greater than 0.952).

In addition, the L^3 model enables efficient collection of data from field populations. Length is the dimension of choice for field use because it is the least ambiguous and usually the largest dimension, minimizing measurement error. Length data for unionid populations has appeared in the literature

(Negus 1966; Isom 1971, for example), facilitating comparison of biomass estimates from many sources.

Finally, the remarkable similarity of slopes of whole wet weight vs. L^3 for Little Brazos River *Amblema perplicata* between samples from 1966 (Little & Gentner, 1970; Table 2) and our 1980 sample suggests that the length/biomass relationship is stable in time for any given population. If this hypothesis is correct, the L^3 model would be very useful for studies of secondary productivity of unionids. Given an appropriate means of marking and relocating individuals and a knowledge of population densities, periodic biomass estimates by the L^3 model could be analyzed to obtain rates of net production for the unionid component of the freshwater ecosystem.

We caution that the L^3 model is merely a tool for estimating biomass, not the best model for all comparative purposes. For example, Cameron *et al.* (1979) found 'b', the slope in the logarithmic model, always higher for shell dry weight than for tissue dry weight. This same relationship held for our 4 species (Table 1). These two observations suggest, in general, unionids increase shell dry weight more rapidly with length than they increase tissue dry weight. We note Cameron *et al.* (1979) worked with Canadian species and we worked with southern United States species. This generality deserves attention, but our point is that morphometric relationships such as this would not have been revealed by the L^3 model.

However, for the purpose of predicting biomass, we have shown that the L^3 model is a convenient and adequate predictor for 4 unionid biomass parameters: whole wet weight, tissue wet weight, tissue dry weight, and shell dry weight. It is particularly effective because it yields good estimates from small sample sizes and uses the simplest possible shell measurement. Therefore, we believe that the combination of high accuracy and minimal data requirements makes the L^3 model the model of choice for predicting unionid biomass.

Summary

We measured 4 biomass parameters (whole wet weight, tissue wet weight, tissue dry weight, and shell dry weight) and six shell dimensions (length, height, inflation, profile, girth, and circumference) for 4 species of Texas unionids (*Quadrula*

quadrula, *Q. pustulosa*, *Lampsilis anodontooides*, and *Amblema perplicata*) collected from 2 locations. We fit this data to two general models: a logarithmic model in which we regressed $\ln(\text{biomass})$ on $\ln(\text{shell dimension})$ and a cubic model in which we regressed biomass on a variety of cubic functions of the external dimensions (i.e. length^3 , $\text{height}^2 \times \text{inflation}$, etc.).

The cubic models produced a better overall fit than the logarithmic models (as measured by r^2 , the coefficient of determination). However, no one cubic model was selected as best fit for all biomass parameters for all clams. We then compared all best fit cubic models to one cubic model, length^3 (L^3). L^3 had a significantly lower fit than the best fit models in only 7 of 24 comparisons (p value = 0.05). The lowest r^2 value for any L^3 model biomass estimate was 0.952, suggesting that L^3 was an adequate model, even though it was not the best fit in all cases. There was no significant pattern of dependence of the ratio, $\text{biomass}/L^3$, on length. Also, the L^3 model provided good estimates of the regression parameters from extremely small sample sizes, providing more evidence that the L^3 model serves as an unbiased, robust estimator of biomass. Finally, we compared previously published biomass data for *A. perplicata* to our data and found evidence that the length/biomass relationship does not change significantly in time for a given population.

We conclude that the L^3 model is an adequate, convenient tool for predicting unionid biomass from easily measured shell dimensions.

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Received September 1, 1980.

