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Size-biomass relationships for some herbaceous plants of the Chilean arid region

Relaciones entre tamaño y biomasa de algunas plantas herbáceas de la región árida de Chile

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ABSTRACT

Because plant growth is very limited or some species are rare, rapid and non-destructive methods are needed to assess productivity of herbaceous plants in arid ecosystems. As an alternative to destructive methods, dimensional analysis has proven to be a useful tool to estimate aboveground-dry biomass of plants in these systems. Here, we provide information on the relationships between size and biomass of some herbaceous species of the Chilean arid region. The multiplicative model accounted for the size-biomass relationships in most of the species studied.

Key words: Arid lands, dimensional analysis, plant biomass.

RESUMEN

Debido a que el crecimiento de plantas en ecosistemas áridos es muy limitado y algunas especies son raras, se necesitan métodos rápidos y no destructivos para determinar la productividad. Como una alternativa a los métodos destructivos, se ha usado el análisis dimensional como una herramienta útil para estimar la biomasa seca sobre el suelo de plantas en sistemas áridos. Aquí, entregamos información sobre la relación entre tamaños y biomasa de algunas especies de herbáceas de la región árida de Chile. El modelo multiplicativo dio cuenta mejor de la relación entre tamaño y biomasa en las especies estudiadas.

Palabras claves: Zonas áridas, análisis dimensional, biomasa de plantas.

INTRODUCCION

The arid region of Chile (29-32°S) is characterized by winter rainfall between 25 and 150 mm (di Castri & Hajek 1976). June is the only bioclimatically favorable month; consequently, the growing season for plants is very limited (Hajek & di Castri 1975). This condition is reflected in the woody vegetation that is principally made up of evergreen and drought-deciduous shrubs. In a wet winter, a dense cover of herbs, which had remained as dormant seeds most of the year, develops between early winter and late spring. This herb layer constitutes the main source of forage for livestock, particularly sheep and goats, raised by local inhabitants (Fuentes & Hajek 1978).

Land managers and researchers require reliable estimates of plant biomass to assess site productivity, carrying capacity for livestock or treatment effects in manipulative field experiments. The usual techniques, such as harvesting of standing biomass are slow, expensive, and destructive (Murray & Jacobson 1982). These techniques are not appropriate in arid regions where plant growth is low, plant cover reduced or some species are scarce. Rapid and non-destructive methods are needed to quantify plant biomass if we want to measure productivity without greatly disturbing the system. Methods known as dimension analysis have been used to establish statistical relationships between plant biomass and plant dimensions (Whittaker 1965, 1966, 1970, Ludwig *et al.* 1975). This technique has been widely used to determine tree and shrub productivity, measured as dry-aboveground biomass (Baskerville 1965, Whittaker 1965, Buckman 1966, Telfer 1969, Lyon 1970, Whittaker & Woodell 1971, Ludwig *et al.* 1975, Brown 1976, Harrington 1979, Murray & Jacobson 1982). However, few

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studies have used the method for estimating herb biomass (e.g., Gutiérrez & Whitford 1987a,b). Allometric equations, which are nonlinear models of the form $Y = aX^b$, have been used successfully to describe relationships between some plant measurements and biomass, and generally high values of R^2 have been observed (Johnson *et al.* 1988).

In the Chilean arid region, information relating standing biomass to plant dimensions is available for some shrubs (Azócar *et al.* 1981, Gutiérrez *et al.* 1987), but is lacking for herbaceous vegetation. This paper is intended to partially fill that gap. Our objective was to test the adequacy of simple equations in predicting vegetative biomass of herbaceous plants from parameters such as crown diameters and plant height, which can be easily measured in the field.

MATERIAL AND METHODS

Individuals of 23 species of herbs were collected in Lagunillas (30°06'S, 71°21'W), 15 km S of Coquimbo during the winter season of 1987. The study area corresponds to a coastal marine terrace with soils derived from fossil dunes lying on top of a calcareous hardpan ("tertel") of marine origin. There are large outcrops of "tertel" in some places. The 49-year annual rainfall average is 102.6 mm (di Castri & Hajek 1976) with most of the precipitation falling between June and August (Muñoz 1985). Maximum air temperatures reach 25°C in summer, while minimum temperatures reach 3°C in winter (INE 1987). Total anual rainfall in 1987 was 170 mm, that is, 60 mm above the annual average for the area.

The number of individuals collected for each species varied between 10 and 13. They were selected to cover the entire range of sizes observed within the populations. Since 1987 was a relatively rainy year, we were confident to have adequately represented the range size of the species. Plant height (at the center), crown diameter (mean of two perpendicular measurements) and shape were recorded for each individual. Volume of foliage was determined for each species using the formula for the appropriate geometric body (inverted cone, upper-half prolate spheroid or upper-half spheroid), according to the natural shape of plants. For those species with a prostrate growth, cover was calculated using the mean diameter to obtain the radius of a circle. Because herbs having reproductive structures (flowers or inflorescences) may show different dimensional parameter relationships, we included individuals only in a vegetative state. At the time of sampling, all aboveground vegetative biomass of each individual was harvested at ground level and placed within individual paper bags for transport and drying. Plants were oven-dried at 50°C for 72 h; the material was then weighed to the nearest mg in a Sartorius scale. Because of the small proportion of the total biomass represented by the root system, and the error involved in digging and weighing roots, these data are not reported.

Regression analyses were used to obtain the relationships between aboveground-dry biomass (biomass, hereafter) and foliage cover or volume. Because the error involved in determining biomass is smaller than that involved in measuring plant dimensions, biomass was considered as the independent variable and volume or cover as the dependent variable. To estimate biomass from volume or cover, we used the inverse regression (Draper & Smith 1981). Following previous studies of plant size-biomass relationships (Ludwig *et al.* 1975, Murray & Jacobson 1982, Gutiérrez & Whitford 1987a,b), each dependent-independent variable pair was fitted by least squares using the linear regression form associated with the following arithmetic models:

Arithmetic model	Regression form
$Y = a + bX$	$Y = a + bX$
$Y = aX^b$	$\ln Y = \ln a + b\ln X$
$Y = e^{(a + bX)}$	$\ln Y = a + bX$

where Y = volume or cover and X = biomass. Once the straight lines have been fitted, biomass can be estimated by solving the equation:

$$X_o = (Y_o - a)/b$$

Details on the procedure to calculate confidence intervals for X_o are found in Draper & Smith (1981).

The criteria used to assess the goodness of fit of the models were the coefficients of determination (R^2) and the standard errors of the values estimated by the models (SEE).

RESULTS AND DISCUSSION

Size/biomass relations for the 23 species of herbs are given in Table 1. In general, we found a good fit between the two variables. This was reflected by the high value of the determination coefficients. Nine out of 23 species had an R^2 over 0.90 and nine species had R^2 over 0.80. The other five species had R^2 between 0.649 and 0.893. These values are in the range of those observed for crested wheatgrass (*Agropyron desertorum*, Graminae) (Johnson *et al.* 1988). The high values of R^2 show that both foliage cover and volume are good estimators of aboveground biomass in these species. Consequently, the proposed equations may be useful tools for predictive purposes. It has been reported that there is a strong relationship between canopy volume and aboveground biomass of several grasses and forbs, with R^2 exceeding 0.80 for both linear and allometric regression equation (Tausch 1980, cited by Johnson *et al.* 1988). In this study, the multiplicative model provided the best fit for 20 species (Table 1). For *Cryptantha glomerata* and *Erodium malacoides,* however, the exponential model, and for *Oxalis micrantha* the simple linear model accounted better for the actual relationship between size and biomass.

Most studies of plant biomass are oriented towards the assessment of plant productivity (Brown 1976). Tree biomass is commonly estimated by empirically relating weight to stem diameter. Harvesting is a much slower and more expensive technique. Uresk *et al.* (1977) estimated that clipping big sagebrush (*Artemisia tridentata*) phytomass was 120 times more expensive than using dimensional analysis. One of the problems arising from working with trees or shrubs is that the regression coefficients change with the age of the individuals and with their phenological stages (Ludwig *et al.* 1975). Hence, for trees and shrubs the equations should be

TABLE 1

Best fit regression between foliage volume (V) (in cm^3) or cover (in cm^2) and biomas (B) (g of aboveground-dry matter) of herbaceous species. R^2: coefficient of determination. SEE: standard error of the estimates. n: number of individuals.

Mejor ajuste de regresión entre volumen (V) (en cm^3) o cobertura (C) (en cm^2) del follaje y biomasa (B) (g de materia seca sobre el suelo) de especies herbáceas. R^2: coeficiente de determinación. SEE: error estándar de los valores estimados por el modelo. n: número de individuos.

SPECIES*	FAMILY	GEOMETRIC SHAPE	REGRESSION	R^2	SEE	n
Adesmia tenella H. et Arn.	Papilionaceae	inverted cone	$V = 776.961B^{0.97144}$	0.734	0.455	12
Alstroemeria kingii Phil.	Amaryllidaceae	inverted cone	$V = 544.523B^{1.1066}$	0.849	0.426	10
Calandrinia aff. *aurea*	Portulacaceae	upper-half prolate spheroid	$V = 11102.771B^{1.52093}$	0.941	0.290	11
Calandrinia sp. 1 indet.	Portulacaceae	circle	$C = 127.289B^{0.73082}$	0.983	0.241	10
Chaetanthera limbata (D. Don) Less	Compositae	inverted cone	$V = 727.555B^{2.21816}$	0.776	0.475	10
Chaetanthera linearis Poepp. ex Less	Compositae	inverted cone	$V = 3249.869B^{1.3877}$	0.913	0.448	10
Cryptantha glomerata Lehm.	Boraginaceae	inverted cone	$V = e^{(2.51152 + 9.6874B)}$	0.649	1.020	13
Erodium cicutarium (L.) L'Hérit.	Geraniaceae	inverted cone	$V = 409.141B^{1.86282}$	0.783	0.771	10
Erodium malacoides (L.) L'Hérit.	Geraniaceae	circle	$C = e^{(2.07783 + 9.00653B)}$	0.851	0.422	11
Erodium moschatum (L.) L'Hérit.	Geraniaceae	circle	$C = 513.279B^{1.15765}$	0.884	0.388	10
Eryngium coquimbanus Phil. ex Urban	Umbelliferae	circle	$C = 1662.105B^{1.51836}$	0.890	0.362	10
Helenium aromaticum (Hook.) Bailey	Compositae	upper-half prolate spheroid	$V = 9166.401B^{1.37088}$	0.920	0.416	10
Lastarriaea chilensis Remy	Polygonaceae	upper-half spheroid	$V = 1892.549B^{1.74113}$	0.981	0.216	10
Malva nicaensis All.	Malvaceae	upper-half prolate speroid	$V = 21810.570B^{1.50399}$	0.862	0.643	10
Mesembryanthemum cristallinum L.	Aizoaceae	circle	$C = 377.602B^{1.12854}$	0.875	0.488	13
Medicago polymorpha L.	Papilionaceae	inverted cone	$V = 881.310B^{1.57536}$	0.893	0.654	10
Nolana paradoxa Lindl.	Nolanaceae	circle	$V = 213.023B^{089946}$	0.949	0.345	11
Oenothera contorta (Greene) Mung.	Onagraceae	inverted cone	$V = 4969.778B^{2.15545}$	0.976	0.301	11
Oenothera coquimbensis Gay	Onagraceae	upper-half spheroid	$V = 4357.048B^{1.8916}$	0.833	0.751	10
Oxalis micrantha Bert. ex Savi	Oxalidaceae	circle	$C = 4.38694 + 426.235B$	0.925	1.863	12
Plantago hispidula R. et Pav.	Plantaginaceae	inverted cone	$V = 2584.016B^{1.57566}$	0.889	0.522	11
Quinchamalium chilense Mol.	Santalaceae	inverted cone	$V = 2983.970B^{2.18461}$	0.960	0.318	10
Schismus arabicus Nees.	Graminae	inverted cone	$V = 1995.480B^{1.20438}$	0.793	0.417	10

* Nomenclature follows Marticorena & Quezada (1985).

considered site and time specific. For herbs this is not usually the case, because the standard errors of the biomass estimates are reduced given the greater uniformity in plant age, particularly with annuals. Accordingly, the equations provided here might the useful to other investigators working in different places. However, these equations should be used cautiously because sample sizes were rather small, and therefore the standard errors of the regression coefficients are expected to be larger than with larger samples, and thus the estimates of biomass may not be very precise.

Using dimension analysis, Gutiérrez and Whitford (1987a,b) were able to follow the biomass dynamics of Chihuahuan Desert annual plants subjected to nitrogen and water treatments without disturbing the experimental set up for a complete growing season. Other techniques, such as harvesting, do not allow this type of nondestructive long-term observations. On the other hand, cover or plant volumen alone are not satisfactory estimates of resources uptaken by plants. Consequently, dimensional analysis is a technique that may help to advance studies of plant dynamics in herbaceous communities, a subject which up to now has been neglected in Chile.

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