Size-biomass Relationships of Several Chihuahuan Desert Shrubs

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ABSTRACT: Rapid, nondestructive methods are needed to quantify plant biomass dynamics. Methods known as dimension analysis can be used to establish regression relationships between plant biomass and easily obtained plant measurements. Regression analyses were used to estimate the dry weight of foliage, living and dead stems and roots from canopy area and volume for eight desert shrubs. The results show that volume and canopy area are generally suitable estimators. Regression equations developed for *Larrea tridentata* compare favorably with equations in similar studies in Arizona and Nevada, suggesting that our results might be applicable in other desert regions, at least for shrubs with well-defined growth forms. Other considerations when using these techniques are discussed.

INTRODUCTION

Recent efforts to understand how ecosystems function, one of the goals of the International Biological Program (Hammond, 1972), require measurement of plant biomass dynamics. Rapid, nondestructive methods are necessary for making these biomass estimates because of the labor and expense involved in measuring productivity and the need to preserve the ecosystem. One such method is to establish a relationship between easily obtained plant measurements and plant biomass, a technique termed dimension analysis (Newbould, 1967; Whittaker, 1965, 1966, 1970).

This technique has been widely used in forestry (*see* reviews by Madgwick, 1970 and Satoo, 1970). Diameter at breast height measurements have been used to estimate timber production (Kittredge, 1944; Rothacker *et al.,* 1954; Baskerville, 1965) and biomass of tree components such as foliage and small stems (Whittaker and Woodwell, 1968). However, studies to estimate biomass of shrubs using dimension analysis are scarce.

In an attempt to predict shrub foliage biomass, a relationship to crown diameter was established by Kittredge (1945) for two chaparral shrubs, *Ceanothus* and *Arctostaphylos;* by Medin (1960) for *Cercocarpus;* and by Mason and Hutchings (1967) for *Juniperus.* Burk and Dick-Peddie (1973) and Chew and Chew (1965) used canopy volume to predict the biomass of creosote bush (*Larrea tridentata*) in the Chihuahuan Desert. Wallace and Romney (1972) and Romney *et al.*

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(1973) used this same approach for a number of Mojave Desert shrubs.

The purpose of this study was to establish dimensional relationships for two easily measured plant properties, canopy area and volume, to the dry weight of foliage, living and dead stems and roots for a number of shrubs in our area and to evaluate the usefulness and applicability of our results. The shrubs considered are common Chihuahuan Desert plants: creosote bush *(Larrea tridentata)*, tarbush *(Flourensia cernua)*, mesquite *(Prosopis glandulosa)*, long leaf Mormon tea *(Ephedra trifurca)*, torrey Mormon tea *(Ephedra torreyana)*, snakeweed *(Xanthocephalum sarothrae)*, zinnia *(Zinnia acerosa)* and one semisucculent, soap-tree yucca (*Yucca elata*). Nomenclature follows Correll and Johnston (1970).

METHODS

Field and laboratory techniques.—The shubs were harvested from selected topographic areas adjacent to the New Mexico State University College Ranch, located next to the Jornada Experimental Range 40 km N of Las Cruces. This area is described as semidesert grassland (Wright and Van Dyne, 1970).

Eight to 15 individuals of each species were harvested from mid-September through early October 1970, the period of maximum development for the growing season and before autumn frosts. For each species, individuals were selected to cover the entire range of size variation within populations. Canopy height (at the center), diameter (mean of two perpendicular measurements) and shape were recorded for each plant. Canopy cover was calculated using the mean diameters to obtain the radius of a circle. Canopy volume was determined for each species by using the formula of a solid (*e.g.,* spheres, cones, etc.) which appeared to give the best fit of the natural shape of the canopy. For example, an inverted cone generally fits the canopy shape of *Larrea,* whereas the upper half of a spheroid fits the canopy shape of species such as *Prosopis* and *Xanthocephalum* (Fig. 1).

Prior to excavating the root system, all aboveground components, standing dead and live stems, leaves and fruits, were clipped or sawed at ground level from the root crown and placed in individual paper bags for transport and drying. The major portion of the root system was carefully excavated and bagged. In the laboratory the live stems-leaves component was allowed to air-dry for several days to facilitate hand separation. Then all component materials were dried in a circulating oven at 60 C for 48-72 hr, allowed to cool for 4-6 hr and weighed to the nearest gram.

Data analysis.—Regression analysis was used to obtain the relationships of plant component biomass to plant canopy cover and volume. Initially, data plots were used to elucidate functional relationships between the dependent and independent variables, which often suggested certain data transformations (*e.g.,* logs, reciprocals, powers). Various linear and curvilinear models were then attempted with the objective of building an accurate model while favoring less complex regression equations when possible.

The criteria used in testing the goodness of fit of the models were those suggested by Draper and Smith (1966): the coefficients of determination (R^2), the standard error of the estimate (S.E.E.) expressed as a percent of the mean response ($S.E.E./\overline{Y}$), and residual plots for examining constancy of model variance. Often the addition of a statistically significant second-order term would increase the R^2 value of a model, or decrease the standard error, yet the model variance would be less satisfactory than the linear model. Thus, each model was judged and selected with respect to these three criteria and to its complexity.

RESULTS AND DISCUSSION

Size-biomass characteristics.—The size and biomass characteristics of the shrubs harvested are given in Table 1. *Prosopis* was the largest shrub considered, averaging over 10 kg biomass for aboveground parts. The largest individual harvested weighed over 60 kg. Another species with a large biomass is *Yucca,* primarily due to its heavy

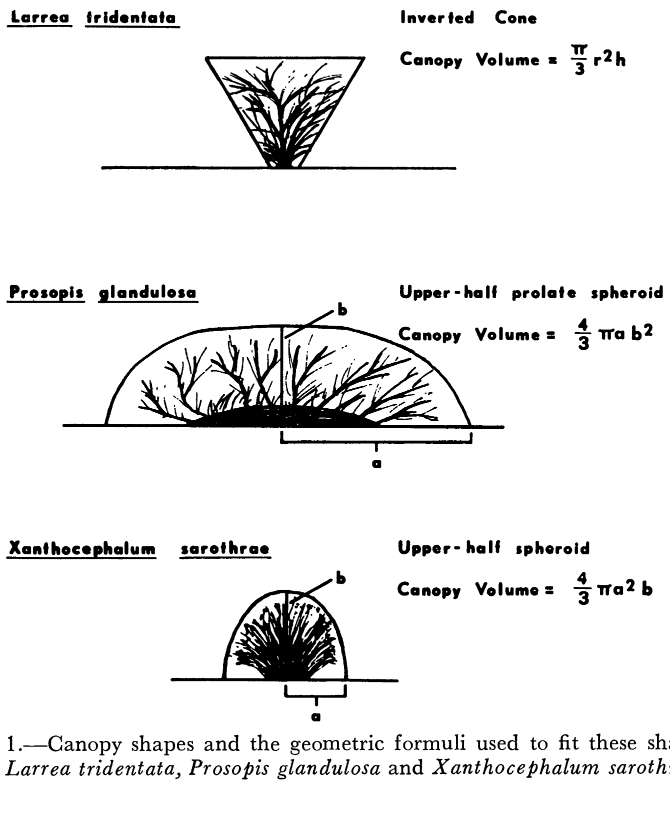

Fig. 1.—Canopy shapes and the geometric formuli used to fit these shapes for *Larrea tridentata, Prosopis glandulosa* and *Xanthocephalum sarothrae*

TABLE 1.—Size and biomass characteristics of desert shrubs harvested. The number of individuals of each species harvested is given. Area is computed by assuming a circular canopy. Volume is computed by using the formula which best fits the natural shape of the canopy of each species.

Species	Number of individuals harvested	Canopy area (m^2)			Canopy volume (m^3)			Total above-ground weight (g)	Total below-ground weight (g)
		Min	Mean	Max	Min	Mean	Max	Mean	Mean
Larrea tridentata	12	.02	.62	1.43	.001	.17*	.55	958	522
Flourensia cernua	8	.004	.68	2.01	.0001	.42#	.42	980	446
Prosopis glandulosa	11	.0007	3.19	13.8	.00002	3.71#	22.10	10217	8397
Ephedra trifurca	10	.013	.78	3.60	.003	.60#	3.12	1304	532
E. torreyana	10	.039	.34	.78	$7.x10^{-7}$	.052#	.24	135	127
Xanthocephalum sarothrae	15	.078	.27	.58	.0009	.032#	.15	65	16
Zinnia acerosa	10	.008	.079	.28	.0005	.016#	.53	78	10
Yucca elata	10	..	..	..					
(Leaves)		.24	.61	.90	.005	.121*	.29	697	2171
(Caudex)		.044	.032	.095	.0002	.003ç	.022	1767	....

* inverted cone
\# upper half of spheroid
ç cylinder

caudex and its characteristically large root. The smaller plants, *E. torreyana, Xanthocephalum* and *Zinnia,* often referred to as shrublets or subshrubs, averaged a canopy volume of 0.016 to 0.052 m^3, and had correspondingly smaller total biomasses. The remaining species were intermediate in size with mean canopy volumes varying between 0.12 to 0.60 m^3.

Regression equations.—The equations relating biomass to canopy area and volume for the eight shrubs are presented in Table 2. The regressions giving the best fit were either the zero-intercept linear models, $Y = bX$, or the zero-intercept curvilinear (2nd order polynomial) models, $Y = bX + cX^2$. In general, the relationships for canopy volume tended to be linear whereas those for canopy area tended to be curvilinear, as shown in Figure 2. The positive sign on most of the second-order terms of the curvilinear regressions indicate

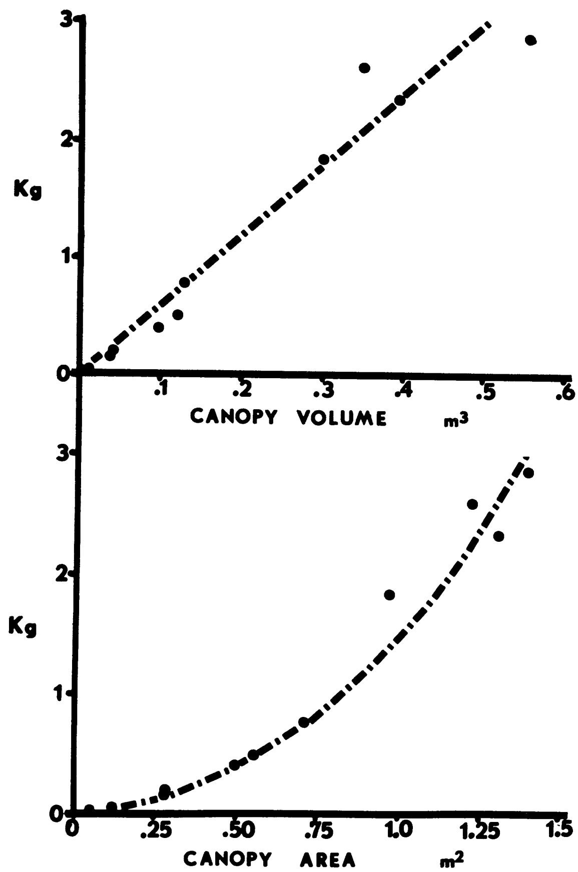

Fig. 2.—The relationship of total aboveground biomass to canopy area and volume for creosote bush, *Larrea tridentata*

TABLE 2.—Estimation equations for biomass (B, in g) of desert shrubs by their component parts based on canopy area (A, in m²) and on canopy volume (V, in m³). The coefficient of determination is R^2

Species	Components	Canopy area equations	R^2	Canopy volume equations	R^2
Larrea	Leaves	B = 105 A	.96	B = 345 V	.99
tridentata	Live stems	B = 715 A + .024 A²	.98	B = 3448 V	.98
(11)*	Dead stems	B = 365 A + .015 A²	.87	B = 1920 V	89
	Total aboveground	B = 1504 A²	.98	B = 5836 V	.97
	Total belowground	B = 761 A + .009 A²	.82	B = 2919 V	.84
Flourensia	Leaves	B = 88 A	.96	B = 123 V	.93
cernua	Live stems	B = 828 A	.97	B = 1163 V	.95
(8)	Dead stems	B = 507 A	.88	B = 700 V	.83
	Total aboveground	B = 1425 A	.95	B = 1987 V	.91
	Total belowground	B = 596 A	.88	B = 811 V	.80
Prosopis	Leaves	B = 3+60 A + 4 A²	.99	B = 79 V	.95
glandulosa	Live stems	B = 94+ 136 A²	.85	B = 1386 V	.96
(11)	Dead stems	B = 138 A²	.98	B = 1313 V	.94
	Total aboveground	B = 287 A²	.98	B = 2778 V	.99
	Total belowground	B = 220 A²	.99	B = 2130 V	.98
Ephedra	Green stems	B = 888 A — 65 A²	.99	B = 1239 V — 160 V²	.99
trifurca	Corky stems	B = 1221 A — 181 A²	.96	B = 1798 V — 373 V²	.99
(10)	Dead stems	B = 129 A + 56 A²	.99	B = 211 V + 53 V²	.99
	Total aboveground	B = 2238 A — 190 A²	.98	B = 3249 V — 481 V²	.99
	Total belowground	B = 664 A	.89	B = 1593 V — 229 V²	.95

TABLE 2.—(continued)

Species	Components	Canopy area equations	R^2	Canopy volume equations	R^2
E.	Green stems	B = 349 A	.98	B = 962 V	.96
torreyana	Corky stems	B = 279 A	.93	B = 1057 V	.92
(10)	Total aboveground	B = 627 A	.98	B = 2393 V	.98
	Total belowground	B = 137 A	.97	B = 2251 V	.95
Xanthocephalum	Leaves	B = 283 A	.92	B = 962 V	.96
sarothrae	Stems	B = 359 A	.88	B = 1251 V	.97
(10)	Total aboveground	B = 642 A	.90	B = 460 V	.91
	Total belowground	B = 137 A	.90	B = 2212 V	.98
Zinnia	Leaves	B = 172 A	.91	B = 951 V	.89
acerosa	Stems	B = 669 A	.82	B = 3746 V	.81
(10)	Total aboveground	B = 845 A	.84	B = 4702 V	.84
	Total belowground	B = 90 A	.93	B = 493 V	.90
Yucca	Green leaves	B = 1435 A	.89	B = 6218 V #	.96
elata	Dead leaves	B = 3.30 x 10^7 A^2 ç	.95	B = 2.09 x 10^5 V ç	.98
(10)	Caudex	B = 8.70 x 10^7 A^2 ç	.97	B = 5.46 x 10^5 V ç	.99
	Root	B = 8.41 x 10^7 A^2 ç	.94	B = 8.67 x 10^5 V + 2.06 x 10^7 V^2 ç	.93

* number of plants used in determining coefficients in the equations
ç based on caudex area rather than leaf canopy area

that as canopy area increases there is a proportionally greater increase in biomass.

Generality of size-biomass equations.—We initially hoped other investigators could use our species-specific equations in their particular areas. However, the question must be raised as to whether these equations can be generally applied to a species throughout its distributional range. To address this question, comparable equations were sought for a species in another area. Three studies involving creosote bush, *Larrea tridentata*, are available for comparison.

In a study conducted approximately 15 km S of our site, Burk and Dick-Peddie (1973) obtained a regression equation for relating canopy volume to total aboveground biomass for creosote bush. The equation they obtained was B = 5630 V, also using an inverted cone for canopy shape. This compares with our equation of B = 5836 V (Table 2). Thus, for the same species relatively close to our site the correspondence is close, as might be expected.

In southeastern Arizona, about 8 km N of Portal, Chew and Chew (1965) studied the productivity of a creosote bush community. They developed curves for the prediction of standing dry weight and ring-age from crown (canopy) volume. However, they presented only the curves relating standing dry weights to ring-age of creosote bush. Their curves were fitted by inspection and no regression coefficients were given. However, they did present predicted leaf weights per m^2 of crown cover (canopy area) for creosote bush plants of different ages. Their values ranged from 85 g m^{-2} for 5-year-old plants to 150 g m^{-2} for 25-year-old plants. Our estimated regression coefficient for leaf weight per m^2 of canopy area (Table 2) of 105 g m^{-2} falls within their range. Our plants are of unknown age.

In the northern Mojave Desert near Mercury, Nevada, Romney *et al.* (1973) and Wallace and Romney (1972) calculated regression equations for aboveground biomass from volume for creosote bush. Their volume index was not based on an inverted cone shape as was ours, although it was proportional to it. Therefore, the slope coefficient reported in their paper is not directly comparable to ours, but with the appropriate volume adjustment to make it compatible, their equation is B = 6156 V. Again, our equation (B= 5836 V) is similar to theirs.

Creosote bush has a relatively well-defined growth form; thus, predictive equations might be expected to be similar from one desert area to another. Species exhibiting variable growth forms, *e.g.*, mesquite, which is shrublike in the Chihuahuan Desert and treelike in the Sonoran Desert, would obviously not be as readily predictable as creosote bush.

Chew and Chew's (1965) results illustrate another important aspect of the generality of size-biomass equations with respect to age. If a shrub in one area varies greatly in age from those in another, and the growth form of the shrub tends to change with age, size-biomass equations may be expected to differ, particularly if the shrubs tend to be even-aged within each area, but of different ages between areas. For creosote bush this problem appears minimal.

Another consideration to be given these equations concerns the harvesting dates used to develop the relationships. Our results are derived from plants harvested near the end of the growing season in 1970. The regression equations for plant components which vary with the season and year, *e.g.*, leaves of deciduous plants, must be used accordingly.

Estimating the biomass of various component parts also involves less obvious problems. When we harvested the roots, primarily the larger (> 5mm diam) perennial roots were collected. These roots probably comprise 90% of the total root biomass due to their size and weight, but the 10% that was not collected is the fraction that is very functional in absorption. This adsorptive fraction of root biomass varies with the growing season (Hernandez and Caldwell, in press), making any predictions of functional root surface area from perennial root biomass pretentious.

Applicability of size-biomass equations.—In view of the effort required to harvest and process the vast amount of plant material needed to develop predictive equations, the usefulness and applicability of the equations in proportion to the effort involved must be considered. The purpose of this study was to use easily measured plant characters to predict biomass. In fact, these equations have been used to estimate initial standing crop biomass for several shrubs on our study sites in southern New Mexico.

Data on seasonal and yearly biomass dynamics are requisite to study ecosystems. Using the techniques outlined in this article, repeated measures of canopy size at selected intervals can provide such data readily. Biomass estimates for creosote bush at the end of the 1970 and 1972 growing seasons at our study site (Table 3) were computed using the appropriate regression equations. Canopy size data, then, can be obtained to provide the long-term (year to year) biomass dynamics.

Current research dealing with various treatments and manipulation of rangelands, such as the use of herbicides to control shrubs (Valentine, 1970), requires quantification of the plant species affected. The ease of estimating plant biomass using dimension methods would certainly enhance investigation of such effects. We measured the effect of herbicide treatments on density, cover and biomass for creosote

TABLE 3.—Estimated components of growth in creosote bush based on changes in canopy volume after the 1970 and 1972 growing season

Component	1970	1972
Canopy volume (m^3 ha^{-1})	1077	1262
Live stems (kg ha^{-1})	3715	4353
Dead stems (kg ha^{-1})	2069	2424
Belowground (kg ha^{-1})	3145	3684
% change	15	

bush on one such manipulation site in southern New Mexico, using our dimension analyses (Table 4). The decrease in live biomass is considerable. Less than 40 man-hrs were required to obtain the data for any given year, using a belt transect method which samples 5% of the shrubs in the 9-ha manipulation site.

Another potential use of these regression equations would be for converting plant cover (canopy area) data collected in previous years to plant biomass estimates. For example, species cover and height data collected on desert vegetation in the Rio Grande Valley by Gardner (1951) could be used to estimate biomass of these species for comparing this area with another area. However, this must be done with caution, as discussed under the topic of model generality.

TABLE 4.—Vegetational characteristics for creosote bush on a treated site in southern New Mexico in 1971 (before herbicide treatment); in 1972 (after first herbicide treatment); and in 1973 (after second herbicide treatment)

	1971	1972	1973
Density (# ha^{-1})	1017	862	491
Canopy area (%)	9.3	2.8	1.4
Leaf biomass (kg ha^{-1})	106	23	13
Live stem biomass (kg ha^{-1})	1055	234	125

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