

Sampling Big Sagebrush for Phytomass

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Highlight: A double sampling procedure was employed for obtaining more reliable weight estimates for leaves, flowering stalks, live wood, dead wood, various combinations of the preceding, and total phytomass of sagebrush shrubs. Easily obtained dimension measurements were related to harvest categories using regression analyses. Volume (length \times width \times height) and length measurements were the most highly correlated to phytomass. Double sampling reduced the variance of the mean phytomass estimates ranging from 33% to 80% for the various categories assuming optimum allocation. The precision achieved by combining dimension measurements with harvesting is significantly higher than by harvests without supporting dimensional measurements.

Efforts to obtain reliable phytomass estimates for rangeland shrubs by harvest methods are time consuming and costly. One approach is to establish a relationship between one or a few easily obtained plant measurements and harvest data. This approach has been termed double sampling or dimension analysis.

Aboveground phytomass has seldom been measured in desert shrubs. Harniss and Murray (1976) found a relationship between foliage of big sagebrush and the independent variables, circumference, and height of plant. A correlation ($R^2 = 0.93$) was obtained with the developed dry weight predictor to determine total phytomass estimates of sagebrush. Chew and Chew (1965) determined shrub weights of creosotebush (*Larrea divaricata*) in Arizona, and Ludwig et al. (1975) used a double sampling method involving dimension analysis to estimate phytomass on eight species of desert shrubs in New Mexico. The results show that volume and canopy area were generally suitable estimators. Medin (1960) used a crown diameter-weight relationship to predict foliage phytomass in mountain-mahogany (*Cercocarpus montanus*) shrubs on Colorado mule deer range. There appears to be little published data on phytomass sampling in big sagebrush (*Artemisia tridentata*) in the Pacific Northwest (Daubenmire 1970).

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This paper presents the results of a double sampling procedure to obtain more reliable phytomass estimates of leaves, flowering stalks, live wood, leaves + live wood, dead wood + live wood + dead wood, flowering stalks + leaves, miscellaneous fragments, and total phytomass for big sagebrush, the most abundant shrubby species in the shrub-steppe region of southeastern Washington.

Study Area and Methods

The study site is located on the Arid Lands Ecology (ALE) Reserve on the United States Energy Research and Development Administration's Hanford Reservation. Topographically, the site is located on the low, east-facing slopes of the Rattlesnake Hills at an elevation of about 1,300 feet above mean sea level. The vegetation of the area is representative of the *Artemisia tridentata*/*Agropyron spicatum* association (Daubenmire 1970). Prior to the initiation of the study reported here, there had been little or no grazing by domestic livestock since 1943 (Rickard et al. 1975).

In November 1974, a total of 20 (n) big sagebrush shrubs were selected within a 300 \times 300-m experimental pasture. The shrubs were not selected in a strictly random manner; instead, attempts were made to obtain a sample of different sized shrubs varying from smallest to largest. For each of the n shrubs the following dimensions were measured: (1) longest diameter of the canopy, (2) longest diameter of the canopy measured at right angles to the above dimension, and (3) maximum heights. The individual shrubs were then cut off at ground level and oven-dried weights obtained for the following hand-separated categories: leaves, live wood, flowering stalks, dead wood + dead leaves, and miscellaneous parts. These dimensions were also taken on all sagebrush shrubs (n') rooted within eight 15 \times 30-m plots located at random within the larger 300 \times 300-m pasture.

The objective of this sampling design was to minimize the variance of the estimated mean phytomass for each category for a fixed cost. The sampling procedure involved double sampling in conjunction with linear regression (Cochran 1963, p. 327-354). Double sampling is a combination of two different methods for estimating phytomass: (1) clipping, separating, and obtaining dry weights of total shrub parts, and (2) taking height, length, width, or volume (length \times width \times height) dimension measurements on shrubs, including those harvested. Double sampling can be effective in reducing the variance of mean phytomass estimates if the linear correlation ρ between phytomass and dimension measurements is sufficiently near 1, and the cost ($c_{n'}$) of making dimension measurements on a shrub is substantially less than the cost (c_n) of clipping, drying, and weighing. Cochran's (1963) Figure 12.1 (page 338) gives the relation between $c_n/c_{n'}$ and ρ for fixed values of the relative precision of double and single sampling.

Dimension and oven-dry weight measurements were obtained for the n clipped shrubs. These data were used to estimate a linear regression (calibration) equation relating phytomass (dependent variable) with all shrub dimensions (independent variable). A separate equation was estimated for each phytomass category. The additional information contained in the dimension measurements obtained on each of the n' shrubs within the eight 15×30 -m plots were used in conjunction with the regression equation to estimate the mean phytomass per shrub (\bar{Y}_{ds} ; ds stands for double sampling) for each category. The equation is

$$\bar{Y}_{ds} = \bar{Y}_n + b(\bar{X}_{n'} - \bar{X}_n) \quad (1)$$

where \bar{Y}_n is the mean phytomass per shrub based on the $n = 20$ clipped shrubs, \bar{X}_n is the mean volume of the 20 clipped shrubs, b is the estimated slope of the regression of biomass per shrub on volume per shrub, and $\bar{X}_{n'}$ is the mean volume per shrub of the $n' = 568$ shrubs in the eight plots. Volume was usually chosen as the independent variable because it generally had the highest estimated correlation ρ with all biomass categories.

The variance of \bar{Y}_{ds} was estimated using the approximate formula

$$\text{Var}(\bar{Y}_{ds}) = S^2_{y.x} \left[\frac{1}{n} + \frac{(\bar{X}_{n'} - \bar{X}_n)^2}{\sum_{i=1}^{20} (X_i - \bar{X}_n)^2} \right] + \frac{S^2_y - S^2_{y.x}}{n'} \quad (2)$$

where $S^2_{y.x}$ is the residual variance about the regression line, S^2_y is the variance of the 20 biomass data points,

$$\sum_{i=1}^{20} (X_i - \bar{X}_n)^2$$

is the sum of squared deviations of the 20 volume measurements from their mean \bar{X}_n , n is the number of shrubs for which both biomass and volume measurements were made ($n = 20$), and n' is the number of shrubs for which only dimension measurements were taken ($n' = 568$).

The average biomass per shrub \bar{Y}_{ds} is multiplied by the average number of shrubs per square meter, \bar{Z} , to approximate \bar{Y} , the average biomass of sagebrush/ m^2 , i.e.,

$$\bar{Y} \approx \bar{Y}_{ds} \bar{Z} \quad (3)$$

The standard error of \bar{Y} is approximated by the following (Kempthorne and Allmoris 1965):

$$\left[\text{Var}(\bar{Y}) \right]^{1/2} = \left[\bar{Z}^2 \text{Var}(\bar{Y}_{ds}) + \bar{Y}_{ds}^2 \text{Var}(\bar{Z}) \right]^{1/2} \quad (4)$$

Double sampling is an effective technique if the variance of \bar{Y}_{ds} is less than the variance of the mean biomass estimate \bar{Y}_s (g/bush) that one would obtain if the entire effort had been devoted to clipping shrubs and obtaining dry weights, with total cost C remaining the same as for the double sampling procedure (see equation 7 for the assumed cost function). The ratio of $\text{Var}(\bar{Y}_{ds})$ to $\text{Var}(\bar{Y}_s)$, assuming the optimum number of samples and n' were used in the double sampling scheme, can be estimated using the equation (Cochran 1963, pages 337–339):

$$\frac{\text{Var}(\bar{Y}_{ds(\text{opt})})}{\text{Var}(\bar{Y}_s)} = \frac{V_n + V_{n'} \frac{c_{n'}}{c_n} + 2 \sqrt{V_n V_{n'}} \frac{c_{n'}}{c_n}}{S^2_y} \quad (5)$$

where $V_n = S^2_{y.x}$ and $V_{n'} = S^2_y - S^2_{y.x}$.

The optimum ratio of n' to n can be estimated using

$$\frac{n'}{n} = \sqrt{\frac{V_{n'} c_n}{V_n c_{n'}}} \quad (6)$$

as given by Cochran (1963, equation 12.9). For comparison purposes, we assumed that $c_n/c_{n'}$ was equal to 120/1, i.e., a clipped estimate of phytomass is 120 times as expensive to obtain as are the dimension measurements on a shrub.

The ratio 120:1 is appropriate if estimates on all plant parts are desired. If estimates on only a few or a single plant part are needed, the cost ratio would be smaller due to lower harvesting costs. To illustrate the effect of a lower ratio, we have computed equations 5 and 6 when an estimate of only total phytomass is needed, assuming a cost ratio of 10:1.

Results and Discussion

Dimension data were collected on 568 live and 275 dead shrubs (Table 1). These data showed that dead shrubs are smaller on the average for length, width, height, and volume (length \times width \times height). Shrub density was estimated at $2,342 \pm 246$ (\pm SE) shrubs/ha of which $1,577 \pm 261$ and 765 ± 100 are live and dead, respectively. Dimension measurements obtained on the 20 clipped shrubs are given in Table 2. The average dimension measurements in Table 2 tend to be greater than those in Table 1. Since these 20 shrubs were not chosen at random, there may have been a selection bias toward larger shrubs.

Phytomass estimates obtained via clipping and drying were highly correlated (linearly) with volume and length (Table 3). Various combinations of length, width, and height were correlated to the various phytomass categories. Only those that showed the highest correlations are presented here. For most categories, volume (length \times width \times height) had the highest correlation. In estimating phytomass, volume (V) was chosen as the independent variable for all phytomass categories except for flowering stalks, and a miscellaneous category when the independent variable length was used. The R^2 (square of the linear correlation coefficient) values ranged from a low of 0.45 for miscellaneous to a high of 0.86 for total phytomass.

The estimates of phytomass obtained in this study using double sampling are presented in Table 4. Equation 1 was used to estimate the mean phytomass on a per-shrub basis. These were converted to g/m^2 using equation 3. These results indicate that wood makes up approximately 62% of the total phytomass of sagebrush. Dead wood accounted for 11% of the phytomass, while leaves and floral parts made up 14 and 8% of the total, respectively. Total phytomass of sagebrush was estimated to be $69 \text{ g}/\text{m}^2$.

Double sampling has apparently reduced the variance associated with mean phytomass values. This occurred because of the high cost ratio ($\approx 120:1$) and the good correlation between phytomass estimates (Y) and dimension measurements (X). Table 5 shows that reduction in the variance of the phytomass estimates ranged from 33 to 80% for the various categories. Hence, it appears that double sampling as used here was effective in obtaining more precise estimates of sagebrush phytomass than would have been the case if only harvesting had been employed.

When estimating total phytomass only and not considering the cost of separating it to the various categories, a reduction in variance of 56% was estimated assuming a cost ratio of 10:1 (Table 5). These results show that double sampling was more effective than harvesting shrubs alone to obtain total phytomass of big sagebrush.

Table 1. Dimension measurements (cm) of live and dead sagebrush shrubs.

Dimension	Dead (n = 275)			Live (n = 568)		
	$\bar{X} \pm SE$	Range	CV ¹	$\bar{X} \pm SE$	Range	CV
Length	53 ± 1.2	10 – 128	37	71 ± 1.2	14 – 199	41
Width	35 ± 0.9	10 – 88	42	48 ± 0.9	10 – 131	45
Height	36 ± 0.7	12 – 73	31	49 ± 0.8	12 – 117	41
Volume ²	86248 ± 5796	2310 – 739200	111	238848 ± 12817	2880 – 2190384	128

¹ Coefficient of variation = $(SE \times \sqrt{n} / \bar{X}) \times 100$.
² Volume (cm³) = length × width × height.

Table 2. Dimension measurements (cm) for 20 live sagebrush shrubs.

Dimension	$\bar{X} \pm SE$	Range	CV ¹
Length	86 ± 8	30 – 185	39
Width	68 ± 6	27 – 142	39
Height	70 ± 5	28 – 104	31
Volume ²	536500 ± 134403	22680 – 2732100	112

¹ Coefficient of variation = $(SE \times \sqrt{n} / \bar{X}) \times 100$.
² Volume (cm³) = length × width × height.

Table 3. Estimated regression equations for estimating phytomass (g/shrub) using volume (V) measurements (length × width × height) or length (L).

Dependent variable	Estimated equation	R ²
Leaves	$\hat{Y}_{ds} = 43 + 0.0000907 V$.68**
Live wood	$\hat{Y}_{ds} = 128 + 0.000603 V$.80**
Leaves + live wood	$\hat{Y}_{ds} = 171 + 0.00694 V$.82**
Flowering stalks	$\hat{Y}_{ds} = -128 + 2.269 L$.52**
Dead wood	$\hat{Y}_{ds} = -26 + 0.000197 V$.80**
Live wood + dead wood	$\hat{Y}_{ds} = 128 + 0.000811 V$.77**
Flowering stalks + leaves	$\hat{Y}_{ds} = 59 + 0.000193 V$.66**
Miscellaneous	$\hat{Y}_{ds} = -11 + 0.348 L$.45**
Total phytomass	$\hat{Y}_{ds} = 196 + 0.00102 V$.86**

**Significant at $\alpha \leq 0.01$.

Table 4. Estimated average phytomass of sagebrush using double sampling.

Dependent variable	n ¹	g/shrub ± SE†	g/m ² ± SE††
Leaves	20	65 ± 10	10 ± 2
Live wood	20	272 ± 48	43 ± 10
Leaves + live wood	20	337 ± 53	53 ± 12
Flowering stalks	19	33 ± 19	5 ± 3
Dead wood	19	49 ± 40	8 ± 7
Live wood + dead wood	20	322 ± 72	51 ± 14
Flowering stalks + leaves	20	105 ± 22	16 ± 4
Miscellaneous	20	13 ± 3	2 ± 1
Total phytomass	20	440 ± 70	69 ± 16

¹ n = clipped shrubs + dimension measurements; n' = 568 plants for dimension measurements only.
† Obtained using equations (1) and (2).
†† Obtained using equations (3) and (4).

For the fixed cost ratio $c_n:c_{n'} = 120:1$, the ratio $n':n$ of sample sizes is presented in Table 5. The ratio ranges from 28:1 to 10:1 for the various tissue categories. The various categories with lower ratios require a greater proportion of clipped plots. For example (assuming $c_n = c_{n'}$ for the moment), if one examines a total of 100 shrubs, a ratio of 10:1 indicates about 9 shrubs would be clipped (dimension measurements also being taken), and 91 shrubs would be measured for dimensions only. Having a ratio of 20:1 would reduce the clipped number of shrubs by approximately one-half (to about 5) while increasing to 95 the number of shrubs where only dimension measurements are taken.

In double sampling, cost is a major factor to consider. Once this has been determined, then the number of samples n (clipped

Table 5. Estimated optimum ratio $n':n$ of sample sizes and the estimated reduction in variance obtained using double sampling assuming a cost ratio of 120:1.

Category	Estimated optimum ratio $n':n^1$	Reduction in variance (%) under optimum allocation ²
Leaves	16:1	58
Live wood	23:1	73
Leaves + live wood	24:1	75
Flowering stalks	12:1	42
Dead wood	10:1	33
Live wood + dead wood	21:1	69
Flowering stalks + leaves	16:1	56
Miscellaneous	10:1	35
Total phytomass	28:1	80
Total phytomass ³	8:1	56

¹ Obtained using equation (6).
² Obtained using equation (5).
³ Assuming a cost ratio of 10:1.

+ dimension measurements) and n' (only dimension measurements taken) can be determined if some prior knowledge of these parameters is known. Cochran (1963) considers the case where the cost of the two samples is

$$C = nc_n + n'c_{n'} \tag{7}$$

where C is the total cost and c_n and $c_{n'}$ are the costs of obtaining clipped and dimension measurements, respectively. If we assume the total cost C to be \$1,000 and $c_n:c_{n'} = 120:1$ as outlined earlier and using the optimum ratio for the total phytomass ($n':n$) of 28:1, then sample sizes for n and n' can be determined.

From equation 7 we have that

$$\$1,000 = 120n + n'.$$

From the optimum ratio we obtain
 $n' = 28n$.

By substituting for n' we obtain
 $\$1,000 = 120n + 28n$, or
 $n = 6.8$.

Solving for n'
 $\$1,000 = 120(6.8) + n'$, or
 $n' = 184$.

Assuming a cost of \$1,000, one would clip and take dimension measurements of 7 shrubs plus obtain dimension measurements of 184 shrubs.

Concerning the design of future sampling plans for estimating sagebrush phytomass, we see from Table 5 that the optimum ratio $n':n$ differs for each plant part. This occurs due to changes in V_n and $V_{n'}$ (equation 6) since $c_n:c_{n'}$ was held constant at 120:1. Hence, the optimum n and n' will vary for each plant part. This suggests that when planning a double sampling study with several variables (plant parts), it will not be possible to obtain the maximum reduction in variance for all variables simultaneously. One approach is to use the n and n' that will achieve the maximum reduction in variance for the most

important variable (perhaps total phytomass). More generally, n and n' could be estimated for each plant part and a compromise made based on the relative importance of achieving maximum reduction in variance for the plant parts.

Also note from equation (2) that $\text{Var}(\bar{Y}_{ds})$ can be reduced if \bar{X}_n and $\bar{X}_{n'}$ (the mean dimension measurements on the n and n' shrubs, respectively) are in close agreement. In these data, the two means are rather far apart (Tables 1 and 2), which may be due to a biased selection process for the 20 shrubs. This bias might have been less had the 20 shrubs been selected by using some kind of a random selection process. However, we also note that the variance of double sampling will decrease if

$$\sum_{i=1}^{20} (X_i - \bar{X}_n)^2$$

is large, i.e., if small as well as large shrubs are included in the 20 selected shrubs. By random selection of shrubs for clipping and volume measurements, we would have to take whatever shrubs were randomly selected so that a large sum of squared deviations would not necessarily result. One approach to this problem would be to divide the population of shrubs into non-overlapping size categories and obtain random samples from each group.

The data examined here suggest that double sampling can be an effective technique in reducing the variance of the mean phytomass estimates of the various phytomass categories of big sagebrush. The precision achieved by combining dimension

analysis with clipping and harvesting is significantly higher than by only harvesting shrubs when cost is held constant.

One of the major benefits of this double sampling procedure is that it is nondestructive when determining phytomass estimates of the various categories of sagebrush. Once a relationship between clipped shrub values and dimension measurements has been established, then repeated phytomass inventories may be conducted on various sites by obtaining dimension measurements only, assuming the calibration relationship does not change.

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Responses of Vegetation and Sheep to Three Grazing Pressures, by Frank Oren Thetford, Jr., PhD, Rangeland Resources, 1975.

A study was conducted over a 2-year period, 1973 through 1974, on perennial ryegrass-subclover pastures with stocking rates of 7.4 (moderate), 9.9 (heavy), and 12.4 (overstocked) ewes per hectare to establish guidelines on stocking intensity for dryland improved pastures in western Oregon. Climatic conditions varied annually and caused variation in growth of the vegetation and differences in stocking dates among treatments. Grazing significantly depressed total forage yields in each year. However, there was no significant difference noted between years for total forage yields. Ryegrass yields remained the same for both years in all treatments. The yield of other grasses (primarily annuals) increased in heavily stocked and overstocked treatments during the period of this study, but not in the moderately stocked pastures. Moderately stocked pastures had more ryegrass available per head per day than the other treatments in all seasons. Nutritive value of the herbage followed normal seasonal trends. Herbage in 1974 was of lower nutritive value than in 1973. Animals in moderately stocked pastures were able to obtain sufficient forage of good quality to meet or exceed

dry matter intake, protein, and energy requirements throughout both years. The data indicated that during the fall (1973) and summers (1973, 1974) diets of animals from overstocked pastures were deficient in dry matter intake, crude protein, and digestible energy. Digestibility of dry matter in the diets increased from 77% both years in early spring to 55% during the summers; also, there was no difference among treatments. Annually, during early spring ewes on all treatments gained weight at the same rate. Ewes from moderately stocked pastures lost the least weight in the summer; ewes on the overstocked treatment lost the most. Weight gains of ewes and lambs were higher in 1973 than in 1974. There were no significant differences among treatments for the rate of gain of lambs. Likewise, no noticeable differences were observed in the total number of lambs born on each treatment. The results from the heavily stocked treatment were highly variable and sometimes they were similar to either the moderate or the overstocked treatment. Therefore, data indicate that 7.4 ewes per hectare may be the proper spring through fall stocking rate for these pastures.