CONF-751169--1

BNWL-SA-5567

SAMPLING BIG SAGEBRUSH FOR PHYTOMASS

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This paper is based on work performed under U. S. Energy Research and Development Administration Contract E(45-1):1830

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Sampling Sagebrush for Phytomass

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SAGEBRUSH PHYTOMASS

Abstract

Big sagebrush (Artemisia tridentata) was subjected to a double sampling procedure to obtain reliable phytomass estimates for leaves, flowering stalks, live wood, dead wood, various combinations of the preceeding, and total phytomass. Coefficients of determination (R^2) between the independent variable and various phytomass categories ranged from 0.45 to 0.93. Total phytomass was approximately 69 ± 16 (± S.E.) g/m^2. Reductions in the variance of the phytomass estimates ranged from 33% to 80% using double sampling assuming optimum allocation.

This paper presents the results of a double sampling procedure to obtain reliable phytomass estimate 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, *Artemisia tridentata*, the most abundant shrubby species in the shrub-steppe region of southeastern Washington.

Study Area and Methods

This study site is contained within 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 east-facing slopes of the Rattlesnake Hills at an elevation of about 1300 feet above mean sea level. The vegetation of the area is representative of *Artemisia tridentata*/*Agropyron spicatum* association (Daubenmire, 1970). Prior to the initiation of the study reported here, there had been little or no grazing by cattle since 1943 (Rickard *et al*., 1975).

In November, 1974, a total of 20 (n) sagebrush (*Artemisia tridentata*) shrubs were selected within a 300 x 300 meter area. The shrubs were not selected in a strictly random manner but attempts were made to obtain a cross section of shrubs according to general size. 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 dimensions, and (3) maximum heights. The individual shrubs were then cut off at ground level and oven dry weights obtained for the following hand-separated categories: leaves, live wood, flowering stalks, dead wood, dead leaves, and miscellaneous parts. Within the 300 x 300 meter study area, the above dimensions were taken on all sagebrush shrubs (n') within eight randomly located 15 x 30 meter plots.

The sampling procedure involved double sampling in conjunction with linear regression (Cochran, 1963, pp 327-354). The objective of this sampling design was to minimize the variance of the estimated mean phytomass for each category for a fixed cost. Double sampling is a combination of two methods for estimating phytomass: (1) clipping, separating, and obtaining dry weights, and (2) taking height, length, width, or volume (length x width x 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 if the cost ($c_{n'}$) dimension measurements on a shrub is substantially less than the cost (c_n) of clipping and obtaining the dry weight biomass of the shrub. 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.

As indicated above, both dimension measurements and oven dry weights were obtained for the n clipped shrubs. These data were used to estimate a linear regression (calibration) equation relating phytomass (dependent variable) with 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 x 30 meter plots were used in conjunction with the regression equation to estimate the mean phytomass per shrub ($\overline{Y}_{ds}$; ds stands for double sampling) for each category. The equation is

$$\overline{Y}_{ds} = \overline{Y}_n + b(\overline{X}_{n'} - \overline{X}_n), \tag{1}$$

where $\overline{Y}_n$ is the mean biomass per shrub based on the n = 20 clipped shrubs, $\overline{X}_n$ 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 $\overline{X}_{n'}$ is the mean volume per shrub of the n' = 568 live shrubs in the eight plots. Volume was usually chosen at the independent variable because it usually had the highest estimated correlation $\hat{\rho}$ with all biomass categories.

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

$$\mathrm{Var}(\overline{Y}_{ds}) = S^2_{y\cdot X}\left[\frac{1}{n} + \frac{(\overline{X}_{n'} - \overline{X}_n)^2}{\sum_{i=1}^{20}(X_i - \overline{X}_n)^2}\right] + \frac{S^2_y - S^2_{y\cdot X}}{n'}, \tag{2}$$

where $S^2_{y\cdot X}$ is the residual variance about the regression line, S^2_y is the variance of the 20 biomass data points, $\sum_{i=1}^{20}(X_i - \overline{X}_n)^2$ is the sum of squared deviation of the 20 volume measurements from their mean $\overline{X}_n$, 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 $\overline{Y}_{ds}$ is multiplied by the average number of shrubs per square meter, $\overline{Z}$, to approximate $\overline{Y}$, the average biomass of sagebrush/m^2 as shown by the following:

$$\overline{Y} \simeq \overline{Y}_{ds}\overline{Z}. \tag{3}$$

The standard error of $\overline{Y}$ is approximated by the following (Kempthorne and Allmorus, 1965):

$$\left[\mathrm{Var}(\overline{Y})\right]^{1/2} \approx \left[\overline{Z}^2 \ \mathrm{Var}(\overline{Y}^2_{ds}) + \overline{Y}^2_{ds} \ \mathrm{Var}(\overline{Z})\right]^{1/2}. \quad (4)$$

Double sampling is an effective technique if the variance of $\overline{Y}_{ds}$ is less than the variance of the mean biomass estimate $\overline{Y}_s$ (gms/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. The ratio of $\mathrm{Var}(\overline{Y}_{ds})$ to $\mathrm{Var}(\overline{Y}_s)$, assuming the optimum number of samples n and n' were used in the double sampling scheme, can be estimated using the equation (see Cochran, 1963, pp 337-339):

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

where V_n is estimated by $S^2_{y \cdot x}$, $V_{n'}$ by $S^2_y - S^2_{y \cdot x}$.

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 1/120, i.e., a clipped estimate of phytomass was 120 times as expensive to obtain as are the dimension measurements on a shrub.

Results and Discussion

Dimension data collected on the 568 live and 275 dead shrubs contained within the eight 15 x 30 meter plots (Table 1) indicate that dead shrubs are smaller on the average for length, width, height, and volume (length x width x height) on the ALE site. This area is characterized by having an estimated total of 2,342 ± 246 shrubs/ha of which 1,577 ± 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 (linearly) correlated 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 x width x height) had the highest correlation. In estimating phytomass, the variable volume (V) was chosen as the independent variable for all biomass 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.

Our main objective in using double sampling was to minimize or reduce the variance of the estimate of mean phytomass for a fixed cost. Double sampling was effective in this regard because the clipped phytomass (Y) can be determined more precisely than dimension measurements (X); X is much less expensive to obtain (recall that we estimated the cost ratio $c_n/c_{n'}$ to be 1/120). Table 5 shows that reductions in the variance of phytomass estimate 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 the usual clipping and drying had been used.

For the fixed cost ratio $c_{n'}/c_n$ = 1/120, 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, 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 plots by approximately one-half so that the overall time required to obtain an estimate of $\hat{Y}$ would be reduced.

Concerning the designs of future sampling plans for estimating sagebrush phytomass, we can see from equation (2) that $Var(\overline{Y}_{ds})$ can be reduced if $\overline{X}_n$ and $\overline{X}_{n'}$ (the mean dimension measurements on the 20 and 568 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 may have been reduced had the 20 shrubs been selected by using some kind of a random selection process. We also note that the variance of double sampling will decrease if

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

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.

Double sampling is an effective technique in reducing the variance of the mean phytomass estimates of the various categories of big sagebrush. The accuracy achieved with time and costs is significantly lower than by harvesting shrubs only. The results of this study apply to generally short-statured shrubs of big sagebrush and may not apply to other areas where large statured shrubs are found.

Literature Cited

Cochran, W. G. 1963. Sampling Techniques. John Wiley and Sons, Inc. New York.

Daubenmire, R. 1970, Steppe vegetation of Washington. Wash. Agr. Exp. Sta. Tech. Bull. 62. 131 p.

Kempthorne, D., and R. R. Almoras. 1965. Errors of observation. In: Methods of Soil Analysis, Part 1. (Black, ed.). Amer. Soc. Agr., Inc., Madison, Wisc.

Rickard, W. H., D. W. Uresk, and J. F. Cline. 1975. Impact of cattle grazing on three perennial grasses in south-central Washington. J. Range Manage. 28:108-112.

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	10 - 128	37	71 ± 1	14 - 199	41
Width	35 ± 1	10 - 88	42	48 ± 1	10 - 131	45
Height	36 ± 1	12 - 73	31	49 ± 1	12 - 117	41
Volume[2]	86248 ± 5796	2310 - 739200	111	238848 ± 12817	2880 - 2190384	128

1/ Coefficient of variation

2/ Volume (cm^3) = length x width x 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

[2] Volume (cm^3) = length x width x height

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

Dependent Variable	Equation	R^2
Leaves	$\hat{Y}_{ds}$ = 43.03 + 0.0000907 V	.68**
Live wood	$\hat{Y}_{ds}$ = 128.36 + 0.000603 V	.80**
Leaves + live wood	$\hat{Y}_{ds}$ = 171.39 + 0.0006937 V	.82**
Flowering stalks	$\hat{Y}_{ds}$ = -127.65 + 2.269 L	.52_*
Dead wood	$\hat{Y}_{ds}$ = -25.60 + 0.00197 V	.80**
Live wood + dead wood	$\hat{Y}_{ds}$ = 127.80 + 0.0008108 V	.77**
Flowering stalks + leaves	$\hat{Y}_{ds}$ = 58.58 + 0.0001934 V	.66**
Miscellaneous	$\hat{Y}_{ds}$ = -11.40 + 0.3482 L	.45**
Total phytomass	$\hat{Y}_{ds}$ = 196.24 + 0.001021 V	.86**

**Significant at $\alpha \leq 0.01$

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

Dependent Variable	n[1]	n'	g/shrub ± SE[2]	g/m² ± SE[3]
Leaves	20	568	65 ± 10	10 ± 2.3
Live wood	20	568	272 ± 48	43 ± 10
Leaves and live wood	20	568	337 ± 53	53 ± 12
Flowers and seeds	19	568	33 ± 19	5.3 ± 3.2
Dead wood	19	568	49 ± 40	7.8 ± 6.5
Miscellaneous	20	568	13 ± 3.3	2.1 ± 0.6
Live wood and dead wood	20	568	322 ± 72	51 ± 14
Flowers, seeds, leaves	20	568	105 ± 22	16 ± 4.4
Total phytomass	20	568	440 ± 70	69 ± 16

[1] n = clipped shrubs + dimension measurements; n' = dimension measurements only

[2] obtained using equation (1)

[3] obtained by using equation (3)

Table 5. Estimated optimum ratio n'/n of sample sizes and the estimated reduction in variance obtained using double sampling.

Category	Estimated Optimum Ratio n'/n[1]	Reduction in Variance (%) Under Optimum Allocation[2]
Leaves	16:1	58
Live wood	23:1	73
Leaves and live wood	24:1	75
Flowers and seeds	12:1	42
Dead wood	10:1	33
Miscellaneous	10:1	35
Live wood and dead wood	21:1	69
Flowers, seed, leaves	16:1	56
Total phytomass	28:1	80

[1]/obtained using equation (6)

[2]/obtained using equation (5)