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PACIFIC SOUTHWEST Forest and Range Experiment Station

A technique for SAMPLING LOW SHRUB VEGETATION, BY CROWN VOLUME CLASSES

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ABSTRACT: The effects of herbicides or other cultural treatments of low shrubs can be sampled by a new technique using crown volume as the key variable. Low shrubs were grouped in 12 crown volume classes with index values based on height times surface area of crown. The number of plants, by species, in each class is counted on quadrats. Many quadrats are needed for highly precise measurements. Shrub dry-weight was highly correlated with crown volume for each of the four species studied, but ratios of weight to volume were variable.

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RETRIEVAL TERMS: herbicide effects; sampling techniques; crown volume measurement; shrub cover.

Studies of wildland management often require a technique for measuring the amount of woody vegetation on an area at a given time. Their objective may be to describe the current plant cover in terms of total biomass, potential fuel loading, or other important characteristics. Most commonly they seek to show, through repeated measurements, the changes resulting from natural plant succession or from cultural treatment. We have been particularly concerned with measuring the effects of herbicide treatments on low shrubs that grow after bulldozing or burning of brushfields.

One approach in sampling woody vegetation is to count plants, by classes based on form and size of plants. Shrubs are separated from trees on the basis of form. Shrubs can be subdivided by height: high, intermediate, or low. We have further divided the low shrubs into classes according to volume of crown. Each plant—from the smallest seedling up to a plant 5 feet tall—is placed into 1 of 12 crown-volume classes. Each class is assigned a mid-point crown volume in cubic feet—an index value obtained by multiplying height of crown by area of crown surface.

To sample stands of low shrubs, we count on many quadrats the number of plants in each of the 12 crown volume classes. Number of plants in each class is multiplied by the mid-point value of the class to give total crown volume for that class. The data can be summarized to show—by species, and for all species combined—the total number of plants, the number in each size class, the crown volume index of each size class, and the total crown volume for all plants. Information on stand continuity can be obtained in terms of percent of quadrats stocked with one or more plants. This procedure produces a descriptive picture of the shrub cover as a quantitative expression of plant numbers and sizes.

Total crown volume of all shrubs shows well the amount of woody vegetation remaining after an herbicide treatment. Observers can be trained to evaluate a shrub cover in terms of cubic feet of crown per acre. We have selected total cubic feet per acre as the best single variable for determining adequacy of sampling. It has proved useful for expressing relative competitive effects of shrubs in a young pine plantation.[1] From an adequate sample of total crown volume for each species, we can determine–by subsampling–the weight of woody material that is present as potential fuel for wildfire.

OTHER SAMPLING APPROACHES

We developed the technique of sampling by crown volume classes after trying other commonly used approaches for rating effectiveness of herbicide treatments. These approaches included: (a) simple ocular ratings of damage to the brush cover; and (b) quadrat measurements of percent of plants killed and of numbers of plants surviving.

The qualitative ocular ratings of damage and the quantitative records of percent kill served well in comparing treatments within a study. But they did not give good pictures of the resultant brush stands, except for extreme conditions of "no effect" or "complete kill." The qualitative ratings, usually expressed as a number coded to a descriptive statement, could not be combined to give true mean values for treatments. Percent kill records could give unrealistic ratings of plant control. For example, a high kill of 80 percent could leave a thin stand of 200 plants per acre if the initial stand was 1,000 plants, or a thick stand of 2,000 plants per acre if the initial stand was 10,000 plants.

Number of brush plants per acre surviving after treatment always is a critical measurement. It partially describes the resultant stand, and success of a treatment can be judged solely by whether it reduces the stand to an acceptable low density of plants. However, numbers of surviving plants may not serve well for comparing treatments in a study if initial numbers per plot were highly variable. A combination record of surviving plants and percent kill of the initial stand gives a better picture of treatment effects.

But all records based on counts of "live plants" and "dead plants" do not give the full picture of treatment effect because they do not indicate the vigor and size of the surviving plants. A better picture can be gained by recording live plants, by classes, such as unaffected, partially topkilled, and topkilled and resprouting. But analyses of such data will be complicated because mean values for several variables are involved. We added additional refinement by stratifying the plants according to kind and age, such as first-year seedlings, older seedlings, and sprouts. This stratification added to the variables, and greatly complicated identification of the plant classes during field recording.

We selected total crown volume of brush per acre as the major variable for measurement because it reflects a combination of number of plants and their vigor and size. Mean plant numbers, determined from counts on a large number of sample quadrats, and distribution of each species by crown size classes give a good picture of the current stand and the effects of past herbicide treatment. Potential growth and needs for additional treatment can be judged, and proper follow-up treatments can be determined.

CROWN-VOLUME SIZE CLASSES

We use the term "crown volume" as an index value to express the cubic feet of space within and under the shrub crown. The cubic volume is the space which subtends the crown surface. If the crown is visualized as circular, the cubic volume is cylindrical in shape. The volume index is expressed in cubic feet–the product of crown surface area and average height above ground of the crown surface. This simple expression of shrub crown volume has been used by others.[2,3]

Crown surface area is the area included within the average spread of the branchlets and leaves *(fig. 1)*. The average spread is determined by visually adjusting any irregularities in the crown edges so that the crown forms a circle for which the diameter can be readily measured. For highly irregular crowns of some plants with a few widely spread branches, two or more circles must be visualized, measured, and combined. Any crown area that does not have the amount of living twigs and leaves that is typical of the species is subtracted from the total area within the green crown periphery.

The crown surface area is not necessarily filled with foliage. For plants with relatively sparse foliage, some soil surface may be seen by looking directly down through the crown. Conversely, plants with dense crowns may have several overlapping foliage layers.

For most upright shrub plants the cylinder of space below the crown surface is not entirely filled with branches, but low-growing plants usually fill most of the space *(fig. 1)*. Variations in growth form are caused by inherent differences between species or by different ages of the brush plants. For each species

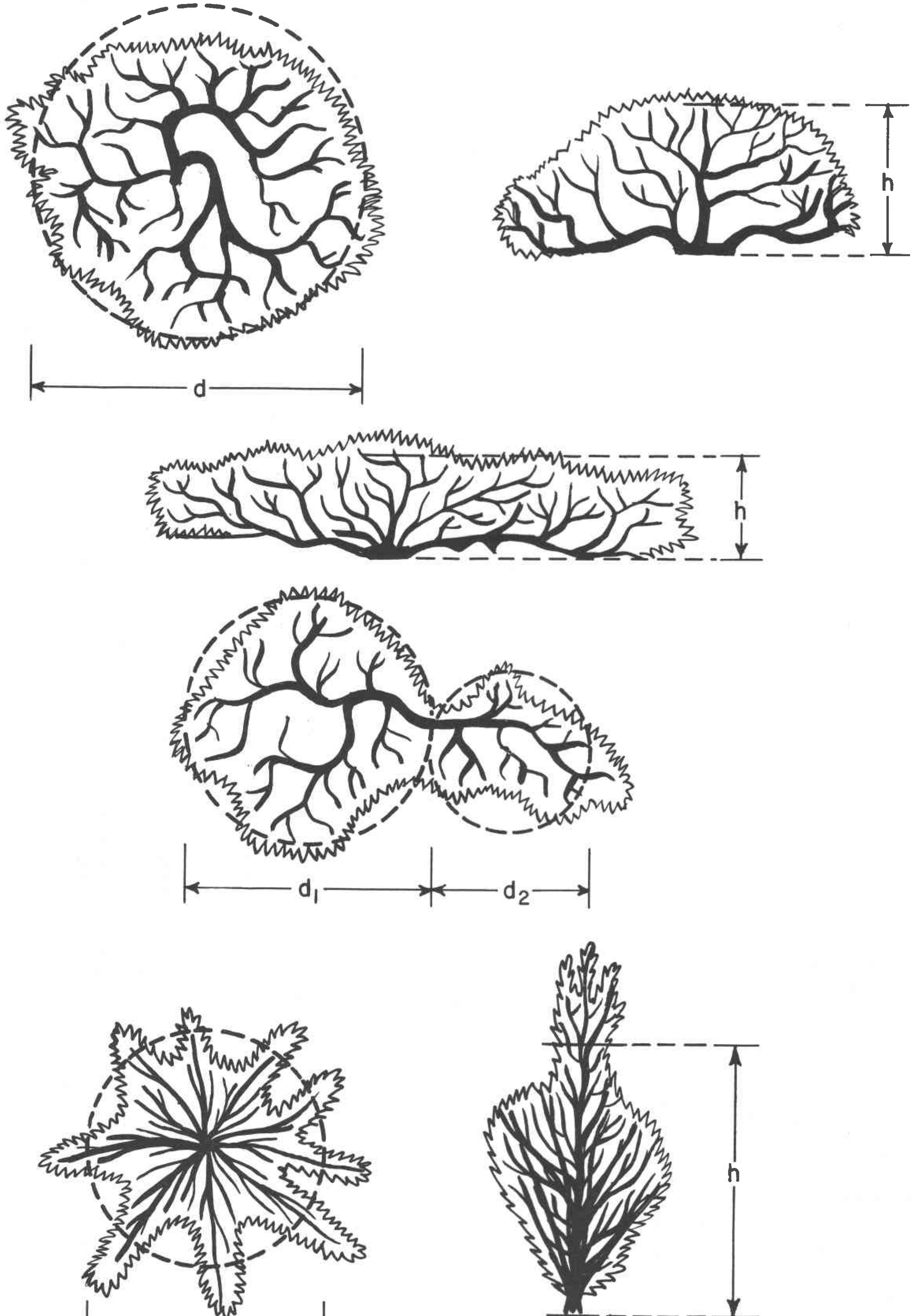

Figure 1–*Crown surface area is determined by measuring the diameter (d) of a circle. Height (h) of upright shrub species varies widely.*

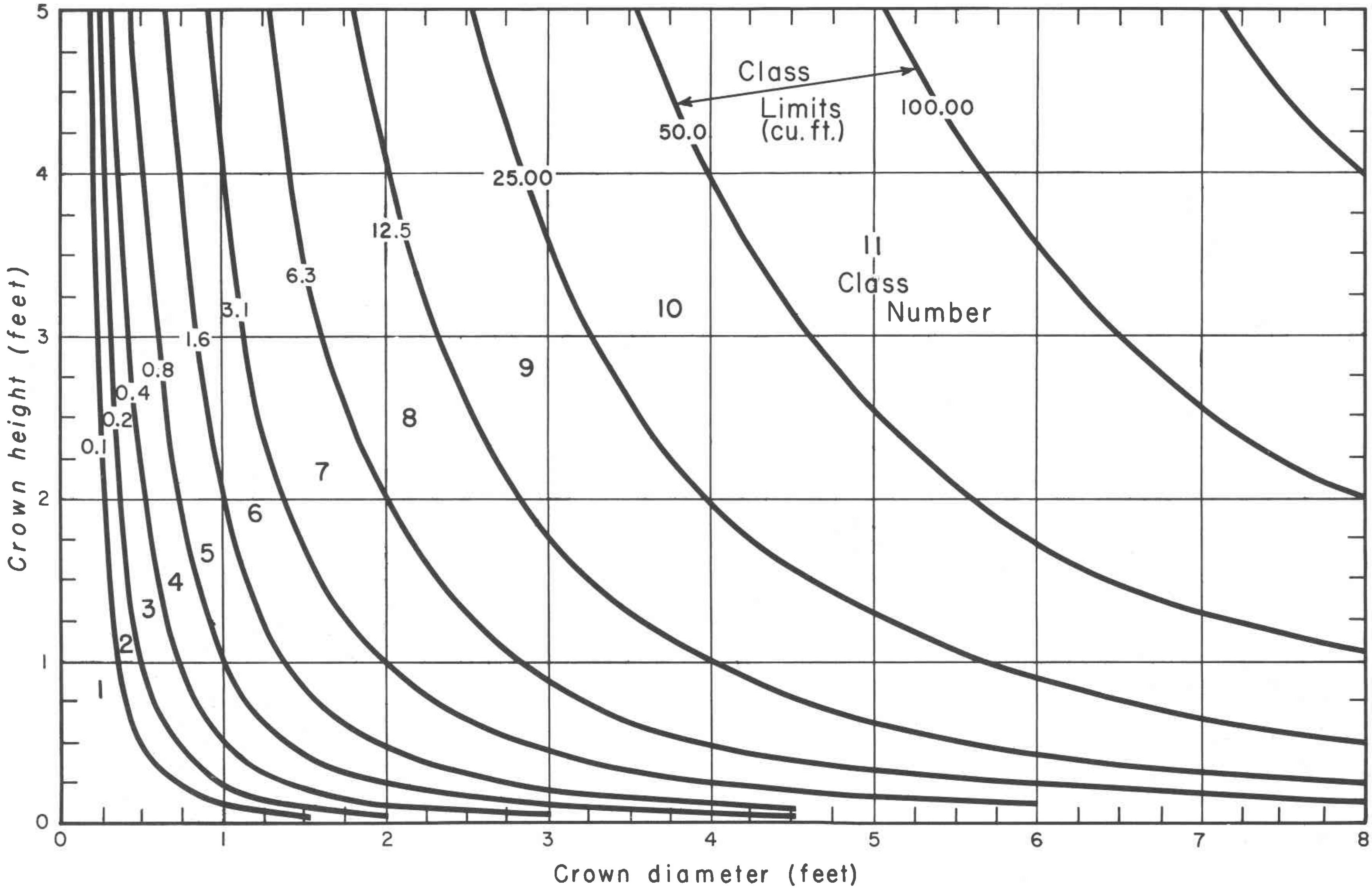

Figure 2–*Limits of crown volume classes related to crown height and diameter.*

Table 1.–*Crown volume limits and midpoint values for each 12 volume classes*

Crown volume class	Upper class limit	Assigned class value
	Cubic feet	
1	0.10	0.02
2	.20	.15
3	.40	.30
4	.80	.60
5	1.56	1.18
6	3.12	2.34
7	6.25	4.68
8	12.50	9.37
9	25.00	18.75
10	50.00	37.50
11	100.00	75.00
12	200.00	150.00

most plants in a size class appear to have a similar growth form with a close relationship between crown volume and total dry weight of the crown.

Crown volume classes have been selected as those suitable for measuring young brush regrowth where individual brush plants are less than 5 feet tall. On recently cleared areas and on areas effectively treated by herbicides, most plants have less than 1 cubic foot of crown volume. These small plants have been placed into classes having narrow ranges in crown volume–0.1, 0.2, 0.4, 0.8 cubic foot within a class–for more precise measurement of the many plants *(table 1)*. The ranges are greater for the classes of larger plants that are less numerous. For the largest plants the classes are quite broad with ranges of 25, 50, and 100 cubic feet. For the smallest size class the assigned value is less than the midpoint because most plants in the class are tiny seedlings under 0.01 cubic foot in volume. This class could be subdivided to show numbers of plants under 0.01 cubic foot volume if needed in a specific study. However, such small plants add little to volume, and all can be readily killed by broadcast herbicide treatments.

The curves used in the field for classifying plants by crown volume are shown in Figure 2. Class limits, as indicated by the curves, are determined by multiplying mean crown height in feet by crown surface area in square feet. But the horizontal scale is calibrated as mean crown diameter in feet to simplify field measurements. After a few hours of training an observer assigns most plants to the proper class without actually measuring height and diameter, except for a few plants that fall near a class limit. Occasional measurements are made, however, to check the estimates. If two or more observers are sampling plots, they should check their estimates together at least once each day. Obtaining consistency between observers has presented no problems.

Calculating crown volume from class midpoint values is less precise than measuring the heights and diameters of all plants and calculating the actual volumes for each plant. However, for a large sample the error due to grouping the data should be negligible. This was checked by an office analysis of data collected in 1964 on 122 plots that had been cleared in 1961 and treated by herbicides in 1962 and 1963. Mean crown volume for each plot was determined from field measurements of crown height and area of each plant on 40 quadrats, 2 by 5 feet in size. In the office, the crown volume of each individual plant rooted in the quadrats was estimated as closely as possible from the quadrat data, the plants were grouped by the various crown volume classes, and a computed mean crown volume was determined for each plot. The mean crown volumes estimated from the grouped data were closely related to the volumes measured in the field for 40-quadrat samples. Considerable discrepancy occurred in comparing the two crown volume figures for an individual quadrat.

On log-log scale the plot means fall close to the line *(fig. 3)*. Correlation coefficient was 0.999 for mean plot volumes ranging from 100 up to 130,000 cubic feet per acre. For mean volumes less than 100 cubic feet per acre, almost all of the computed means are above the actual means because the brush stands were predominantely tiny seedlings much smaller than the midpoint value of the class. This source of error, which was recognized in setting up the volume classes, is of no practical significance because such low mean values are involved.

The relationship held for the brushfield plots at Mount Shasta, California with low growing species and for the plots in a timber burn at Foresthill dominated by tall plants of deerbrush *(Ceanothus integerrimus* H. & A.*)*. The plotted data illustrate how mean crown volume can be used to illustrate the levels of current brush control obtained from different herbicide treatments. Recording of plants by crown volume classes on many plots at Mount Shasta in 1966 and 1967 showed that this sampling technique yielded the kind of data from which the effects of herbicide treatments could be soundly evaluated.

SAMPLING TOTAL CROWN VOLUME

Shrub samples were taken during studies of brush control in brushfields that had been cleared for planting of pines. The study areas are on the lower, gentle slope of Mount Shasta at elevations from 4,000

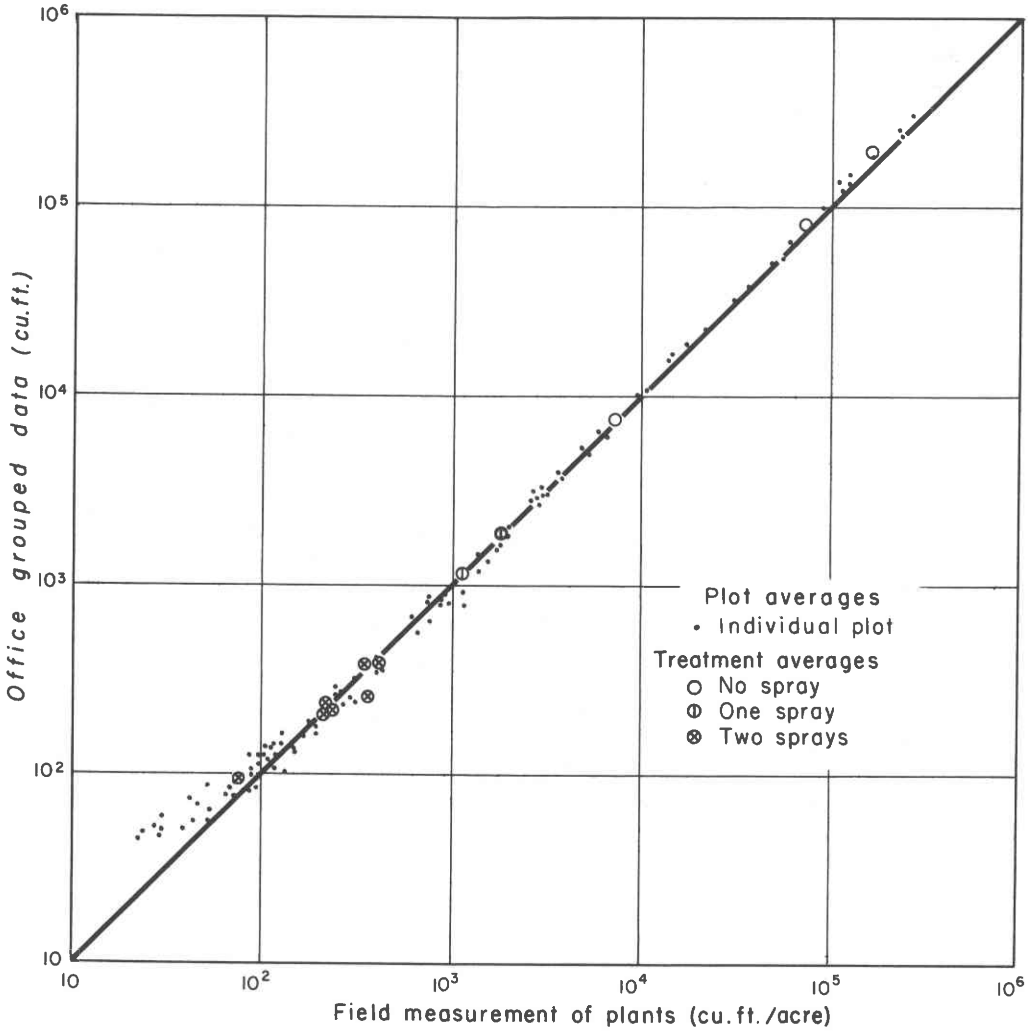

Figure 3–*Crown volumes computed from grouped data related to volumes measured by individual plants.*

to 6,000 feet in the Shasta-Trinity National Forests in northern California. The brushfields are dominated by greenleaf manzanita *(Arctostaphylos patula* Greene*)*. Major associated species include snowbrush *(Ceanothus velutinus* Doug. ex. Hook*)*, chinkapin *(Castanopsis sempervirens* Kell. Dudl.*)*, and bitter-cherry *(Prunus emarginata* Dougl.*)*.

The plots included stands of brush regrowth–both seedlings and sprouting plants–ranging in age from 2 to 7 years. The areas had received a variety of herbicide applications: from no herbicide application to repeated treatments that had killed almost all plants. Stand density ranged from scattered small plants to an almost complete crown cover of plants from 2 to 3 feet tall.

Most of the 166 plots were sampled with 2- by 2-feet square quadrats (0.09 milacre). A few plots were sampled with 0.25 and 1.00 milacre circular quadrats. The number of samples and the number of quadrats per sample for each quadrat size were:

	Quadrats per sample	Size of quadrat
No. of samples:	*(No.)*	*(milacre)*
132	30	0.09
16	100	.09
9	200	.09
5	100	.25
4	100	1.00

Preliminary analysis indicated that the standard deviation was a function of average crown volume. Plotting of standard deviation over the mean for each of the 166 samples *(fig. 4)* suggested that the coefficient of variation (CV) was nearly constant for stands having crown volumes from 100 up to 52,000 cubic feet per acre. We believe that probable values of

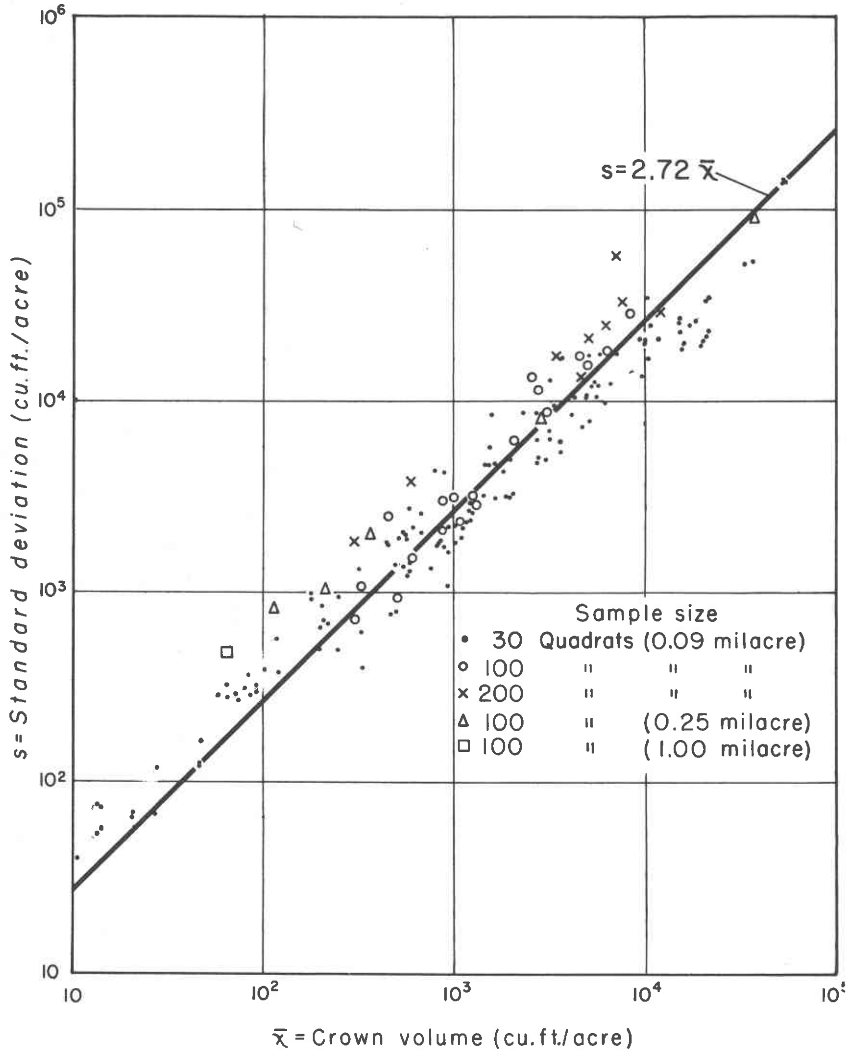

Figure 4—*Relationship between standard deviation and mean crown volume per acre of brush.*

CV for future samples can be obtained from the CV values of these 166 samples.

Plotting standard deviation over mean crown volume showed only slight differences between the 157 samples from 0.09-milacre quadrats and the nine samples from larger quadrats. Thus, we can assume that the standard error of mean crown volume is not greatly influenced by size of quadrat. Consequently, our choice of quadrat can be based on features that affect sampling efficiency other than size.

The 2- by 2-foot quadrat for sampling cleared manzanita brushfields was based on characteristics that affect sampling efficiency: (1) the small quadrat area can be readily scanned from one position, and the plants easily counted; (2) more quadrats can be observed because there are fewer plants per quadrat and a higher proportion of unstocked quadrats; and (3) the frequency of stocked quadrats gives some indication of stand continuity.

Field observations and analysis of the samples at Mount Shasta indicated that the 0.25- and 1-milacre quadrats were too large to measure stand continuity. In quadrats this large most of them will be stocked.

The standard deviation of crown volume is almost proportional to the mean *(fig. 4)*. Therefore, we can assume that the coefficient of variation is a constant, or:

(1) $CV = K$

Taking logarithms on both sides of equation (1) gives:

(2) $\log(CV) = \log(K)$.

Since the values in Figure 4 do not fall exactly on a line, the values of $\log(s/\bar{x})$ vary about some average value. The average of $\log(s/\bar{x})$ for the 166 values in Figure 4 is 0.434. The antilogarithm of 0.434 equals 2.72 which is geometric mean.

For the five groups of samples, the distribution of the coefficients of variation are shown in Table 2: 50 percent of the 166 values are under 2.66, and 92 percent are under 5; 58 percent are less than the arithmetic mean value of 2.98.

Because the standard deviation is proportional to the mean crown volume, the relative error of future samples can be calculated for any anticipated CV and sample size. Or the sample size can be computed for any CV and relative error. The relative error of a sample is the ratio of the standard error over the mean, or:

(3) $r = (s/n^{1/2}) / \bar{x}$

From equation (3), the sample size is:

$n = ((s/\bar{x}) / r)^2$ or

(4) $n = CV^2/r^2$.

The relative errors for selected sample sizes for a CV of 3 and 5 are:

Size of sample (No. of quadrats):	Coefficient of variation 3 (relative error)	5
50	0.42	0.71
100	.30	.50
200	.21	.35
400	.15	.25
800	.11	.18
1,600	.07	.12
3,200	.05	.08

The values 3 and 5 are more conservative values for estimating errors and sample than the arithmetic and geometric means of our sample. With samples of 100 quadrats the relative error is 30 and 50 percent for coefficients of variation of 3 and 5 respectively. Our experience indicates that the CV should be less than 5 in about 90 percent of the samples and less than 3 in about 60 percent.

If total area of the quadrats makes up much of the plot, sampling without replacement should be considered. This means there is a finite number of possible quadrats. Calculate the standard error by:

(5) $s(\bar{x}) = (s/n^{1/2})(1 - n/N)$ in which N is the total possible number of non-overlapping quadrats.

If the sampling ratio (n/N) is 0.10, the standard error is 10 percent smaller than the error obtained by sampling with replacement. Or a sampling ratio of 0.20 means 20 percent fewer quadrats will obtain the desired error.

Our analysis procedure gives a guide for selecting number of quadrats per sample required to fulfill a study objective. For example, if the study is to evaluate three treatments—no spray, one spray, and two sprays—which may give a wide range of mean values, say of 30,000 cu. ft., 10,000 cu. ft., and 2,500 cu. ft. per acre, the differences are statistically significant with standard errors as great as 50 percent of the mean at 90 percent probability (CV = 5). A total of 100 quadrats will be needed to sample each treatment. The treatment could be replicated with 50 quadrats in each of two replicates or 25 quadrats in each of four replicates. A more difficult sampling situation would be a study of four different herbicides which might result in mean crown volumes between 1,500 and 3,500 cu. ft. per acre. Relative standard errors of 10 to 15 percent might be needed to show significant differences, requiring about 1,600 quadrats per herbicide treatment. This amount of sampling may not be justified if each herbicide gives good control.

The number of quadrats per sample is determined largely by the manpower requirements for sampling. For 11 days of sampling at Mount Shasta, 330 to 500 of the 2- by 2-feet quadrats were counted per

Table 2.—*Frequency distribution of coefficients of variation in five groups of plot-samples, by quadrat size and number per sample*

Quadrat size (milacre)	Quadrats per sample	Coefficient of variation 0.9-1.9	2-2.9	3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	8-8.9	Total
	No.	*No. of samples*								
0.09	30	43	40	29	14	6	–	–	–	132
.09	100	2	6	5	1	2	–	–	–	16
.09	100	–	2	–	4	–	2	–	1	9
~~.025~~ .25	100	–	2	–	1	1	–	1	–	5
1.00	100	–	2	1	–	–	–	1	–	4
All samples		45	52	35	20	9	2	2	1	166
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
Percent of total		27.1	31.3	21.1	12.0	5.4	1.2	1.2	0.6	–

man-day. In general, the largest number of quadrats sampled per day was in brush stands with a high proportion of unstocked quadrats. Production per man was about the same for one man working alone as for a 2-man crew. Except in the heavier stands, one man can sample about 200 quadrats per half day. On plots up to 20 acres we have counted 100 quadrats per plot. When the plots were adjacent we averaged two plots per half day.

On large areas, such as a plantation where the brush stand is to be evaluated for administrative purposes, we recommend taking as many quadrats as is possible in one half-day, but at least 100 quadrats. Our analysis of the 166 samples indicates the relative error should be less than 50 percent in about 9 out of 10 samples.

SAMPLING CROWN WEIGHTS

We measured dry weights of the crowns of four species that differed in crown shape and density. For each species, 10 to 20 plants per class were selected from several crown volume classes. In sampling each class, plants were taken in a brush stand that typically included many plants of that crown class. The plants to be measured and weighed were chosen as the nearest plants of that size class to sampling points located at 20-step intervals along a line selected at random. Height and crown diameter were measured and the crown volume calculated for each plant in a sample. The plant was cut, dried to a constant weight in an oven, and weighed.

For each of the four brush species, dry weight was closely correlated with volume of crown. Figure 5 illustrates the relationship in manzanita. The relationship, however, differed markedly between species. The average ratio of dry weight to volume and the correlation coefficient for each of the four species is:

	Plants in sample	Average ratio: dry wt./vol.	Standard error of ratio	Correlation (R)
	(No.)	*(in lbs./ 1,000 cu. ft.)*		
Species:				
Manzanita	160	177.2	7.3	0.96
Chinkapin	90	143.5	9.2	.97
Snowbrush	86	82.1	5.3	.94
Bittercherry	160	37.7	3.6	.93

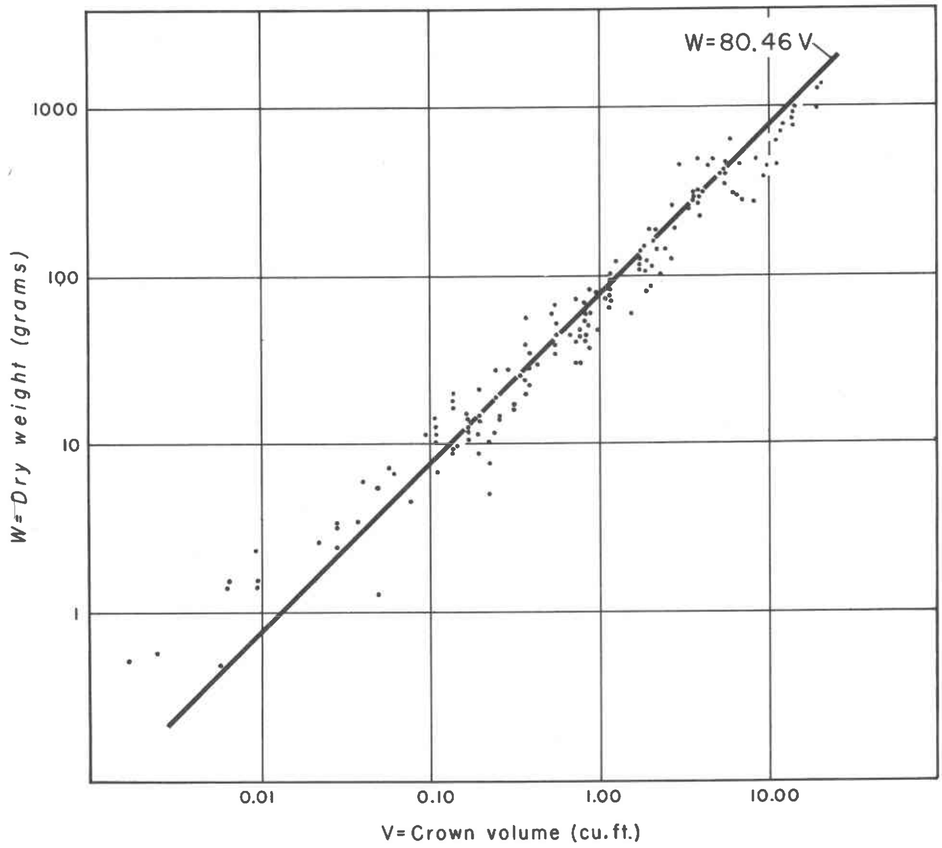

Figure 5–*Relationship between dry weight and crown volume of manzanita plants.*

Table 3.—*Numbers, crown volumes, and dry weight per acre—by crown volume classes—for four shrub species and for the total stand*

Item	Crown volume class No. and midpoint value . . .												Total	Percent
	1 0.02 cu. ft.	2 0.15 cu. ft.	3 0.30 cu. ft.	4 0.60 cu. ft.	5 1.18 cu. ft.	6 2.34 cu. ft.	7 4.68 cu. ft.	8 9.37 cu. ft.	9 18.75 cu. ft.	10 37.50 cu. ft.	11 75.0 cu. ft.	12 150.0 cu. ft.		
Plants per acre:														
Manzanita . . . . . . No.	4,400	250	190	700	220	610	700	1,000	300	80	0	0	8,450	89
Snowbrush . . . . . No.	200	10	90	90	0	20	40	70	30	30	10	10	600	6
Chinkapin . . . . . . No.	0	0	0	0	0	50	100	80	50	5	5	4	294	3
Bittercherry . . . . . No.	0	0	0	0	0	0	20	70	60	5	5	0	160	2
Total . . . . No.	4,600	260	280	790	220	680	860	1,220	440	120	20	14	9,504	100
Volumes per acre:														
Manzanita . . . . cu. ft.	88	38	57	420	260	1,427	3,276	9,370	5,625	3,000	–	–	23,561	69
Snowbrush . . . cu. ft.	4	2	27	54	–	47	187	656	562	1,125	750	1,500	4,914	14
Chinkapin . . . . cu. ft.	–	–	–	–	–	117	468	750	938	187	375	600	3,435	10
Bittercherry . . . cu. ft.	–	–	–	–	–	–	94	656	1,125	187	375	–	2,437	7
Total . . . . . . cu. ft.	92	40	84	474	260	1,591	4,025	11,432	8,250	4,499	1,500	2,100	34,347	100
Dry Weight per acre:														
Manzanita . . . . . . lbs.	16	7	10	74	46	253	581	1,660	997	532	–	–	4,176	80
Snowbrush . . . . . lbs.	1	(1)	4	8	–	7	27	94	81	161	108	215	706	13
Chinkapin . . . . . . lbs.	–	–	–	–	–	10	38	62	77	15	31	49	282	5
Bittercherry . . . . . lbs.	–	–	–	–	–	–	4	25	42	7	14	–	92	2
Total . . . . lbs.	17	7	14	82	46	270	650	1,841	1,197	715	153	264	5,256	100

[1] Trace

The differences in the ratios between species can be attributed to differences in the arrangement and weight of branches and foliage within the crowns.

The ratios reported here can be used for the four species on sites similar to those at Mount Shasta. But they should be checked before being used to estimate crown weights of these species on widely different sites.

The ratios can be used to estimate the dry weight per acre from crown volume samples of each species. Because of the high correlation between the dry weight and volume, estimates of weight would have only slightly greater errors than estimates of total crown volume per acre.

The results from sampling a hypothetical stand of four brush species are shown in table 3. Numbers of plants per acre, by species, are not directly related to crown volumes, by species, because of the many small plants of manzanita. The percentages of total dry weight of bittercherry and snowbrush are smaller than the percentages of total crown volume in these two species.

NOTES

[1]Bentley, Jay R.; Carpenter, Stanley B.; and Blakeman, David A. *Effect of early brush control on growth of young ponderosa pine in plantations.* 1969. (Unpublished rep. on file at Pacific Southwest Forest and Range Experiment Station, U.S. Forest Serv., Berkeley, Calif.)

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