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FREQUENCY SAMPLING IN SAGEBRUSH-BUNCHGRASS VEGETATION[1]

D. N. HYDER,[2] C. E. CONRAD, PAUL T. TUELLER, LYLE D. CALVIN, C. E. POULTON, AND FORREST A. SNEVA

Agricultural Research Service, U. S. Dept. of Agriculture, Burns, Oregon
and
Oregon Agricultural Experiment Station, Corvallis, Oregon

Density and dispersion characteristics of species are important for the classification of range sites and conditions. Cover characteristics are commonly sampled for this classification, but a method using quadrat frequency to indicate density and dispersion offers advantages in speed and objectivity if appropriate and efficient techniques are developed.

Recent literature documents a method to achieve the speed and objectivity of frequency sampling while retaining the concept of plant cover for evaluating range conditions (Parker and Harris 1958). This approach has resulted in extensive use of a ¾-inch-diameter loop for frequency sam-

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[2] Present address: Agricultural Research Service, U. S. Dept. of Agriculture, Colorado State University, Fort Collins, Colorado.

pling. These frequency data have been called "cover indexes," but cover bias among species has detracted from the technique. The point method (Levy and Madden 1933) is a frequency technique used widely. Point data generally are interpreted quantitatively as plant cover even though the pins have cross-sectional areas that introduce a little bias. Increasing the sample-unit size to a ¾-inch loop or larger increases cover bias. Whereas point data can be described as either frequency or cover, present or absent data using loops or quadrats should be described only as frequency. Quadrat-frequency data are difficult to interpret as plant cover because they represent most directly an abstraction or blend of density and dispersion characteristics (Curtis and McIntosh 1950, Aberdeen 1958).

Range sites and conditions are sampled to provide numerical evaluations that classify the associations for subsequent contrasts in space or time. This classification depends on selecting and sampling vegetation characteristics that remain relatively stable from season to season. Consequently, plant cover and density characteristics have received most attention. The characteristics of plant density and dispersion, as blended in frequency data, might be more appropriate for range-site-and-condition classification than plant cover. This possibility justifies objective development of frequency-sampling techniques.

This paper reviews theoretical considerations important to frequency sampling, and reports the results of a study designed to determine appropriate quadrat sizes and efficient allocations of sampling units for frequency sampling of the *Artemisia arbuscula/Festuca idahoensis* association in southeastern Oregon (Fig. 1).

Theoretical Considerations

Appropriate quadrat sizes

Techniques for determining appropriate quadrat sizes for frequency sampling are less objective than one might desire because ecological interests about a community generally include all the species. Sampling-efficiency evaluations can determine the most appropriate quadrat size needed to sample a single species in various stands. But the problem is more complicated both statistically and ecologically when all species in a community or a layer thereof are to be sampled with a single quadrat size. Some concessions then must be made because any quadrat size will sample some species more adequately than others. One desires satisfactory sample precision for a maximum number of species while retaining precision and normality in the frequency data for the most common species.

FIG. 1. The *Artemisia arbuscula/Festuca idahoensis* association in southeastern Oregon.

The number of species encountered in a sample has been found to increase as the log of the sample area increases (Cain and Castro 1959, p. 175). Assuming that an area has been sampled with several quadrat sizes and an equal number of quadrats per transect, the relation between mean number of species encountered per transect (Y) and quadrat area (S) approximates the form

$$\hat{Y} = a + b \log X \quad (1)$$

When the values are plotted on linear grid, the relation is described as a species-area curve. A tangent drawn to the curve at a point representing a 1:1 ratio between the rates of percentage increase in number of species and quadrat area can be used to designate a minimal quadrat area (Cain and Castro 1959, p. 172).

Considering the problem of appropriate quadrat sizes, Curtis and McIntosh (1950) concluded that a quadrat should be one to two times as large as the mean area per individual of the most common species. All randomly distributed species would have quadrat frequencies of 63 and 86% for quadrat sizes one and two times the mean area per individual, respectively.

These guides will be used to estimate appropriate quadrat sizes from quadrat-frequency data obtained on an *Artemisia arbuscula/Festuca idahoensis* association. The calculations needed involve density-frequency relations.

If the individuals are distributed randomly, a species density per quadrat (d) is given by

$$d = -\log_e (1 - p/100). \quad (2)$$

Also, where p_1 is the frequency percentage using quadrat size a_1, and p_2 the frequency using quadrat size a_2, the relation between two quadrat areas and species frequencies is given by

$$\log_{10}(100 - p_1/100 - p_2) = 0.4343\, D\, (a_2 - a_1). \quad (3)$$

D represents species density using a standard unit of measure, as density per square foot, and the constant 0.4343 permits the use of $\log_{10}$ rather than $\log_e$. These relations are given in detail by Greig-Smith (1957, p. 15), but his final equation omitted density D.

The rarity of random distributions of individual plants restricts direct application of equations 2 and 3 for estimating densities. But equation 3 will be used to estimate quadrat sizes giving frequencies of 63 and 86% from data of preliminary frequency samples.

Efficient allocation of sampling units

The first problem to be considered is appropriate quadrat sizes and the second one is efficient allocations of sampling units. Our considerations about unit allocations are drawn from subsampling theory presented by Cochran (1953, Chapter 10).

Sampling efficiency is determined by both cost and variance components. The most effective sampling, considering variance alone, requires random placement of each quadrat. Thus, the variance of the frequency percentage is given by

$$V_p = pq/n - 1, \quad (4)$$

where p is the frequency percentage, q is its complement $(100 - p)$, and n is the total number of quadrats (subplots). When cost is also considered, subsampling theory becomes particularly applicable to frequency sampling because recording the species present in quadrats involves less time than randomizing individual locations. Consequently, quadrats (subplots) are often located within transects (plots).

If transects and quadrats within transects are located randomly, the analysis of variance of frequency data is given by

Sourch of variation	Error mean square
Among transects	$\sigma_s^2 + k\sigma_t^2$
Among quadrats within transects	σ_s^2

where σ_s^2 is the component of variance due to quadrats; σ_t^2 is the component of variance due to transects; and k (the number of quadrats per transect) is assumed to be constant. The mean squares reduce to

Source of variation	Error mean square	
Among n transects	$= \dfrac{k[\Sigma p^2 - (\Sigma p)^2/n]}{n-1}$	(5)
Among k quadrats within n transects	$= k(\Sigma pq)/n(k-1)$	(6)

where p is the percentage of quadrats in any transect containing the species, and q is its complement $(100 - p)$. Equations 5 and 6 are required in the computation of variance components for quadrats (s_s^2) and transects (s_t^2).

If n transects are a small fraction (less than 5%) of all possible transects, the variance of the sample-mean-frequency percentage is given by

$$V_p = (\sigma_s^2/kn) + (\sigma_t^2/n),$$

and its computation is abbreviated to

$$V_p = [\Sigma p^2 - (\Sigma p)^2/n]/n(n-1). \quad (7)$$

Equations 5, 6, and 7 can be modified to handle samples that cover more than 5% of the total sample area.

A given variance can result from different allocations of k and n, but the optimum allocation gives a specified variance for the lowest cost or the lowest variance for a specified cost. The cost per quadrat (c_s) and the cost per transect independent of the number of quadrats (c_t) are needed with variance components to calculate the optimum number of quadrats per transect (k_{opt}), as follows:

$$k_{opt} = \sqrt{\sigma_s^2\, c_t/\sigma_t^2\, c_s}\,. \quad (8)$$

This equation shows that more quadrats should be taken on each transect when the variability among quadrats is high relative to that among transects or when the cost per quadrat is low relative to that among transects.

Variance and cost components from a preliminary frequency sample will provide a substantial guide for an efficient quadrat-transect allocation of sampling units. But this review of subsampling theory implies the application of normal-theory statistics to populations that are often assembled non-randomly, and requires some restrictions.

Normality of frequency data

Non-random dispersion of individuals does not preclude the application of normal-theory statistics to frequency data accumulated by random sampling. According to the central limit theorem, "As the size of the sample increases, the distribution of the means of all possible samples of the same size drawn from the same population becomes more and more like a normal distribution provided that the population has a finite variance." (See Li 1957, p. 33.) Frequency data generally appear normal about intermediate mean percentages and skewed about low and high means. The sample size must be extra large for only the species with high or low frequencies, for example, below 5% or above 95%. This requirement directs attention to quadrat size because we want one that will give intermediate mean frequencies for a maximum number of species. The outcome can be the determination of two or more quadrat sizes for sampling all species of interest at intermediate frequencies. Otherwise, the requirement for extra large samples can apply to some species of interest.

Ground rules for frequency sampling

Quadrat-frequency techniques are considered to be objective because they involve only a recording of the species present in quadrats. Species must be promptly and accurately identified and the individuals of each species recognized.

To be present in a given quadrat, the center of an individual plant or half of its area must be within the quadrat. This ground rule is the same as would apply for counting densities. The presence of single-stemmed plants taken at ground level is relatively easy to observe, but the occurrence of multiple-stemmed plants requires uniform ground rules regarding the recognition of individuals. Distinct units or clumps of multiple-stemmed plants, such as bunchgrasses, can be recognized as individuals, but indistinct clumps resulting from vegetative reproduction can require that each stem taken at ground level be recognized as an individual. Uniform rules have not been established and each sampling situation requires attention to this problem.

Procedure

A macroplot 100 by 50 feet, representing the *Artemisia arbuscula/Festuca idahoensis* association classified by Eckert (1957, p. 37), was selected on the Squaw Butte Experimental Range in southeastern Oregon. Frequency sampling was undertaken in July 1961, to determine (a) appropriate quadrat sizes and (b) cost and variance components needed for estimating optimum allocations of sampling units. At least half of the areas of individuals (clumps of bunchgrasses and individual stems of all other species) viewed at ground level were required to be inside a quadrat to indicate presence.

Systematic sampling with 50 quadrats per transect and 10 transects per macroplot was completed using quadrat sizes of 3 by 3, 6 by 6, 9 by 9, 12 by 12, 18 by 18, and 24 by 24 inches. The macroplot base line was extended to 200 feet and individual transects to 100 feet to permit sampling with the two largest quadrat sizes. Quadrat-frequency percentages by transects and number of species encountered were analyzed to determine an appropriate quadrat size.

To estimate the cost per quadrat, the time required to record species presences for 500 12-inch quadrats placed systematically was measured. An observer named the species present and a recorder tabulated the occurrences.

To estimate the cost per transect, the time required to establish twenty 50-foot transects was measured. The macroplot was located permanently by iron stakes at the corners and 100-foot tapes were stretched along the sides to facilitate transect location across the macroplot. Relative costs (time requirements) for quadrats and transects were computed.

Variance components were computed from the frequency data obtained with quadrats of an appropriate size, and optimum numbers of quadrats per transect (k_{opt}) were calculated. The calculation of variance components was based on the assumption of randomness in the selection of sampling units, whereas systematic sampling was conducted. The authors assume that the variance components under systematic sampling are the same for the purposes of this study as would have resulted from random sampling because variance within a sample, rather than among samples, is under consideration.

To estimate the total sample size needed at an assumed level of precision two restricted-random samples (preferred to systematic ones for comparative work) were obtained with 9-inch quadrats. Each sample included 20 transects placed by restricted randomization—one in each 5-foot section of the 100-foot base line. In the first sample, each transect included 20 quadrats placed 2.5 feet apart along the 50-foot transect after the first quadrat had been placed randomly at ½, 1, 1½, 2, or 2½ feet from the base line. In the second sample, each transect included 10 quadrats placed 5 feet apart after the first quadrat had been placed randomly at 1, 2, 3, 4, or 5 feet from the base line. Appropriate numbers of transects were computed for several species to estimate the total sample size required.

Results and Discussion

Appropriate quadrat size

Thirty-one species were found on the 100- by 50-foot macroplot. Only 14 of them were encountered with 500 3-inch quadrats and 29 were encountered with 500 24-inch quadrats. The numbers of species encountered per transect of 50 quadrats of different sizes are plotted in Fig. 2 and fitted by least squares analysis according to the semi-log relation of equation 1. A tangent with a 1 : 1 slope between the percentage rate of increase in number of species and percentage increase in quadrat area was drawn to the species-

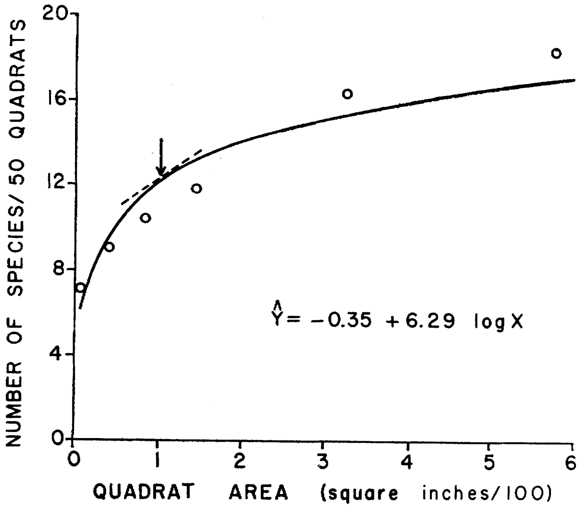

FIG. 2. A species-area curve with tangent and arrow indicating a minimal quadrat size.

area curve. The tangent point on the curve indicates an appropriate quadrat area of about 100 square inches, a 10-inch quadrat size.

Poa secunda was the most common species and is considered in further evaluations of appropriate quadrat sizes (Table I). The initial calculation

TABLE I. Frequency percentages of species encountered on 500 quadrats[a] of various sizes

Species	Quardat size (inches) 3 x 3	6 x 6	9 x 9	12 x 12	18 x 18	24 x 24
Poa secunda Presl.	41	73	84	92	97	98
Festuca idahoensis Elmer	21	39	56	68	86	95
Tortula muralis (L.) Hedw.	7	28	43	58	89	95
Artemisia arbuscula Nutt.	3	11	23	32	38	61
Phlox diffusa Benth.	6	11	17	18	32	43
Agropyron spicatum (Pursh) Scribn & Smith	2	3	5	9	17	25
Astragalus miser Dougl.	0.2	1	1	0.4	10	14
Stipa thurberiana Piper	1	1	2	2	7	12
Astragalus stenophyllus T. & G.	1	1	3	5	7	10
Phlox longifolia Nutt.	2	4	7	14	7	9
Sitanion hystrix (Nutt.) J. G. Smith	1	3	7	7	5	7
Chrysothamnus viscidiflorus (Hook.). Nutt.	—	1	1	3	6	7
Agoseris glauca (Pursh) D. Dietr.	0.2	0.4	1	2	2	5
Erigeron linearis (Hook.) Piper	—	0.2	0.2	0.5	2	4
Erigeron filifolius Nutt.	1	0.4	1	0.3	2	3
Antennaria dimorpha (Nutt.) T. & G.	—	0.4	0.2	1	1	2
Arenaria franklinii Dougl.	—	—	—	1	1	2
Allium acuminatum Hook.	—	—	—	—	1	2
Astragalus purshii Dougl.	—	—	—	—	1	2

[a]The species with frequencies less than 2% in 24 x 24-inch quadrats are omitted.

for estimating *Poa secunda* density (number per square foot) involves equation 3

$$D = (\log q_1 - \log q_2)/0.4343\ (a_2 - a_1)$$

where q_1 is the frequency-percentage complement using 3-inch quadrats (59%), q_2 is the frequency-percentage complement using 6-inch quadrats (37%), a_1 is the area of a 3-inch quadrat (0.062 square feet), and a_2 is the area of a 6-inch quadrat (0.250 square feet).

This calculated density D can be called "effective" density because it is determined by an observed difference in frequency percentage with a given change in quadrat area. If plant dispersion is non-random, the "effective" density (D) can be different from the expected density (d) calculated from a single frequency percentage by equation 2 but expressed in number per square foot.

Poa secunda "effective" density (D), estimated at 2.48 per square foot, enters equation 3 for the calculation of appropriate quadrat areas, as follows:

$$a_2 = [(\log q_1 - \log q_2) + 0.4343\ D\ a_1]/0.4343\ D$$

where q_1 is the frequency-percentage complement using 6-inch quadrats (37%), q_2 is the complement of the frequency 63% or 86%, a_1 is the area of a 6-inch quadrat (0.250 square feet), and a_2 is the quadrat area estimated to give a *Poa secunda* frequency of 63% or 86%, respectively. This calculation estimates appropriate quadrat sizes of 6.0 and 9.6 inches square, respectively, for *Poa secunda* frequencies of 63% and 86%. Thus, a quadrat size of 6 to 10 inches square would be appropriate for frequency sampling of the *Artemisia arbuscula/Festuca idahoensis* association in southeastern Oregon.

Relative costs (time requirements) for quadrats and transects

The reading and recording of species frequencies on 500 12-inch quadrats required 122 man-minutes, an average of 0.24 man-minute per quadrat.

The establishment of twenty 50-foot transects required 14 man-minutes, an average of 0.7 man-minute per transect. Relative costs (time requirements) were 1 to 3, respectively, for quadrats (c_s) and transects (c_t). This ratio indicates a slight cost advantage when the number of quadrats (k) is increased relative to the number of transects (n).

Variance components for quadrats and transects and the estimation of k_{opt}

Variance components and estimations of k_{opt} were calculated from frequency percentages of six most frequent species found in 9-inch quadrats (Table II). The time requirement per 9-inch quadrat was not determined but is assumed to be the same as determined for 12-inch quadrats.

Variance components for quadrats (s_s^2) were always larger than those for quadrats (s_t^2). This variance comparison indicates advantage when k

TABLE II. Frequency percentages, variance components, and estimations of k_{opt} for six species as sampled with 500 9-inch quadrats allocated 50 per transect

Species	Frequency percent (p)	Variance components: for quadrats (s_s^2)	Variance components: for transects (s_t^2)	Optimum number of quadrats per transect (k_{opt})
Poa secunda...........	83.6	1,147	37	10
Festuca idahoensis......	55.8	2,395	85	9
Tortula muralis........	42.6	2,311	174	6
Artemisia arbuscula.....	22.8	1,786	−26	infinite
Phlox diffusa..........	17.4	1,408	35	11
Sitanion hystrix........	7.2	645	27	8

is increased relative to n. Considering both costs and variances, k_{opt} ranged from six per transect for *Tortula muralis* to an infinite number for *Artemisia arbuscula.* Among herbaceous species, approximately 10 quadrats per transect can provide optimum sampling efficiency. Similar calculations of data from 12-inch quadrats estimated a k_{opt} of 18, 10, and 22, and with data of 6-inch quadrats of 8, 12, and 13, for sampling *Poa secunda, Festuca idahoensis,* and *Phlox diffusa,* respectively. Apparently, 10 to 20 quadrats per transect would be appropriate and efficient for sampling this vegetation.

Total sample size

An appropriate quadrat size of 9 by 9 inches was employed in restricted-random sampling with allocations of 10 and 20 per transect. Twenty transects were sampled with each allocation. Table III includes mean frequencies, confidence intervals, and estimations of the numbers of transects ($N = 4V_p/(\text{e.c.i.})^2$) needed at desired levels of precision. These desired levels of precision were taken from a table of expected-confidence-half intervals (e.c.i.) computed from variance functions given in equation 4, as follows:

$$\text{e.c.i.} = \pm\, 2\sqrt{pq/n - 1}.$$

TABLE III. Statistics of restricted-random frequency samples using a 9-inch quadrat placed to obtain 10 or 20 quadrats in each of 20 transects

Number of quadrats per transect and species	Frequency percent (p)	5% Confidence interval (±)	e.c.i. from Table IV (±)	Number of transects needed (N)
20 quadrats/transect				
Poa secunda.........	81.2	5.7	7.8	10
Festuca idahoensis....	48.5	5.0	10.0	5
Phlox diffusa........	11.2	3.1	6.3	4
Artemisia arbuscula..	8.8	3.7	5.7	8
Agropyron spicatum..	4.8	2.3	4.4	5
10 quadrats/transect				
Poa secunda.........	81.5	5.7	7.7	10
Festuca idahoensis....	49.0	7.9	10.0	11
Phlox diffusa........	9.0	4.8	5.7	13
Artemisia arbuscula..	7.5	3.4	5.4	7
Agropyron spicatum..	3.5	2.3	3.9	6

Since variances are correlated with frequency percentages, a complete set of e.c.i. values (Table IV) is needed to evaluate the precision of frequency data.

TABLE IV. Expected-confidence-half intervals (e.c.i.), as derived from $\text{e.c.i.} = \pm\, 2\sqrt{pq/n - 1}$ where $n - 1 = 100$[a], for judging the precision of frequency data (expressed as percentage)

Frequency percentage (p)	Added increment of p: 0	1	2	3	4	5	6	7	8	9
0...........	0.0	2.0	2.8	3.4	3.9	4.4	4.7	5.1	5.4	5.7
10...........	6.0	6.3	6.5	6.7	6.9	7.1	7.3	7.5	7.7	7.8
20...........	8.0	8.1	8.3	8.4	8.5	8.7	8.8	8.9	9.0	9.1
30...........	9.2	9.2	9.3	9.4	9.5	9.5	9.6	9.7	9.7	9.8
40...........	9.8	9.8	9.9	9.9	9.9	9.9	10.0	10.0	10.0	10.0
50...........	10.0	10.0	10.0	10.0	10.0	9.9	9.9	9.9	9.9	9.8
60...........	9.8	9.8	9.7	9.7	9.6	9.5	9.5	9.4	9.3	9.2
70...........	9.2	9.1	9.0	8.9	8.8	8.7	8.5	8.4	8.3	8.1
80...........	8.0	7.8	7.7	7.5	7.3	7.1	6.9	6.7	6.5	6.3
90...........	6.0	5.7	5.4	5.1	5.7	4.4	3.9	3.4	2.8	2.0
100...........	0.0									

[a]The value n-1 = 100 was selected to give expected-confidence-half intervals of 10% at a frequency of 50%. Higher or lower half-intervals can be computed with lower or higher values for n.

For the five species included in Table III, N is 1½ times as much with 10 as with 20 quadrats per transect. Thus, 10 transects of 20 quadrats or 15 transects of 10 quadrats are appropriate and efficient. Of these two allocations of sampling units, that of 15 transects with 10 quadrats each cost a little less time and is recommended for further frequency sampling of the *Artemisia arbuscula/Festuca idahoensis* association.

SUMMARY AND CONCLUSIONS

Appropriate quadrat sizes and efficient allocations of sampling units were determined for frequency sampling of the *Artemisia arbuscula/Festuca idahoensis* association in southeastern Oregon. The theoretical considerations pertinent to these determinations were reviewed.

A quadrat 6 to 10 inches square is appropriate for frequency sampling of the common species, and an allocation of 10 to 20 quadrats per transect attained optimum efficiency.

A sample of 15 transects, each including ten 9-inch quadrats, was convenient, appropriate, and efficient. This allocation of sampling units is recommended for subsequent frequency sampling of this association.

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INFLUENCE OF SMALL PLOT SIZE AND SHAPE ON RANGE HERBAGE PRODUCTION ESTIMATES[1]

GEORGE M. VAN DYNE,[2] W. G. VOGEL, AND H. G. FISSER

Animal Science and Range Management Department
Montana State College, Bozeman, Montana

INTRODUCTION

Small plot clipping is a sampling procedure often employed in grassland-production measurements. Many factors limit the accuracy of this field technique. Time requirements often restrict the number of plots clipped and, consequently, the precision of estimate. For a given number of sample units, accuracy can be increased by enlarging plot size. Since it is usually necessary to exclude grazing, at least seasonally, plots often must be small enough to be located within temporary exclosures. By changing their size and shape a varying number of plots can be included within the exclosure. This paper evaluates the influence of small plot size and shape upon herbage-production estimates on Montana foothill bunchgrass ranges.

Relatively few published investigations have dealt directly with plot effects on weight measurement of range vegetation, but the problem of plot size and shape has been investigated by numerous workers studying non-range herbage production, frequency, counts, and pattern. Several reviews of the subject are available (Schumacher and Chapman 1948, Brown 1954, Greig-Smith 1957, Ursic and McClurkin 1959, Grassland Research Institute Staff 1961, National Academy of Science 1962, Joint Committee 1962). Only work concerning western range vegetation is discussed here; references to other herbage production studies are included in the discussion.

Hanson and Love (1930), in an early study on a Colorado *Bouteloua gracilis-Agropyron smithii* grassland, determined frequency and abundance for individual species in quadrats ranging from 0.25 to 4.0 m^2 in area. Weight data were not reported. They considered a 1- by 2-m quadrat most suitable for frequency determination. Later, working in North Dakota, Hanson (1934) studied plots of 0.1, 0.2, and 0.4 m^2 in a relatively homogeneous *Bouteloua gracilis-Agropyron smithii* grassland. Adjoining plots were combined to evaluate size and shape effects on plant count and area determinations. Greatest efficiency, in terms of minimized variance, was achieved with a 0.1 m^2 plot (2.5 by 4.0 dm). Herbage-yield studies were conducted but were not evaluated to determine the influence of plot size and shape upon variance in weight estimates. Mean yield was approximately 10 to 12 grams per 0.1 m^2. Probable error for total herbage weight varied from 2.2 to 7.7% in various sampling locations. Weight distributions of total herbage were distributed approximately normally, but those of individual species were often skewed.

Pechanec and Stewart (1940) evaluated the influence of plot size and shape upon herbage yield on an *Artemisia tridentata*-mixed grass-forb range of southern Idaho. Their smallest plot measured 5 by 5 ft. Contiguous units were combined to give different sizes and shapes. The 25-ft^2 plot (5 by

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[2] Present addresses: Van Dyne, Animal Husbandry Department, University of California, Davis, Calif.; Vogel, Central States Forest Experiment Station, Columbia, Mo.; Fisser, Range Management Section, University of Wyoming, Laramie, Wyo.