Influence of Number and Spacing of Points on Accuracy and Precision of Basal Cover Estimates[1]

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Highlight

Records from 350 line intercept transects from a foothill bunchgrass range were sampled systematically and at random with 25, 50, and 100 points per line. Statistical analyses were made to compare point densities, point placement, and their interactions for 12 plant categories. Sod-forming species were sampled best by random placement, bunchgrasses by systematic placement, and for plant groups with high basal cover either placement would suffice.

Two common methods of basal area or cover determination are the line intercept technique (Canfield, 1942) and the point-analysis technique (Cockayne, 1926; Levy, 1927). The line intercept technique generally is considered to give accurate results and has been used as the standard for comparison in many methodological studies, but it is a time-consuming procedure. Point analysis technique has frequently been used in range analysis but many factors including number, size, and spacing of points have influenced its success.

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This paper reports a comparison of point procedures for analyzing basal cover of grassland. Records from 350 line intercept transects were obtained from a foothill grassland. This population was sampled both systematically and randomly with 25, 50, and 100 points per 5-ft line.

Theoretical Aspects

Artificial Populations. — The true values of vegetation basal area or cover parameters are seldom known in range investigations. Although precision or repeatability of different procedures is compared in field studies, the validity or accuracy of vegetation sampling techniques usually cannot be established (Schultz et al., 1961). Accuracy and precision of different techniques have been compared by sampling artificial populations for which the values of the parameters were known (Bauer, 1943; DeVries and DeBoer, 1959; Heady, 1961; McIntyre, 1953; and Schultz et al., 1961). It is difficult, however, to construct artificial populations sufficiently complex to simulate real life variation in plant size, shape, and distribution. These characteristics must be considered when investigating the relative efficiency of vegetation estimates (Aberdeen, 1958; Hoell, 1943).

Determination of sampling accuracy and precision of any one method as related to another can be facilitated by comparison of data derived from actual field procedures with measurements taken in close proximity (Heady et al., 1959). The obvious difficulty of determining exact comparisons because of human bias and error inherent with field procedures limits the value of subsequent inferences (Ellison, 1942).

If data derived by a standard field procedure could be sampled as a population by the method under investigation, the determination of relative efficiency of the methods would not be subject to the errors associated with artificial populations, or human bias and error. The field data obtained for this paper consisted of 350 line intercept transects, each 5 ft in length. This sample of an upland range is here considered a population, with known parameters, from which various samples of point data were obtained.

Point Data From Intercepts.— The derivation of point data from intercept readings is dependent upon the basic methodological concepts of the two methods. Both can be considered plot methods, but with certain limitations. A line interception transect is essentially a linear quadrat with no breadth while basal point contact analysis employs units of no area or, in another sense, plotless points (Brown, 1954).

Theoretically a line intercept transect is composed of an infinite number of points. The inference of point data from intercept with this concept is impossible. In practical application, however, the point method, in effect, actually measures small circular plots with finite area. The resulting bias is associated with the variation from true presence or absence data which is theoretically expected from the point method (Hyder et al., 1963; Kershaw, 1964; p. 15; Warren-Wilson, 1959). The amount of area actually measured has been correlated to pin size by

Greig-Smith (1964, p. 43). He indicates that the effective sampled area, recorded by use of a finite diameter pin, has a radius equal to that of the pin.

Goodall (1952) compared pin diameters of 0, 1.84, and 4.75 mm when recording all hits in dense multilayered grassland vegetation. The largest pin generally overestimated cover more than the next smaller size. He expressed concern over the fact that most workers were using pins which usually resulted in cover overestimation. Basal contact hits were analyzed by Ellison (1942) and Whitman and Siggeirsson (1952) on semi-arid shortgrass vegetation. They did not indicate pin diameters, but their results were in general accord with those of Goodall (1952) in that basal cover was overestimated by point analysis.

The 0.01-ft units of the present study, when converted to the metric system, are 3.05 mm in length but have no breadth as associated with pins. Since the length of these units is less than the 4.75 mm diameter of the pins used by Goodall (1952) and since area is not a component as with the usual circular pin, the 0.01-ft units with no breadth should more closely approach estimates of the theoretical point of no dimension. However, since most field work is conducted with pins, analysis of the relationship of intercept data to that derived from points should logically be conducted under conditions of common use. Data derived from a short linear plot closely approaches that of a point. A contiguous series of the linear plots can then be considered a series of points with application to general point analysis procedures. With this conceptual basis the line interception data of the present study can be considered a series of contiguous point plots from which individual units of cover data may be selected for analysis on the basis of generalized point procedures. The closeness to which any point-sampling result compares with the population parameter then will indicate the accuracy of that particular point-sampling procedure.

Population of Intercept Transects

Field Measurements. — Line-intercept data were collected with a mechanical device (Fisser and Van Dyne, 1960) from 350 transects located by a multistage randomization procedure (Van Dyne, 1960) on a foothill grassland in southwestern Montana in 1958. Five transects were located in each of 70 clusters on about 12,000 acres.

Intercepts along transects 5 ft in length were noted at ground level with a pointed needle attached to a sliding mechanism on an immovable horizontal bar in which a steel tape, calibrated in hundredths of feet, had been imbedded. The data from each transect thus consisted of 500 units. Unit distances along the line were noted with the aid of a cross hair device on the slide. Each unit of intercept was identified and recorded at the number of the intercept on a prepared form. Every unit of intercept, from the zero end of the tape to the last unit, number 500, was in a definite known position along the line, and each unit was 0.01 ft in length but had no measurable breadth.

Ground level intercepts of all individual plant species, litter, fecal material, rock, erosion pavement, and bare ground were recorded. These data from the 350 transects, each with 500 units identified by kind of intercept and location on the line were considered the population. More detailed discussion of the experimental procedures is given by Fisser (1961).

Results. — Physical characteristics of the experimental sites are summarized in Table 1. The research unit was in a foothill area of rough terrain with elevations ranging from 5,260 ft to 6,120 ft. Approximately one-half of the area was classified as silty site. The light to rocky textured soils were mildly alkaline with weak structure.

The study area was predominantly a grass range although a variety of important forb and browse species was present. The vegetation was dominated by bluebunch wheatgrass *(Agropyron spicatum)*, prairie junegrass *(Koeleria cristata)*, Idaho fescue *(Festuca idahoensis)*, needleandthread *(Stipa comata)*, and blue grama grass *(Bouteloua gracilis)* and forbs such as silky lupine *(Lupinus sericeus)* and prairie milkvetch *(Astragalus striatus)*. Needleleaf sedge *(Carex eleocharis)* was the most common rhizomatous species. Shrubs were present but dominated only on limited areas. Average ovendry production, as determined by clipping procedures, was almost 1,000 lb/acre (Table 1).

From the population of 350 line intercept transects, i.e., sets of 500 "points", each of infinite thinness and of 0.01-ft length, 12 vegetation categories of important species and groups of plants were selected for analysis (Table 2). Percent frequency, based on presence or absence by transect, ranged from 100% for All Live Vegetation to 17% for Shrubs. Percent basal cover over all transects was 15.9% for All Live Vegetation. Small Clubmoss *(Selaginella densa)* was most abundant with 8.9% basal cover. Basal cover of All Grasses was 4.3%. The most abundant species was Bluebunch Wheatgrass with 0.5% basal cover. All Grasses contributed 27% of All Live Vegetation composition.

Variance, based on numbers of 0.01-ft intercepts per 5-ft transect line, ranged from 3977 for All Live Vegetation to 3 for Needleleaf Sedge. Small Clubmoss exhibited extreme differ-

Table 1. Characteristics of the experimental range[1].

Factor	Units	Mean	Standard deviation	range
Physiographic				
Elevation	feet	5260	350	4780-6120
Slope	percent	17	12	1-71
Edaphic				
Soil depth	inches	7.2	3.5	2-24
Sand	percent	75	9	46-93
Clay	percent	8	4	2-25
Rock	percent	16	16	1-62
Vegetational				
Grasses and sedges	lb/acre	580	350	<10-1740
Forbs	lb/acre	260	300	<10-1350
Shrubs and half-shrubs	lb/acre	100	230	<10-2080

[1]Averages for data from 1958 and 1959 (Van Dyne and Kittams, 1960).

Table 2. Population characteristics for 12 vegetation groupings from 350 transects.

Plant Group	Percent frequency[1]	Percent basal cover[2]	Percent cover composition[3]	Variance[4]
All live vegetation[5]	100	15.9	100	3977
All grasses	98	4.3	27	213
Bunchgrasses	79	2.3	14	151
Sod-formers	73	2.0	12	164
Bluebunch wheatgrass	32	0.5	3	25
Needleandthread	38	0.4	3	18
Needleleaf sedge	32	0.1	1	3
All forbs	58	1.6	10	251
Upright forbs	33	0.4	3	27
Mat forbs	38	1.2	8	288
Small clubmoss	52	8.9	56	3514
Shrubs	17	0.3	2	44

[1]Frequency—based on presence or absence by transect
[2]Cover—based on total intercepts over all transects
[3]Composition—based on percent of total basal cover intercept
[4]Variance—based on number of 0.01-ft intercept units per 5-ft transect
[5]Includes lichens and moss

ences of amounts intercepted per line with a variance of 3514.

Point Sampling from the Population

Procedures. — Point samples from the line intercept transects were taken by different intensities of sampling and by random and systematic selection. From each transect 25, 50, and 100 units were selected. Random number tables were utilized for random selection. Systematic selection was conducted by designating every 20th, 10th, and 5th unit along the transect line for the 25, 50, and 100-point samples, respectively. Distances between these points on the ground were 2.4, 1.2, and 0.6 in, respectively.

The six sets of point data were summarized by percent transect frequency of occurrence, percent basal cover, variance, and coefficient of variation for each of the 12 vegetation groupings selected from the population. These statistics were converted to the 500-unit-intercept basis by multiplying cover values of the 25, 50, and 100-point samples by 20, 10, and 5, respectively. Cover variance and coefficient of variation values of the 25, 50, and 100-point samples were multiplied by 400, 100, and 25, respectively.

Methods of Analysis.—Analysis of variance and appropriate F tests, following procedures outlined by Snedecor (1956), were used to compare different intensities of point sampling, systematic vs. random sampling, and point vs. line intercept technique for frequency of occurrence, mean percent basal cover, and coefficients of variation of cover for the 12 important species or groups of plants. Number of point transects required to sample within 10% of the mean with 95% confidence on the basis of 350 individual and randomly located transects, were calculated by the procedure of Stein (1945).

Results of Point Sampling

Percent Frequency of Occurrence by Transect.—As expected, the percent transect frequency of occurrence decreased significantly as the number of points were decreased (Table 3). The degree of change increased markedly for the vegetation variables with lesser amounts of occurrence (Fig. 1), accounting

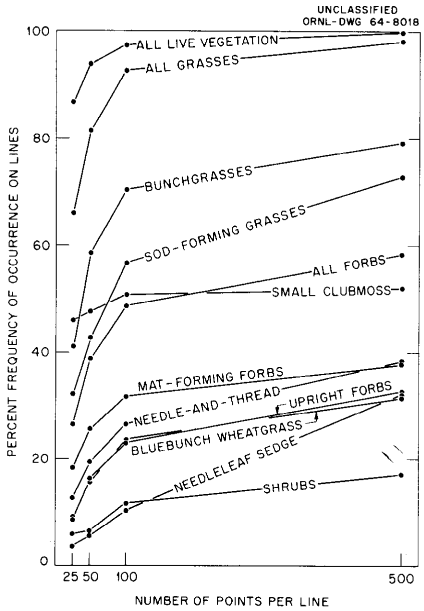

FIG. 1. Percent frequency of transect occurrence of selected vegetation categories, averaged for systematic and random placement, as a function of number of points per line.

Table 3. Mean squares from analysis of variance of percent transect frequency of occurrence, mean percent basal cover, and cover coefficient of variation data for 12 plant groups with (A) random and systematic spacing of points at three densities (25, 50, and 100 points per line) and (B) for systematically spaced points at four densities (25, 50, 100, and 500 points).

		Degrees of freedom	Percent frequency	Percent cover[1]	Coefficient of variation
			A		
Plant(s)	P	11	4643.9**	3229.469**	87237.**
Density	D	2	1457.5**	.022	23820.**
Spacing	S	1	137.0**	.479	5460.**
P x D		22	37.2**	.159	1449.**
P x S		11	9.6**	.190	639.**
D x S		2	0.4	1.116	424.
Error		22	1.2	.191	168.
			B		
Plant(s)		11	3056.**	2177.8**	47584.**
Density		3	1303.**	.4	11010.**
Error		33	26.	.1	1424.

[1] Mean squares for cover should be multiplied by .04 to convert them from a point to a percent basis.
** P < .01

for the significant plant group by point density interaction. Percent frequency of occurrence was slightly but significantly greater when points were taken systematically than when selected randomly except for needleleaf sedge, the only rhizomatous plant which was analyzed individually.

Mean Percent Basal Cover.—There was no significant difference in average percent basal cover among 100, 50 and 25 points per line or between random and systematically spaced points (Table 3). A comparison of systematically spaced points only shows that 25 points per line gave slightly higher estimates of basal cover than did 50, 100, or 500 points per line. There was no relative difference among plants in the way in which their basal cover was estimated by varying the point densities (Fig. 2).

Coefficients of Variation.— A comparison among coefficients of variation evaluates concomitant differences in estimates of means and variances for the different point densities and spacing. Different plants can also be compared directly with this statistic. Because means were similar for different point densities and because variances of estimates of cover varied inversely with point densities, the coefficients of variation for various plant groups increased significantly with decreasing numbers of points per line (Fig. 3). Averaged over all plants and point densities, the coefficients of variation were significantly higher for random than for systematic spacing (Table 3).

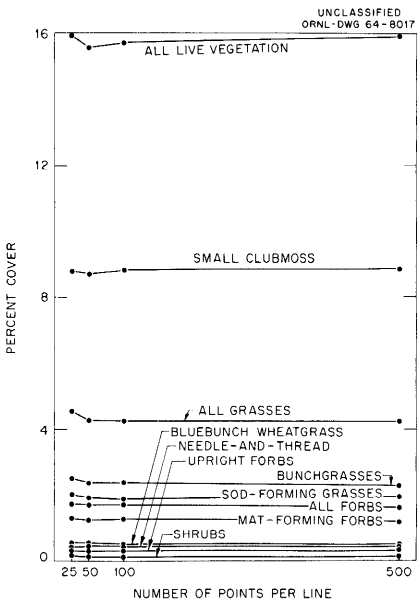

FIG. 2. Mean percent basal cover of selected vegetation categories, averaged for systematic and random placement, as a function of number of points per line.

Number of Transects Required.—A practical measure of variability is the calculated number of transects required to estimate cover within 10% of the mean with 95% confidence. In almost all instances point sampling would require more lines (although fewer points) than the line intercept technique (Table 4). The high variability of this foothill range is reflected in the impractical number of 5-ft line intercept transects required for sampling cover of most plant groups. Only for major plant groups All Live Vegetation and All Grasses were the actual number of transects, i.e., 350, sufficient to sample with the above precision.

Further insight into vegetation variability is shown by comparison of All Live Vegetation variation among five lines in a

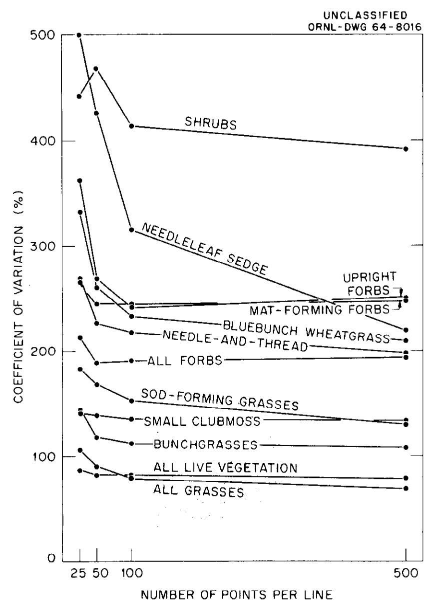

FIG. 3. Coefficients of variation in percent of selected vegetation categories, averaged for systematic and random placement, as a function of number of points per line.

cluster with the variability among the 70 clusters (Table 5). The analysis of variance and the F test indicate that between-cluster variation was significantly greater than within-cluster variation for all data. Although not significant, the F ratio was slightly greater at any point density for systematically as compared with randomly spaced points. The concomitant decrease of F values with sample point numbers indicates that variation within clusters became greater in relation to the between-cluster variation as the number of sampling units were decreased.

Table 4. Numbers of transects and point samples required to sample within 10% of the mean with 95% confidence.

Plant group	Number of 500-unit lines	Point samples required[1] 100 pts. Syst.	Rand.	50 pts. Syst.	Rand.	25 pts. Syst.	Rand.
All live vegetation	243	105	107	107	110	121	132
All grasses	185	131	141	170	190	236	308
Bunchgrasses	453	108	132	119	156	178	248
Sod-formers	656	139	128	167	179	198	239
Bluebunch wheatgrass	1712	134	163	168	198	274	351
Needleandthread	1522	121	146	131	186	184	273
Needleleaf sedge	1878	206	213	375	295	570	496
All forbs	1461	97	102	94	124	121	161
Upright forbs	2445	93	129	115	162	208	223
Mat forbs	2387	97	101	98	117	115	158
Small clubmoss	697	101	103	108	106	111	112
Shrubs	5963	112	126	143	160	127	191

[1] Data given as percent of the number of 500 unit lines required to sample within the stated limits.

Table 5. Mean square and F values of between-cluster and within-cluster analysis of variance on "All Live Vegetation" data from 350 transects in 70 clusters, each with 5 transects.

Mean square	Degrees of freedom	Intercept data	Point sample data 100 pts. Syst.	Rand.	50 pts. Syst.	Rand.	25 pts. Syst.	Rand.
Between cluster	69	12,356	408	514	126	124	32	33
Within cluster	280	1,912	77	79	20	22	7	7
"F" (All Sig. to 0.01)		6.5	6.6	6.5	6.2	5.5	4.7	4.6

Discussion

Intensity of Point Sampling.— For most plant categories and for all point sampling intensities, the relative frequency was directly proportional to the logarithm of basal cover (Fig. 4). But in plant categories containing many rhizomatous species, the relative frequency was less affected by the number of points per line. Needleleaf sedge was the major exception to the relative frequency-basal cover relationship. Basal cover of this species was estimated at 0.13, 0.13, and 0.16%, respectively, for 100, 50, and 25 points as compared to 0.15% for 500 points. The number of points per line had greater influence on the coefficient of variation for this species than any other (Fig. 3).

Lack of significant influence of number of points per line on percent cover is expected. The minor variations in estimates of percent cover by different point densities are not strongly related to plant growth forms (Fig. 2).

The number of transects required to sample within 10% of the mean with 95% confidence varied inversely with percent basal cover (Table 4). However, needleleaf sedge required relatively fewer lines and small clubmoss required relatively

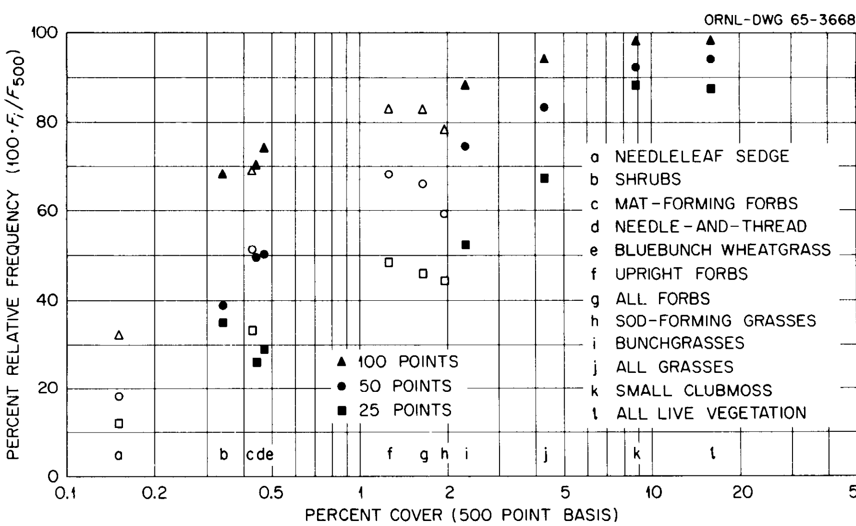

FIG. 4. Percent relative frequency of 12 plant categories as a function of the logarithm of percent basal cover. The open triangles, circles and squares are for categories containing many rhizomatous species.

more lines than would be expected in comparison with the other 10 categories. For needleleaf sedge this effect is caused by its rhizomatic growth form. For small clubmoss, however, the reason is not clear but may be due to the extreme range of plant size.

Systematic vs. Random Spacing. — Averaged over all plant categories, there were significantly higher estimates of frequency with systematic than with random spacing. But there were significantly lower coefficients of variation and few transects required for sampling by random than by systematic placement of points (Tables 3 and 4.) Cover estimates, however, were not significantly different for systematic and random sampling.

There were important interactions of point density and systematic vs. random placement of points for percent frequency, coefficients of variation, and numbers of transects required for sampling (Table 6).

Averaged over all plant categories, systematic placement of points gave higher estimates of percent frequency than did random placement of 25, 50 and 100

Table 6. Mean values of percent frequency of transect occurrence, percent coefficient of variation, and number of transects required averaged over all plant categories showing interaction of point density and point placement.

	Point Samples					
	100 pts.		50 pts.		25 pts.	
	S[2]	R[2]	S	R	S	R
Frequency Transect Occurrence	45	42	38	35	30	27
Coeff. of Variation	201	212	223	238	256	283
Transects Required[1]	120	133	150	165	204	249

[1] Data are expressed as percent of the numbers required for the 500 unit lines.

[2] S = systematic; R = random.

points per line. However, the relative difference was greater for 25 points per line, leading to the significant point placement x point-density interaction (Table 3). Mean frequency of occurrence varied from 27 to 45% for point samples but was 53% for the population.

For coefficients of variation and for number of lines required, there was greater actual and relative difference between systematic and random placement for 25 points per line than at higher densities. Mean coefficients of variation varied from 201 to 283% for point samples but was 186% for the population.

Estimates of percent frequency and coefficients of variation for the various plant categories did not vary uniformly as point density and point placement varied, resulting in significant interactions (see P x D and P x S in Table 3).

That percent frequency, averaged over random and systematic placement, generally varied directly with percent cover, was discussed above and illustrated in Fig. 4. But frequency of all plant categories did not respond identically to different point placements. Needleleaf sedge was estimated to have greater frequency by random than by systematic placement. In contrast Bunchgrasses, Needleandthread, and all three forb categories had greater estimates of frequency by systematic than by random placement of points. Generally, there was more difference between random and systematic placement of frequency estimates for 100-point sampling than for 50- or 25-point sampling. This is expected because the average distance between points for 100, 50, and 25-point densities, respectively, is .05, .10, and .20 ft. The basal diameter of these categories often exceeded .05 ft but was usually less than .10 ft. For needleleaf sedge, however, the greatest difference between frequency estimates for random and systematic point placement was at the 25-point-per-line density. The basal diameter of this species was usually less than .05 ft; it is rhizomatous and the mean distance between "plants" was probably .20 ft or greater. These data illustrate the importance of relations between plant growth form and sampling metholology, a topic not well understood although recently discussed in some detail by Kershaw (1964) and Greig-Smith (1964).

Estimates of coefficients of variation and of numbers of lines required for sampling varied with point placement and point density for different plant categories. These were greater for systematic than for random sampling for needleleaf sedge but greater for random than for systematic placement for individual bunchgrasses, the All Bunchgrasses, and all three forb categories. There was more difference in coefficients of variation between random and systematic placement of points at the 25-point density than at higher densities.

Practical Implications

There are numerous implications from these studies for sampling foothill bunchgrass range. The "best" sampling plan depends upon the percent basal cover and the growth form of the species to be sampled.

To sample a sod-forming species, such as needleleaf sedge, random placement of points would be better than systematic placement. However, for the dominants, the bunchgrasses, systematic placement would be better, especially if the distance between points is greater than the average basal diameter of the plants. Still, for species or categories with high mean cover, either random or systematic placement would suffice, but points should be spaced widely for greatest efficiency.

For almost all plant categories, estimates of percent frequency by point sampling are considerably lower than the respective population values. These estimates are not related in a linear manner to the point density or to the percent basal cover.

Estimates of percent cover would be relatively accurate with any of the point densities investigated.

Summary

This paper reports a comparison of point techniques for analyzing basal cover of grasslands. A population of 350 line intercept transect records, each recorded to 0.01 ft intervals for 5 ft, was sampled both randomly and systematically with 25, 50, and 100 points (0.01-ft units) per line. Statistical analyses were made to compare point densities, point placements, and their interactions with each other and with 12 plant categories. Comparisons were also made of the various point-sample estimates to the population parameters.

Some practical implications from these studies for sampling foothill grasslands similar to those described herein are:

(1) To sample sod-forming species, such as needleleaf sedge, random placement of points would be better than systematic placement.

(2) To sample the dominant bunchgrasses, systematic placement would be better, especially if the distance between points is greater than the average basal diameter of the plants.

(3) To sample plant categories with high basal cover, either of the point placement procedures would suffice.

(4) Generally, greater efficiency in sampling would occur with 25 than with more points per line.

(5) Basal cover of all species was estimated relatively accurately by both point placements and all point densities.

LITERATURE CITED

Aberdeen, J. E. C. 1958. The effect of quadrat size, plant size, and plant distribution on frequency estimates in plant ecology. Aust. J. Bot. 7:47-58.

Bauer, H. L. 1943. The statistical analysis of chaparral and other plant communities by means of transect samples. Ecology 24:45-61.

Brown, D. 1954. Methods of surveying and measuring vegetation. Comm. Bur. Past. and Field Crops. Bull. 42. Hurley, Berks, England. 233 p.

Canfield, R. H. 1942. Sampling ranges by the line intercept method—plant cover, composition, density, and degree of forage use. Southwestern Forest and Range Exp. Sta. Res. Rep. 4. 26 p.

Cockayne, L. 1926. Tussock grassland investigations in New Zealand. p. 349-361 *IN:* Tansley, A. C. and T. F. Chipp (editors). Aims and methods in the study of vegetation. Crown Agents for the Colonies. London. 383 p.

DeVries, D. M., and T. A. DeBoer. 1959. Methods used in grassland research in the Netherlands and their application. Herbage Abstr. 29:1-7.

Ellison, L. 1942. A comparison of methods of quadratting shortgrass vegetation. J. Agr. Res. 64:595-614.

Fisser, H. G. 1961. A comparison of line intercept, inferred point contact and weight measurement methods on foothill grassland vegetation. M.S. Thesis. Mont. St. Coll. 141 p.

Fisser, H. G., and G. M. Van Dyne. 1960. A mechanical device for repeatable range measurements. J. Range Manage. 13:40-42.

Goodall, D. W. 1952. Some considerations in the use of point quadrats for analysis of vegetation. Aust. J. Sci. Res. 5:1-41.

Greig-Smith, P. 1964. Quantitative plant ecology. Butterworths, Inc. Washington, D. C. 2nd Ed. 256 p.

Heady, H. F. 1961. Techniques in teaching range management techniques. Proc. Ann. Meet. Amer. Soc. Range Manage. 14:68 (abstract).

Heady, H. F., R. P. Gibbens, and R. W. Powell. 1959. A comparison of the charting, line intercept, and line point methods of sampling shrub types of vegetation. J. Range Manage. 12:180-188.

Hoell, P. G. 1943. The accuracy of sampling methods in ecology. Ann. Math. Stat. 14:289-300.

Hyder, D. N., C. E. Conrad, P. T. Tueller, L. D. Calvin, C. E. Poulton and F. A. Sneva. 1963. Frequency sampling in sagebrush-bunchgrass vegetation. Ecology 44:740-746.

Kershaw, K. A. 1964. Quantitative and dynamic ecology. Amer. Elsevier Publ. Co., Inc. 183 p.

Levy, E. G. 1927. The grasslands of New Zealand. New Zeal. J. Agr. 34: 145-164.

McIntyre, G. A. 1953. Estimations of plant density using line transects. J. Ecol. 41:319-330.

Schultz, A. M., R. P. Gibbens, and L. Debano. 1961. Artificial populations for teaching and testing range techniques. J. Range Manage. 14:236-242.

Snedecor, G. W. 1956. Statistical methods. 5th Ed. Iowa State Coll. Press, Ames. 534 p.

Stein, C. 1945. A two-sample test for a linear hypothesis whose power is independent of the variance. Ann. Math. Stat. 16:243-258.

Van Dyne, G. M. 1960. A method for random location of sample units in range investigations. J. Range Manage. 13:152-153.

Van Dyne, G. M., and H. A. Kittams. 1960. Nutrient production of foothill range—a progress report of 1958 and 1959 studies. Anim. Ind., Range Manage. and Wool Lab. Rpt. 26. Mont. Agr. Exp. Sta., Bozeman, Montana. 74 p.

Warren-Wilson, J. 1950. Analysis of spatial distribution of foliage by two-dimensional point quadrats. New Phytol. 58:92-101.

Whitman, W. C. and E. I. Siggersson. 1954. Comparison of line interception and point contact methods in the analysis of mixed grass range vegetation. Ecology 35:431-436.