Adaptation of Distance Measurements For Range Sampling

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Highlight

Modification of a distance measurement technique (the angle-order method) for estimating density, herbage production, and ground cover was tested in 1960 and 1961 at the U. S. Sheep Experiment Station in Idaho. Estimates of plant density and herbage production obtained by the angle-order method were compared with estimates on 9.6- and 96-square-foot plots, and estimates of cover were compared with estimates from line intercepts on 10-meter lines. Several limitations inherent in use of the angle-order method render it unsuitable for sampling complete plant communities of sagebrush-grass rangeland, but it may be used efficiently for estimating density, production, and ground cover for one or two key species.

[1] *In this paper, the term "density" denotes number of plants per unit area.*

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A distance measurement method for estimating density,[1] herbage production, and ground cover, was tested in 1960 and 1961 at the U.S. Sheep Experiment Station, Dubois, Idaho. In most grazing studies at the Sheep Station in the past, the sagebrush-grass range has been sampled by the weight estimate method (Pechanec and Pickford, 1937) on plots either 96 or 100 square feet in area. Reliable estimates of production can be obtained by this method if reasonably accurate estimates of herbage weight are made on all plots. However, this accuracy is not always attained because: (1) weights are difficult to estimate accurately on such large plots, especially in thick vegetation in swales and similar areas, and (2) temporary field assistants often lack the training and experience necessary to estimate weights accurately.

When herbage weight is the only data available, evaluation of changes in vegetation due to grazing treatment is often difficult because weather causes rather large fluctuations in production from year to year. These fluctuations are especially pronounced for two of the highest producing species in the area, threetip sagebrush *(Artemisia tripartita* Rydb.) and arrowleaf balsamroot *(Balsamorhiza sagittata* (Pursh) Nutt.). In addition to estimates of production, estimates of density and ground cover of these and other species would be helpful for evaluating ecological change. Information on amount of ground covered by plants and litter is also quite important from a soil protection and watershed standpoint.

Numerous techniques have been devised in recent years for estimating plant density by measuring distance from a point to a plant or from one plant to another. These methods have been summarized by Cottam and Curtis (1956), Pielou (1959), Dix

(1961), and Strickler and Stearns (1963). The distance measurement technique used in the present study is essentially the same as the angle-order method described by Morisita (1957) and will be referred to by that name. This method is unique among distance measurement techniques because it gives unbiased estimates of density for all populations. With the exception of the wandering quarter method (Catana, 1963), all other distance measurement methods give accurate estimates for randomly distributed populations only.

The angle-order method, with supplementary measurements of individual plant weights and areas, was compared with weight estimate plots and line intercept sampling at the Sheep Station in 1960. A modification of the method was tested in 1961. The purpose of the study was: (1) to compare the angle-order method with other sampling methods to determine if it is a practical method for estimating plant density, herbage production, and ground cover, and (2) to compare estimates of herbage production from 9.6-square-foot plots with those from 96-square-foot plots to determine if the smaller plot is practical to use in the vegetation found at the Sheep Station. Plots 9.6 square feet in area have been successfully used in other areas on vegetation similar to that at the Sheep Station (Frischknecht and Plummer, 1949; Goebel, 1955).

Methods

Sampling methods compared in 1960 were: (1) distance measurements plus individual plant weight and area measurements in four quadrants around sample points (angle-order method), (2) weight estimates and plant counts on 96-square-foot plots, (3) weight estimates and plant counts on 9.6-square-foot plots, and (4) line intercepts on 10-meter lines. Two 4-acre areas were sampled by each of the four methods. The two areas represented different sites and conditions within an 80-acre range pasture; area 1, on a flat hilltop area, contained more sagebrush and much less arrowleaf balsamroot than area 2, which was in a broad swale.

The number of sampling units for each method is shown below:

Area	Angle-order points	96-sq. ft. plots	9.6-sq. ft. plots	Intercept lines
1	30	10	20	10
2	30	10	30	20

All points, plots, and lines were located at random. Training for the different methods was conducted in conjunction with sampling area 1. For area 2, approximately 1 man-day of field time was required for each of the four methods at the above intensity of sampling. In addition to these two areas, a 4-acre area in each of three adjoining pastures was sampled by 25 angle-order points, but no comparison with other methods was made. Using a modification of the angle-order method to be described later, range researchers resampled all five of these areas in 1961.

Weight Estimate Plots.—On the 9.6- and 96-square-foot plots, green herbage weight of each species was estimated in grams and later converted to air-dry pounds of herbage per acre. On these plots, counts were also made of individual plants of the three major species: bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. and Smith), arrowleaf balsamroot, and threetip sagebrush. These counts were converted to number of plants per acre.

Line Intercept.—The line intercept method used was similar to the one described by Parker and Savage (1944). A 10-meter line was stretched above the shrub canopy, and the intercept of the canopy of each shrub was measured to the nearest centimeter. Shrub canopies having spaces no greater than 10 cm between the branches were considered to represent solid foliage cover. When spaces between branches were greater than 10 cm, shrub canopy size was determined by adding the measurement for the individual branches. Because the shrubs in the study area were only 12 to 18 inches tall, stretching the line above the canopy was relatively simple.

After the shrub intercept was recorded, the line was lowered as close to the ground as possible and intercepts of the basal portions of grasses and forbs were measured. Portions of plants 1 cm or less in width were measured to the nearest millimeter; larger intercepts were measured to the nearest centimeter. Often the presence of shrubs made it impossible to lower the line to ground level. When this occurred, a plumb bob was used to facilitate the reading of the basal intercepts. Intercepts were expressed as a percentage of the total length of the intercept lines.

Angle-Order.—In the angle-order method, a wire frame divided into four quadrants was centered at each sample point and used as a guide for sampling (Figure 1). In each quadrant, distances were measured from the sample point to the third nearest plant of each species or group of species as follows: (1) bluebunch wheatgrass, (2) other grasses, (3) arrowleaf balsamroot, (4) other forbs, (5) threetip sagebrush, and (6) other shrubs. Measurements were made to the center of individual grass and forb plants at ground level. For shrubs, measurements were made to the point where the main stem emerged from the ground, regardless of the position of the canopy. Distances 10 feet or less were measured to the nearest one-tenth foot and those greater than 10 feet were measured to the nearest foot. If the third nearest plant of any species was not found within 100 feet of the point, the distance was arbitrarily recorded as 100 feet. This

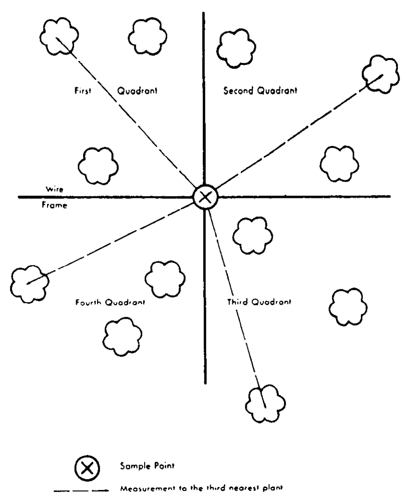

FIGURE 1. Diagram of wire frame used in the angle-order method, showing the distance measurements to the third nearest plant of one species in each quadrant.

procedure introduces a bias that will be discussed later.

The distance measurements were converted to plant density in each category using formulas given by Morisita (1957):

$$m_1 = \frac{n-1}{N} \sum_{i=1}^{N} \sum_{j=1}^{k} \frac{1}{r^2 ij}$$

$$m_2 = \frac{k(nk-1)}{N} \sum_{i=1}^{N} \frac{1}{\sum_{j=1}^{k} r^2\, ij}$$

$$m_0 = \frac{m_1 + m_2}{2} \quad \text{when } m_1 < m_2$$

$$m_0 = m_1 \quad \text{when } m_1 > m_2$$

where:

n = order of plant measured
k = number of equiangular sectors at each point
N = number of sample points
r = individual distance measurements in each quadrant
$\sum_{j=1}^{k} r^2{}_j$ = sum of squared measurements at each point
m_0 = estimate of the number of plants per area (3.1416 sq. ft.)

In the present study, $n = 3$ (third nearest plant) and $k = 4$ (four quadrants at each point). These formulas give unbiased estimates of density for random, aggregated, or uniform populations if $n \geqq 3$ and $k \geqq 4$ (Morisita, 1957).

In the first quadrant sampled at each point (Figure 1), the following data were recorded for each plant to which distance measurements were made: green weight of herbage in grams (later converted to air-dry weight), average basal diameter of grasses and forbs, and average crown diameter of shrubs. Average dry weight per plant multiplied by number of plants per acre gave an estimate of production per acre for each species or group. Average crown or basal area times number of plants per acre gave an estimate of total plant area per acre, which was converted to percentage of ground covered. These procedures for obtaining production and ground cover are a modification of Morisita's angle-order method for estimating density.

Determination of Individual Plants.—Consistent recognition of individual plants is essential for accurate measurements in the angle-order method and accurate plant counts in the plots. In these tests, recognition of individual shrubs, single-stemmed grasses and forbs, and distinct bunch grasses was found to be easy, but individual plants of matforming forbs and loose or indistinct bunch grasses sometimes were difficult to distinguish. The general criterion used to distinguish individuals was separation between live plants at ground level. Records of charted quadrats at the Sheep Station have shown that bunch grasses in this vegetation type deteriorate and break into numerous smaller individual segments. Eventually these segments are replaced by other plants of the same or different species (Blaisdell, 1958). Bunches of grass in the process of subdividing were very difficult to count accurately. One such disintegrating bunch might be recorded as one or as many as 10 individual plants—depending to some extent on how much probing was done to determine separations.

Results

Plant Density.—Estimates of number of plants per acre by the three methods indicate that area 1 had fewer grass, forb, and "other shrub" plants, and more sagebrush plants than area 2 (Table 1). Densities from counts on the 9.6- and 96-square-foot plots and from the angle-order measurements were similar for sagebrush in both areas and balsamroot in area 2. The number of balsamroot plants in area 1 as determined by the angle-order method may be too high because plants were so widely dispersed that the third plant was beyond 100 feet in 28 quadrants at 19 of the 30 points. When this occurred, distance was arbitrarily recorded as 100 feet because analysis of the angle-order data cannot be made unless there is a measurement in every quadrant at every point. Thus, recording 100 feet may have led to overestimation of population density. However, a quadrant with a radius of 100 feet contains over 7,800 square feet; it is highly probable that some small plants may have been overlooked in this relatively large area.

Density estimates for bluebunch wheatgrass from counts on the 96-square-foot plots were considerably lower than those from the other methods in both areas. Because of the relatively

Table 1. Number of plants per acre in areas 1 and 2 as determined by measurement in the angle-order method and by count in 9.6- and 96-square-foot plots.

	Area 1			Area 2		
Species	Angle-order method	9.6-sq.-ft. plots	96-sq.-ft. plots	Angle-order method	9.6-sq.-ft. plots	96-sq.-ft. plots
Bluebunch wheatgrass	20,610	28,590	16,790	38,390	32,520	17,740
Arrowleaf balsamroot	[1]480	230	320	7,540	7,410	6,080
Threetip sagebrush	9,400	10,660	9,120	8,020	7,410	5,720
Other grasses	35,590	[2]—	—	41,600	—	—
Other forbs	46,320	—	—	54,470	—	—
Other shrubs	19,220	—	—	20,230	—	—

[1] Figure probably too high because distances were restricted to 100 feet from the sampling point.

[2] Estimates of density not available for other grasses, forbs, and shrubs in the 9.6- and 96-square-foot plots.

large plot area to be covered, investigators may not have probed thoroughly enough to determine whether there were separations between individual wheatgrass plants on the 96-square-foot plots, and consequently recorded lower densities than those obtained by the other methods. Because the three methods were used on different days, comparison of counts in the 96- and 9.6-square-foot plots was not made in the field. The apparent bias on the large plots was not discovered until the data were summarized.

Herbage Production.—Herbage production estimates from the modified angle-order method generally were higher than those from the weight estimate plots (Table 2). The angle-order estimates for bluebunch wheatgrass, "other grasses," and "other forbs" were two to five times higher than the estimates from the plots. The angle-order density estimates for these plants may be inaccurate because distinguishing individual plants was difficult. However, many plants in this category were quite small and their weights could have been overestimated. For example, a lower density estimate for bluebunch wheatgrass was obtained by the angle-order method than by the 9.6-square-foot plots in area 1. However, production from the modified angle-order method was almost twice as high as that from the 9.6-square-foot plots. This indicates that: (1) the weight estimates for this species were faulty in one of the methods, either too low on the 9.6-square-foot plots or too high for the individual plants in the modified angle-order method; or (2) the number of individual plant weights obtained in the modified angle-order method was too small to accurately determine mean plant weight. It is believed that most of the errors were in the application of the modified angle-order method.

Ground Cover.—The estimates of total ground cover from the two methods were similar in area 1 (Table 2). In area 2, the modified angle-order method indicated considerably higher ground cover than the line intercept method. The percentage of ground cover of the different classes of plants generally was similar for the two methods. The greatest discrepancy was for "other shrubs" in area 2 where the estimate from the modified angle-order method was almost double that from the intercept method.

Table 2. Comparison of herbage production and ground cover estimates obtained from the angle-order method, 9.6- and 96-square-foot plots, and the line intercept method, areas 1 and 2.

	Pounds per acre (dry weight)			Percentage ground cover	
Species	Angle order method	9.6-sq.-ft. plots	96-sq.-ft. plots	Angle-order method	Line intercept
Area 1					
Bluebunch wheatgrass	285	145	108	3.5	2.8
Other grasses	267	71	73	2.2	2.9
Arrowleaf balsamroot	7	2	4	(1)	(1)
Other forbs	321	65	56	2.4	2.0
Threetip sagebrush	170	130	105	15.0	11.9
Other shrubs	171	126	84	5.4	8.6
Total	1,221	539	430	28.5	28.2
Area 2					
Bluebunch wheatgrass	380	163	122	3.6	2.2
Other grasses	232	92	50	1.7	1.9
Arrowleaf balsamroot	147	132	106	1.1	0.5
Other forbs	201	71	59	2.1	2.5
Threetip sagebrush	149	120	110	12.2	9.7
Other shrubs	188	225	140	11.5	6.6
Total	1,297	803	587	32.2	23.4

[1] Less than 0.05 percent.

Sampling Efficiency

Density.—To compute coefficients of variation, each point, plot, or line was considered a sampling unit. The coefficients of variation for density from the 96-square-foot plots were lower than those from the 9.6-square-foot plots for all species and lower than those from the angle-order method for wheatgrass and sagebrush in both areas (Table 3). The coefficients of variation from the angle-order method were equal to or less than those from the 9.6-square-foot plots except for bluebunch wheatgrass in area 1.

The columns showing "number of plants sampled" indicate the actual number counted in plots and the number considered in the angle-order measurements. In the angle-order method, distance measurements were made to the third nearest plant of each species in each quadrant. Therefore, three plants of each species were sampled in each quadrant

Table 3. Comparison of sampling precision of density estimates for the angle-order method and for 9.6- and 96-square-foot plots, areas 1 and 2.

Species	Plants sampled[1]			Coefficient of variation			Points or plots needed[2]		
	Angle-order	9.6-sq.-ft. plots	96-sq.-ft. plots	Angle-order	9.6-sq.-ft. plots	96-sq.-ft. plots	Angle-order	9.6-sq.-ft. plots	96-sq.-ft. plots
	(Number)			(Percent)			(Number)		
Area 1									
Bluebunch wheatgrass	360	126	370	103	63	30	106	40	9
Arrowleaf balsamroot	360	1	7	145	440	179	210	1,936	320
Threetip sagebrush	360	47	201	71	72	18	50	52	3
Points or plots sampled	—	—	—	—	—	—	30	20	10
Area 2									
Bluebunch wheatgrass	360	215	391	57	66	31	32	44	10
Arrowleaf balsamroot	360	49	134	62	106	84	38	112	71
Threetip sagebrush	360	49	126	67	82	45	45	67	20
Points or plots sampled	—	—	—	—	—	—	30	30	10

[1] Number of plants included in the angle-order distance measurements and counted in the 9.6- and 96-square-foot plots.

[2] Number of points or plots needed to sample within 20 percent of the population mean at the 95 percent level of confidence:

$$n = \frac{t^2 C.V.^2}{p^2} \quad \text{where} \quad \begin{aligned} t &= 2.000 \\ C.V. &= \text{the coefficient of variation} \\ p &= 20 \text{ (desired accuracy in percent)} \end{aligned}$$

When these values are substituted, $n = \frac{C.V.^2}{100}$

and 12 plants were sampled at each point.

The number of balsamroot plants sampled by the angle-order method in area 1 may be somewhat misleading. Theoretically, 360 plants were sampled, but the exact number cannot actually be determined because the third plant was beyond 100 feet in almost one-fourth of the quadrants. Thus the density estimate and the coefficient of variation from the angle-order method may be incorrect. However, because balsamroot was so widely dispersed, the density estimates from the other methods may not be very accurate either. Only one balsamroot plant occurred on the twenty 9.6-square-foot plots, and a total of seven plants occurred in the ten 96-square-foot plots in area 1. The coefficients of variation for these methods were higher than for the angle-order method (Table 3).

The number of plants sampled has considerable influence on statistical variation. Note that the method which recorded the fewest plants has the highest coefficient of variation for all species except wheatgrass in area 1 (Table 3).

Weight and Ground Cover.— In the angle-order method, the density of each species at each point was multiplied by weight or area of the appropriate plant to obtain herbage production or ground cover per unit area at that point. The area totals obtained in this manner differ slightly from those presented in Table 2. The point totals were used to compute coefficients of variation for each area. The number of points required to sample weight and cover within 20 percent of the population mean at the 95 percent confidence level was computed using the formula given in Table 3.

The modified angle-order method required more samples (points) to obtain this precision than did the 9.6- or 96-square-foot plots for all plants and groups except balsamroot and "other shrubs" in both areas and sagebrush in area 2 (Table 4). The modified angle-order method also required more samples than the line intercept method for all species except balsamroot.

Resampling in 1961

Areas 1 and 2 and the three adjoining pastures were resampled in June 1961, using a combination of methods based on the results of the 1960 sampling. Density of balsamroot, sagebrush, "other large shrubs," and "other small shrubs" was measured by 10 angle-order points in each area. To reduce the variance, "other shrubs" were split into two groups. Diameter and weight were recorded for every plant to which

Table 4. Number of points, plots, or lines needed to sample weight and ground cover within 20 percent of the population mean at the 95 percent confidence level, areas 1 and 2.

	Weight						Ground cover			
	Area 1			Area 2			Area 1		Area 2	
Species	Angle-order	9.6-sq.-ft. plots	96-sq.-ft. plots	Angle-order	9.6-sq.-ft. plots	96-sq.-ft. plots	Angle-order	Line inter.	Angle-order	Line inter.
Bluebunch wheatgrass	67	50	16	161	38	26	272	49	292	37
Other grasses	104	74	26	72	66	38	177	44	174	34
Arrowleaf balsamroot	292	949	324	35	172	81	357	497	102	182
Other forbs	992	15	123	88	50	40	324	125	686	96
Threetip sagebrush	77	55	40	48	117	49	119	56	83	61
Other shrubs	154	159	26	292	645	81	159	27	408	27
All vegetation	—	16	10	—	49	5	—	7	—	14
Actual samples taken	30	20	10	30	30	10	30	10	30	20

distance measurements were made. Weight of each plant sample was estimated. Many plants were clipped and weighed to check the estimates. Production and percentage of ground cover were computed as described previously. Estimates of production of grasses and forbs other than balsamroot were obtained by clipping ten 9.6-square-foot plots in each area. Since climatic conditions and herbage production were quite different in the 2 years, only density figures will be compared.

The density estimates obtained in 1961 generally were similar to those obtained in 1960 for both balsamroot and sagebrush in all areas (Table 5). However, the data for "other shrubs" generally were more variable and will not be presented here. Sampling groups of species with the angle-order method does not appear to give satisfactory results, even if similar species are grouped together.

Table 5. Comparison of number of plants per acre as measured by the angle-order method in 1960 and 1961, areas 1 and 2, plus three adjoining pastures.

	Arrowleaf balsamroot		Threetip sagebrush	
Area	1960	1961	1960	1961
Area 1[1]	480	610	9,400	10,770
Area 2[1]	7,540	8,910	8,020	8,160
Past. 11	0	0	5,250	5,360
Past. 12	3,120	3,910	9,620	12,760
Past. 14	6,320	5,500	11,750	13,460

[1] Areas 1 and 2 were in different locations within the same pasture.

Discussion

Weight Estimates.—Weight estimates on 9.6-square-foot plots were considerably easier to make than those on the 96-square-foot plots. Moreover, estimates on the smaller plots were considered to be more accurate than those on the large plots because all of the foliage on a small plot can be seen at one time and estimated weights can be confirmed readily by clipping and weighing (Frischknecht and Plummer, 1949). However, more 9.6-square-foot plots are required to sample the vegetation at a given precision.

Line Intercept.—In the line intercept method, intercept readings of the shrub canopy were easy to make and had a relatively low coefficient of variation. This would be a quick and easy method for estimating shrub cover in sagebrush-grass or any vegetation type containing relatively small shrubs. However, measuring intercept of the herbaceous vegetation was rather tedious and time consuming because the line could not always be lowered close enough to the ground to permit accurate observations.

Angle-Order Method.—From the results of the present study it appears that the angle-order method may permit accurate estimation of density, production, and ground cover if the conditions and procedures listed below are met:

1. Individual plants of the species sampled must be consistently distinguished by all observers.
2. Areas and particularly weights of individual plants must be measured or estimated very precisely. Clipping and weighing individual plants or composite samples from an area would reduce weight errors.
3. Weight and area of more than one plant of each species or group should be estimated or measured at each point if possible. Enough plants must be sampled to give reasonable precision in estimating plant weight.
4. Where possible, individual species should be sampled separately. Researchers studying cheatgrass range in Idaho have also encountered difficulties in interpreting angle-order data where several perennial grasses were grouped together.[2]

[2] *James O. Klemmedson, personal communication.*

Because of these limitations, the angle-order method is not a suitable method for sampling plant communities *in toto*. The angle-order method is tedious and slow if each species is to be sampled separately. Such an undertaking is not practical unless the community contains only a very few species.

In a study in Arizona (U.S. Forest Service, 1963) the angle-order method gave accurate density estimates of desert shrubs, but was found to be too time consuming to be practical. However, the angle-order method may be efficient for sampling density, production, and ground cover of one or two key species in an area. For example, at the Sheep Station, measures of threetip sagebrush and arrowleaf balsamroot taken periodically would provide valuable data for determining ecological trend. Other species probably can be best measured by other methods.

Summary

Weight estimates on 100-square-foot plots have been used to sample the sagebrush-grass range at the U.S. Sheep Experiment Station in most grazing studies in the past. However, because production fluctuates from year to year, evaluation of changes in vegetation is often difficult when herbage weight is the only data available. A distance measurement technique (angle-order method) for estimating density and ground cover as well as production was tested in 1960 and 1961. Density and production estimates obtained by the angle-order method and by plant counts on 9.6- and 96-square-foot plots were compared. Also, cover estimated by a modified angle-order method was compared with estimates from line intercepts on 10-meter lines.

Estimates of density, production, and ground cover of the three major species (bluebunch wheatgrass, arrowleaf balsamroot, and threetip sagebrush) were similar for all methods. Estimates of production from the angle-order method for all other species and groups were from two to five times higher than the estimates from the plots. Much of this difference probably can be accounted for by errors in recognizing individual plants, possible overestimation of weights of these plants, and grouping of species having dissimilar weights or areas. Estimates of ground cover generally were similar for the angle-order and the line intercept methods.

Line intercept readings of the shrub canopy were easy to make and had a relatively low coefficient of variation. Measuring intercept of the herbaceous species was time consuming because the line could not always be lowered close enough to the ground for accurate observations to be made.

Weight estimates on 9.6-square-foot plots were easier to make and were considered more accurate than those on the 96-square-foot plots.

The angle-order method may give accurate estimates of density, production, and ground cover if:

1. Sampling is confined to species in which individual plants can be consistently distinguished by all observers.

2. Areas and weights of individual plants can be measured or estimated very precisely.

3. Enough plants are measured to give reasonable precision.

4. Individual species are sampled separately. It is very difficult to obtain useful information if species are grouped together.

Because of these limitations of the angle-order method, it is not suitable for sampling entire plant communities. However, it may be an efficient method for obtaining density, production, and ground cover data on one or two key species.

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