A comparison of three range measurement techniques and a study of the response of native vegetation to protection from sheep grazing

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A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Range Management at Montana State College
Montana State University

Abstract:
A study was conducted on a foothill range in central Montana to determine (1) the relationship of three range measurement techniques--point-quadrats, 3/4-inch loop, and dry-weight--in estimating percent composition of native vegetation and (2) the response of native vegetation to protection from sheep grazing over a four year period. The vegetation was characterized as an intermingling of mixed prairie and Palouse prairie types.

Range exclosures were constructed oh five different sites in 1953.

Basal coverage and composition of- the vegetation were estimated by the point-quadrat method along a series of line transects. The transects were placed within each exclosure and on adjacent areas subject to fall, winter, and spring grazing by sheep. In 1957, the point-quadrat analysis was repeated on all transects. In addition, an index to basal coverage and the composition of the vegetation were determined by the 3/4-inch loop along the same transects. Production and percent composition of the vegetation were determined, from the dry-weight of individual species harvested from 1’ X 6' plots. The percent composition of the vegetation determined by weight was used as the standard for comparison.

The relationship of the three techniques was evaluated by analysis of variance for nine variables. The loop closely estimated the percent composition of all grasses and sedges as a group when considered over five sites and two grazing treatments. The point method underestimated this group of plants. Similar results were determined for rhizomatous grasses and sedges as a group. Large bunchgrasses, like Agropyron spicatum, which produced relatively large amounts of herbage per unit of basal area were underestimated by both the point and loop. Short bunchgrasses, like Koeleria cristate, produced small amounts of herbage per unit of basal area and were overestimated by the point and loop. All bunchgrasses as a group were estimated nearly equal by the three methods.

Estimates of Phlox hoodii and all forbs as a group were high by the point and low by the loop. First hits by the point and loop were recorded on the mat-forming forbs. First hits were also recorded on shrub and half-shrub species. Estimates were high by both methods on this group of plants.

In general, the percent composition by weight of the various components was more closely estimated by the loop method, than by the point method.

The change of vegetation due to grazing and protection from grazing over a four year period was evaluated by analysis of variance for 19 variables. Artemisia 'frigida was the only individually analyzed species to show a statistically significant response to grazing and non-grazing. Considered over all sites it increased under grazing and decreased under protection from grazing. It appeared to be a relatively sensitive plant indicator for determining trend in range condition.;, Considering all sites combined, the basal coverage of all plants (excluding Selaginella dense) as a group did not change significantly under

either grazing treatment, although pronounced variations occurred among sites. Litter and total ground cover increased under both grazing treatments over all sites. The change was significantly greater on the non-grazed areas primarily as a result of increased litter.

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ABSTRACT

A study was conducted on a foothill range in central Montana to determine (1) the relationship of three range measurement techniques--point-quadrat, 3/4-inch loop, and dry-weight--in estimating percent composition of native vegetation and (2) the response of native vegetation to protection from sheep grazing over a four year period. The vegetation was characterized as an intermingling of mixed prairie and Palouse prairie types.

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The relationship of the three techniques was evaluated by analysis of variance for nine variables. The loop closely estimated the percent composition of all grasses and sedges as a group when considered over five sites and two grazing treatments. The point method underestimated this group of plants. Similar results were determined for rhizomatous grasses and sedges as a group. Large bunchgrasses, like *Agropyron spicatum*, which produced relatively large amounts of herbage per unit of basal area were underestimated by both the point and loop. Short bunchgrasses, like *Koeleria cristata*, produced small amounts of herbage per unit of basal area and were overestimated by the point and loop. All bunchgrasses as a group were estimated nearly equal by the three methods.

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In general, the percent composition by weight of the various components was more closely estimated by the loop method than by the point method.

The change of vegetation due to grazing and protection from grazing over a four year period was evaluated by analysis of variance for 19 variables. *Artemisia frigida* was the only individually analyzed species to show a statistically significant response to grazing and non-grazing. Considered over all sites it increased under grazing and decreased under protection from grazing. It appeared to be a relatively sensitive plant indicator for determining trend in range condition.

Considering all sites combined, the basal coverage of all plants (excluding *Selaginella densa*) as a group did not change significantly under either grazing treatment, although pronounced variations occurred among sites. Litter and total ground cover increased under both grazing treatments over all sites. The change was significantly greater on the non-grazed areas primarily as a result of increased litter.

INTRODUCTION

One of the problems confronting the range researcher, range administrator, or ranch manager is the measurement of the change in ground cover, composition, and production of the native vegetation on livestock and game ranges as related to grazing management practices. Various techniques have been used to measure ground cover, composition, and production of vegetation on native ranges. These techniques vary from rapidly made estimates by visual observation to more time-consuming and detailed charting procedures as the pantograph. A desirable technique would be one which is rapid yet accurate in obtaining measurement information about native vegetation.

Three techniques commonly used for the measurement of range vegetation are the point-quadrat, the 3/4-inch loop, and the determination of weight of vegetation harvested from small sampling units. The point-quadrat, first developed in New Zealand, has been used extensively by grassland researchers throughout the British Empire and the United States primarily for estimating ground cover and composition of pasture and range vegetation. The loop method has been used primarily in the United States in the appraisal of trend and condition on national forest ranges. The method of obtaining the weight of vegetation harvested from small sampling units has been used universally for estimating the forage and herbage production of pasture and range lands.

It was desired to compare the three techniques in one area on sites grazed by sheep, and on similar sites protected from sheep grazing. These comparisons were conducted on a ranch near White Sulphur Springs, Montana. The ranch had been leased from the fall of 1952 to the spring of 1957 by the Montana Agricultural Experiment Station for range sheep research. Permanent range exclosures were constructed in 1953 at five sites. The basal area and composition of the vegetation were analyzed at each of these sites by the point-quadrat method. In 1957, the vegetation at each site was again analyzed by the point-quadrat method. In addition, an analysis of the vegetation was made by the loop method and a series of plots were clipped to obtain an estimate of the relative production and percent of composition by weight.

This thesis reports on a comparison of the three techniques of range measurement and on changes in the basal area and composition of the native vegetation over a four-year period as a result of grazing and protection from grazing by sheep.

REVIEW OF LITERATURE

Point-Quadrat Method

The term, point-quadrat, describes the concept of a quadrat or plot reduced in size until it becomes a point, virtually without area. The point method is based on the mathematical concept of the homogeneity of a unit area as represented by a pin point. An accurate representation of the vegetation can be secured by the point method provided a sufficient number of pin points of vegetation are examined (Levy and Madden, 1933). Other names that have been used to describe the point-quadrat method include point-method, point-plot, point-contact, point-transect, and point-observation transect.

History and development

The point-quadrat method was apparently first used in New Zealand by Cockayne who used a mark on the toe cap of one boot as the theoretical point (Levy and Madden, 1933). References to the use of the method appeared in numerous papers by Levy, Davies, and others during the period 1927 to 1933 (Goodall, 1952). After eight years of use in New Zeland, Levy and Madden (1933) published a full account of the point method. They described the point frame and its use, offered suggestions for the number of points to use, and presented four procedures by which the data could be analyzed. These four procedures were (1) The percentage of ground covered by each species, (2) The percentage cover each species is contributing to the total area, (3) The relative frequency of each species in the cover, and (4) The percentage each species is contributing to the pasture sward. Subsequent studies on the fundamentals of the method have been concerned primarily with two of these analytical procedures: percentage cover and percentage composition (Goodall, 1952, Winkworth, 1955).

Hanson (1934) was apparently the first person to make use of the point-quadrat method in the United States. He used a frame similar to the one described by Levy and Madden. The cross members of the frame, supported by two legs, contained 10 vertical holes, 2-inches apart, through which pins, sharpened on one end, could pass. Readings were taken from 20 systematically placed frames in plots measuring 2-rods by 4-rods. Hanson recommended that for extensive surveys of mixed prairie vegetation, the use of the point-quadrat method should be supplemented with other techniques.

Techniques of recording hits

By the Levy and Madden method, all-contacts with each species are recorded as the pin is lowered through the vegetation. Several workers have compared the results of recording all contacts or "hits" with only the first hit (Tinney, et al., 1937; Drew, 1944; Van Keuren and Ahlgren, 1957a). They found that recording only first hits greatly underestimated the lower growing species, whereas recording all hits tended to place the shorter plants on a parity with taller plants.

Some workers have counted only hits made on the base of the plants (Clarke, et al., 1942; Coupland, 1950; Johnston, 1957 and 1958; Whitman and Siggeirsson, 1954; Sturm, 1954; Mattox, 1955). When only basal hits are recorded, the creeping grasses and prostrate, mat-forming plants may be overestimated (Brown, 1954; Whitman and Siggeirsson, 1954). Basal area, however, is considered by some as a better criterion for determining changes in the pasture over a period of years. Basal area does not change appreciably from year to year due to fluctuating climatic conditions, but is more apt to be influenced by plant succession or different intensities of grazing (Albertson and Weaver, 1944; Robinson, 1945; Vose, 1956).

A point-quadrat method which uses vertical pins graduated into inches by bands of paint has been designed to determine a "height index" of pasture swards (Spedding and Large, 1957). Hits are recorded separately for each band on each pin and the data summed to give total hits at each height for each species. A similar procedure has been used by Heady (1957) to obtain a measure termed as "height of plant material". This measurement has been facilitated by a point frame modified by Heady and Rader (1958) to include a ruler which is placed along side each pin between horizontal members of the frame. In addition, a brake device has been installed on the frame to regulate the fall of the pins to the ground.

Vertical vs. inclined pins

Tinney, et al. (1937) modified the vertical point-quadrat so the pins were inclined at an angle of 45 degrees. They compared the inclined point-quadrat with the vertical point-quadrat and stated that the inclined method was more easily read and that it covered a greater area per reading. A greater number of plants were recorded from inclined pins, and consequently, they believed that the accuracy of the point method was increased. This conclusion by Tinney, et al. was later discredited by Winkworth (1955) who maintained that there was little to recommend the inclined method for estimating botanical composition of pastures. He agreed that inclined pins would make more contacts with the vegetation, but that no gain in the precision of estimation of percentage composition would be obtained.

Van Keuren and Ahlgren (1957a) found that the number of hits obtained by inclined points on mixed grass, alfalfa, and clover swards gave a higher correlation with the yield of dry matter than hits obtained by vertical points. Drew (1944) noted little difference in accuracy between vertical and inclined points in the determination of the composition of a grass-lespedeza pasture.

Other workers who have used the inclined point-quadrat in pasture studies include Henson and Hein, 1941; Hein and Henson, 1942; Arny and Schmid, 1942; Arny, 1944; Rhoad and Carr, 1945; Sprague and Myers, 1945; Musser, 1948; Leasure, 1949; Hanson, 1950; Whitman and Siggeirsson, 1954; Mattox, 1955; Winkworth, 1955; Van Keuren and Ahlgren, 1957b.

Comparison of the point-quadrat method with weight analysis

Several workers have compared the percentage composition of pasture mixtures as determined by point readings with the percentage composition determined by dry-weight analysis after hand separation of the clipped vegetation. From a study of mixed prairie vegetation in North Dakota, Hanson (1934) found that the vertical point method gave a higher estimate of the composition of the species in the *Bouteloua-Carex* association than did a dry-weight analysis. The estimate of the composition of *Agropyron smithii* was lower by the point-method than by a dry-weight analysis. The *Bouteloua* and dryland species of sedge have a larger leaf and stem surface for a given amount of weight than has *Agropyron smithii* which has greater thickness and weight. The former species were hit more often by the points and their importance in the pasture was overestimated.

Arny and Schmid (1942) compared botanical composition of grass and alfalfa mixtures as determined by the inclined point-quadrat method with the composition determined by dry weight of hand separated, clipped vegetation. The point-quadrat underestimated alfalfa but overestimated Kentucky bluegrass alone and bluegrass and crested wheatgrass combined. Estimates of smooth brome varied but little between the methods. Correction factors were developed and applied for the overestimation and underestimation values determined by the point-quadrat. In most cases, the corrected percentages closely approached the percentage determined from dry weights.

Similar results to those just discussed were obtained by Arny (1944), Sprague and Myers (1945), and Van Keuren and Ahlgren (1957a and 1957b). Each of these investigators applied correction factors to the point data to adjust for the overestimation of grasses and underestimation of legumes. Sprague and Myers (1945) concluded that inaccurate results would be obtained from the use of a constant for correcting the point-quadrat data due to great fluctuations among plots and variation between dates.

Winkworth (1955) further explains that the two methods (point and weight) measure in different units, and that results obtained by the two methods do not correspond. Correction factors cannot be used since the differences vary with the growth stage of the plants and with the environmental conditions. Goodall (1952) considered the point-quadrat method worthy to be judged on its own merits as an ecological technique, and that its value was independent of agreement with other ecological techniques.

Most comparisons of the point method with dry-weight analysis in terms of botanical composition have been made on the basis of "all hits" or "first hits" by the point-quadrat method. A method relating weight to basal area as assessed by the point-quadrat method has been developed in Canada by Clarke, et al. (1942). Forage yield factors are determined for different species according to their relationship with Stipa comata on a basis of weight per unit of basal area. The method is part of a system used to determine the carrying capacity of native pastures.

Influence of pin diameter

Goodall (1952) demonstrated that pins used in point-quadrat work should be as fine as practicable, and that an optical or sighting apparatus is preferable to a pin where data for percentage cover only are required. An increase in overestimation of percentage cover or percentage basal area is definitely correlated with an increase in pin diameter. Goodall states that the use of a thicker pin is probably less objectionable where the principal interest centers in changes in the vegetation. Winkworth (1955) found that pin size had little effect upon estimates of percentage contribution (composition).

Distribution of points

There has been no standardized practice regarding the distribution of points. For a study on shortgrass vegetation, Ellison (1942) sampled with 400 and 800 points placed equidistant over quadrats measuring 0.5 X 0.5 meter and 1.0 X 0.5 meter. Johnston (1957) examined 1200 points at 1-inch interval along a 100-foot line transect. He used a frame supporting 36 vertical pins placed 1-inch apart. An inclined frame with 20 pins, 1½-inches apart, was used by Mattox (1955) to determine the composition of vegetation on native range in central Montana. The frame was placed at systematically determined intervals along a number of line transects.

Many workers, following the technique of Levy and Madden (1933) have used frames holding ten pins. Blackman (1935) suggested the use of one pin per frame to obtain a more accurate representation of the vegetation and to reduce the bias introduced by the interdependence among pins in a set. These findings have been substantiated by Goodall (1952) and Kemp and Kemp (1956). The latter demonstrated that in one community sampled by 2000 points in random frames of ten points, only one-fourth to one-half as many randomly placed single points, according to species, were required to attain the same degree of precision. Greig-Smith (1957) indicates that plants are so arranged that there is often a pronounced interdependence among pins of the same frame. The accuracy of the data is, therefore, affected and open to theoretical objection because of a lack of statistical independence of the observations.

A further consideration, according to Kemp and Kemp (1956), is that the frame must consist of at least two pins to make it possible to estimate patchiness by comparison of within-frame variability with between-frame variability. It must also be considered that more time is involved in the placement of individual pins at random than in groups even though fewer total points are observed (Goodall, 1952; Kemp and Kemp, 1956).

When changes in the vegetation are the main subject of interest, Goodall (1952) suggests that fixed positions be marked for point-observations on successive occasions.

Number of total points

The number of point-quadrats required for adequate sampling depend upon the nature of the vegetation, the percentage cover, the accuracy desired for various classifications of the plants, the variety of species present, and the part of the plant on which hits are to be recorded. Levy and Madden (1933) considered 100 points as sufficient for charting the dominants of a pasture sward, but 400 to 500 points were needed to record the less abundant species. On a regional grassland survey in South Australia, Crocker and Tiver (1948) concluded that 300 to 500 points per field gave a satisfactory estimate of the dominants and a reasonably good analysis of the less important species. More than 500 points gave little decrease in variability and 100 points were considered inadequate for even broad surveys.

In a study to determine species composition of a seeded sward, Leasure (1949) found that 30 points would accurately estimate the percentage composition of a 1-square yard sample plot. Working in 300 X 500 foot sampling areas of mixed grass range in North Dakota, Whitman and Siggeirsson (1954) determined that a minimum of 1400 all-contact points or 3600 basal-contact points were needed to estimate the three major components of the vegetation with sampling errors of 10 percent or less. The basal-contact points picked up less than half as many species of the total listed as did the all-contact points.

Clarke, et al. (1942) concluded that under the conditions of the native pastures in the Prairie Provinces of Canada, from 400 to 1500 points (basal hits) were needed to determine the dominant species and their relative importance. To determine cover of the less abundant species, 2400 to 4000 points were required. These values were obtained by calculation of the standard error of the mean and reducing it to less than 10 percent of the mean for the first condition and less than 5 percent for obtaining the more detailed information. The analyses showed that where grass cover was about 5 percent, some 3600 points should be tested, but only 2400 points were needed where the cover was approximately 18 percent.

Johnston (1957) conducted a methodology study on four sites in southern Alberta, and suggested the number of points necessary to sample the dominant species at each site to within plus or minus 10 percent of the mean, using basal area as the criteria of measurement. The number of points required at each site varied according to the type of vegetation encountered.

Variation among observers

Goodall (1952) found the personal differences which existed among observers, while not large, made it desirable to use the same observers throughout a series of studies in which comparisons were made. Ellison (1942) went into considerable detail to point out the several sources of human error which add to the variability in obtaining ecological data by different methods and by different observers. Corby (1950, cited by Brown, 1954) found the point-quadrat method to be less objective than is usually claimed, there often being significant differences between analysts.

Johnston (1958) noted some differences in estimates of basal area among observers when using the vertical point-quadrat on several range types in southern Alberta. His data did not indicate any consistency toward either overestimation or underestimation of basal area on the part of individual observers.

Applied modifications of the point-quadrat method

Evans and Love (1957) described a step-point method as used to sample irrigated pastures and improved ranges in California. Botanical composition was determined from 300 to 500 schematically placed individual point readings per acre. The sampling pin was lowered to the ground guided by a definite notch in the toe of the sampler's boot. Estimates of total ground cover were made with the use of a square-foot frame partitioned into four, 6-inch squares. Total ground cover and composition data determined from the step-point method were considered comparable to data determined by the point frame method using ten points per frame and a total of 500 points per acre of range. However, the time required to sample an acre of range with the step-point method was about one-sixth to one-eighth as much as with the point frame.

A systematic sampling process described as the wheel-point method has been developed in South Africa by Tidmarsh and Havenga (1955) for determining basal area of low growing vegetation. A rimless wheel, running on the points of its spokes, is drawn over the area to be surveyed. A record is kept of the plants within whose basal area the sharpened point of a designated spoke reaches the ground. A critical review was made of the wheel-point method by Goodall (1956).

Evanko and Peterson (1955) estimated the kind and amount of soil surface cover on forest ranges by means of a wire with ten beads of solder affixed at 5-centimeter intervals. The wire was stretched lengthwise through the center of a 2 X 5 decimeter plot. The sampling points were taken immediately beneath the juncture of each solder bead and the wire.

Appraisal

In general, the appraisal of the point-quadrat method and its modifications as an analytical tool has been favorable. Crocker and Tiver (1948) gave the following reasons for using the point-quadrat method in regional grassland surveys in South Australia:

> "(a) It permits quantitative determination of botanical composition in terms of cover which is probably the most suitable ecological expression for recording change; (b) It is objective and more rapid than other methods of equal reliability and objectivity; (c) It provides for randomisation and ample replication of sampling; (d) It also permits a close examination of all or almost all species present, and gives plenty of scope for observation; (e) It does not depend entirely on random distribution of species for its usefulness and (f) It does not in any way interfere with the vegetation."

Goodall (1952) states, "....one need be in no doubt that the method will in future serve ecology even better than it has done in the past."

Loop Method

The 3/4-inch loop was developed by the Forest Service as the measurement device for the 3-step method which is used to determine trend in range condition on national forest rangelands (Parker, 1951). The 3/4-inch loop represents a compromise between the point-quadrat and a plot of larger dimensions. The close scrutiny to determine a hit as with the point-quadrat method is not required and the error associated with visual estimates of basal area or cover of plants in a large quadrat or plot is reduced. The small size or area of the loop reduces to a low level the probability of the occurrence of more than one species within the loop. Because the loop has area it is expected that the relative number of "hits" recorded on vegetation will be greater for each loop than for each point-quadrat.

In use, the 3/4-inch loop is attached to the end of a long wire shank. The loop is lowered to the ground surface at specific intervals along an established transect. Whatever is encountered within the area of the loop is delineated and recorded according to a prescribed classification. Depending upon the type of vegetation and information desired, measurement may be made either on the basal portion or on the crown spread of plants (Parker, 1951).

Much of the literature pertaining to the loop method describes improvements in the technique or reports on tests of adaptability. Short (1953) described and illustrated an improved tape holder and an improved loop with an offset handle. Driscoll (1958) described a modification in technique for measuring ground cover on permanent plots. A thin, narrow board is oriented across the center of a circular plot and supported on each end with chaining pins. Notches are cut at equal intervals along one edge of the board to guide the wire shank of the loop as it is lowered to the ground surface.

An evaluation of the loop procedure was made on salt desert shrub range in southern Idaho (Sharp, 1954). Close agreement was generally obtained by three observers although some individual differences did occur. The method was considered reasonably well adapted for obtaining quantitative records of vegetation and other site factors especially if good techniques were used and standards of measurement clearly defined.

Production of Clipped Vegetation

Brown (1954) lists four general procedures for carrying out an analysis by weight. The first procedure listed is the one that was used in the study reported on by this paper. By this procedure each species of the vegetation is clipped separately and weighed. This method is considered to be the most accurate and critical one for analyzing pasture composition and productivity. This method of separating and weighing clipped vegetation has also been called percentage productivity, dry-weight analysis, list-weight, and weight-list (Brown, 1954).

Time of clipping

Annual production of native vegetation is generally determined from sample plots clipped subsequent to the period of major plant growth. This procedure best estimates the production of species completing their major growth by mid-summer unless fall regrowth occurs. Production of species making their major growth during the summer may be less accurately estimated by one clipping since regrowth may occur when these species are grazed during the summer.

To determine forage production on mixed prairie range in South Dakota, Van Dyne (1956) and Lewis, et al. (1956) clipped plots in a series of temporary exclosures. Plants were clipped on three different dates. The first two clippings were made during the growing season, and the last clipping was made after the growing season. All species were clipped and sacked separately, oven dried, and weighed to 1/100 of a gram.

The following clipping procedures have been established by the tri-state regional project contributing to W-25 (Tisdale, et al., 1958). The first clip of a two period clipping pattern is to be made after Poa secunda has produced inflorescences but before its leaves begin to dry. The second clip is to be made after Agropyron spicatum heads are fully developed but prior to shatter. At each clipping all species approaching maturity will be clipped.

Size, shape, and number of sample plots

Some of the important items to consider when clipping sample plots of vegetation are the size, shape, and number of plots which are required to adequately sample a given pasture or type of vegetation. A considerable amount of literature has been published in the field of agronomic research with reference to optimum plot number, size, and shape. Only a limited amount of research has been involved with the most efficient size, shape, or number of plots for sampling production of rangelands.

Information obtained from a sampling study on sagebrush-grass range revealed that, statistically, the smaller the sampling unit the more efficient it is per unit of area (Pechanec and Stewart, 1940). From this study, it was also found that long narrow plots were only slightly more efficient than square ones.

Burlison (1949) evaluated the relative efficiency of various sizes and shapes of plots in sampling Palouse bunchgrass range. Oblong plots were found to be more efficient than square or circular plots of equal area. Plot efficiency was reduced by increasing the width of plots from 0.5 meter to 1.0 meter.

An increase or decrease in sampling error was shown by Costello and Klipple (1939) to be proportional to the square root of the number of plots. They also concluded that different vegetational types require different sampling intensities to secure a given degree of accuracy and that little relationship exists between the area of a vegetational type and the number of plots required to sample it with a given degree of accuracy.

Campbell and Cassady (1949) and Frischknecht and Plummer (1949) have suggested the use of sample plots 9.6 square feet in area. Not only did they find this a suitable size for their respective sampling problems, but it is also convenient in that the harvested weight of the vegetation in grams can be multiplied by ten to obtain pounds per acre. Campbell and Cassady used a square frame for sampling vegetation on southern forest ranges. Frischknecht and Plummer used a circular hoop 42-inches in diameter in the Great Basin area of Utah.

Theoretically, an oblong plot has an advantage over a square one because plant societies exist roughly in circles and there is more likelihood that a long plot will cut into more societies than would a square one of the same area. A long plot will also encounter a greater number and variety of species (Davies, 1931, cited by Brown, 1954). For a given area, a rectangle has a greater length of border than does a square. Therefore, a greater sampling error due to "edge effect" (the greater ratio of border to area) is prevalent in a rectangle, especially when clipping the vegetation. A circle has the advantage of having the least ratio of border to area (Brown, 1954).

Of those concerned with agronomic experiments, Christidis (1931) was one of the first to seriously analyze the efficiency of plot shape. On the basis of his own trials and the work of others he concluded that a long, narrow plot secured the most uniformity among individual plots. Use of the rectangular plot was also recommended by Peterson and Chamblee (1955) on sampling forage crop mixtures and by Robinson, et al. (1948) as a result of investigations of plot technique with peanuts.

Bormann (1953) recommends that some form of rectangular plot should be used with the longest axis of the plot crossing any observed contour, or soil or vegetational banding. Smith (1938) used data from blank experiments with wheat to show that variability of yield decreased as size of sample plots increased. He found no consistant change of variability relative to shape of plots.

Location of plots

An experiment on sampling technique was conducted on mixed prairie range by Hanson (1934). A schematic design for clipping subplots within a series of larger plots was considered as a more reliable system for estimating production and composition than was the use of scattered quadrats.

Pechanec and Stewart (1940) explained that representativeness is achieved only when the element of random selection is included in the sampling procedure. They suggested that in selecting a sampling unit for field use an effective balance must be struck between statistical efficiency and such practical factors as amount of work and accuracy of observation. Their method of subdivided random sampling which incorporated the use of systematically placed plots within randomly selected units was considered satisfactory for their purposes.

Use of statistical variance

For much of the data obtained from sampling studies, the various authors have used statistical variance, or a variability value computed from variance, to determine the most desirable or efficient size, shape, or number of plots. In relation to this subject, Poulton (1948) states,

> "Here we have the key to one reason why better methods have not been more widely accepted. We tend to favor a method which apparently reduces variability. We are inclined to interpret greater variability as indicating faulty methodology, overlooking the fact that it actually may be caused by more accurate measurement of population characteristics resulting from the use of a more efficient method."

Comparison of Methods

Comparisons made of the three methods--point-quadrat, loop, and weight of clipped vegetation--are relatively few. It is, of course, necessary to have a common criteria by which to compare any measurement method. Attempts to compare percentage composition determined by the point-quadrat method with percentage composition determined by weight have been discussed. Percentage composition would appear to be one of the few criteria by which the three methods could be compared. Apparently, few studies have been made to determine if a relationship exists between percentage composition as determined by the loop method and by weight of harvested vegetation.

Johnston (1957) made a comparison of the line interception, vertical point-quadrat, and loop methods on grasslands in southern Alberta. The line intercept encountered the most species, the loop the least, and the point-quadrat was intermediate. The loop method gave the most variable data in estimating basal area and gave extremely higher estimates of basal area. Only where Bouteloua gracilis was dominant did the loop appear useful for estimating basal area. The point-quadrat method gave the least variable data and a somewhat higher estimate of basal area than did the line intercept method. The line intercept was the most time-consuming and the loop method the least time-consuming. All factors considered, the author rated the point quadrat as the most satisfactory of the three methods for characterizing the vegetation of the range types under study.

A comparison study of the line intercept method and the point-quadrat method was made on mixed grass range by Whitman and Siggeirsson (1954). All-hits and basal-hits by the point-quadrat method were considered. Sampling errors were greatest for basal-hits and least for the line intercept. The line intercept and all-hits rated about equal in detecting the species present on the study area; relatively fewer species were recorded by basal-hits. Point contacts produced an over-all higher density value for most species and groups of species than did the line intercept. Johnston (1957) explains that, theoretically, the basal area determined by point contacts should be less than the area determined by the line intercept. In Johnston's study, the diameter of the pin was considered to be the cause for obtaining a greater than expected number of hits by the point-quadrat method.

Grazing and Ecological Studies on Areas Similar to the Study Area

Literature which pertains specifically to the response of vegetation to protection from grazing by sheep on ranges in central Montana is extremely limited. Much information, however, can be applied from ecological and grazing studies made in nearby or more distant areas with similar topographic, edaphic, climatic, and vegetational features. Since the vegetation in central Montana is chiefly a blending of mixed prairie and Palouse prairie types, grazing and ecological studies conducted on these two types shall also be considered.

Grazing studies with sheep

Studies of the effect of heavy, conservative, and light stocking of sheep on ranges in eastern Montana were made by Woolfolk (1949). The dependable perennial grasses produced considerably more herbage on the conservatively and lightly stocked ranges. Six years of heavy grazing by sheep caused a shift from dominance of perennials to a dominance of low value annual species.

Several brief references were made by Heady (1950) to the effects of grazing by sheep on Agropyron spicatum and several other species in a number of Agropyron spicatum communities in a belt extending from the northern to the southern border across central Montana. On one area which had been heavily grazed by sheep, the basal area of Agropyron spicatum was much greater than would generally be expected on an over-grazed range. Many of the more palatable plants had been eliminated by spring-fall grazing, and young plants of Agropyron spicatum were absent. Many of the remaining pedestaled plants of Agropyron spicatum were weakened and some had dead centers. Gutierrezia sarothrae was especially prevalent, and an abundance of Phlox hoodii and Oxytropis lambertii had been favored by early use by sheep.

The utilization of Artemisia frigida by sheep on winter range was determined by weight-sampling before and after grazing on a foothill range near Livingston, Montana (Spang, 1954). The plant was considered as choice feed for sheep under the existing grazing conditions.

Teigen (1949) conducted a study on the forage preferences of range sheep on a forest allotment in the Bridger Mountains in Montana. Classes of forage ranked according to abundance were grasses and grass-like plants, forbs, and browse. Sheep selected forbs, grass, and browse in order of preference. Of the grasses present, Agropyron trachycaulum, Festuca ovina, and Bromus marginatus ranked highest in preference by the sheep.

Pechanec and Stewart (1949) discussed the benefits of deferred and rotation grazing by sheep on spring-fall ranges in southern Idaho. They also expressed the importance of proper stocking rates and the dangers of too early use of the ranges in the spring. Ranges improperly managed soon showed a loss of palatable perennial grass and forbs and were eventually invaded by sagebrush and cheatgrass.

Other studies on a spring-fall sheep range near Dubois, Idaho, indicated that heavy stocking in the fall will not markedly affect grass and forb production, but may cause a decrease in the abundance of shrubs (Mueggler, 1950). Heavy stocking in the spring will, however, severely reduce grass and forb production and greatly increase the abundance of undesirable shrubs.

Pechanec (1945) listed a number of indicators of downward trend on overstocked sheep ranges on the sagebrush-perennial grass type in Idaho. The first sign of overstocking became evident within three years after the practice was begun. In order of occurrence, the signs of overstocking were: (1) a decrease in vigor of palatable perennial weeds and finer grasses, (2) an increase in number and size of annuals, (3) a decrease in the vigor of the more robust perennial bunchgrasses, (4) the establishment of numerous young sagebrush plants, (5) the death of portions of perennial weed and bunchgrass clumps, and (6) excessive pedestaling of bunchgrasses on slopes and less favorable sites.

Grazing studies with cattle

The vegetation in five exclosures, fenced for 15 to 26 years, was compared to that on adjacent grazed range on national forest in southwestern Montana (Evanko and Peterson, 1955). The cover and composition of the vegetation varied greatly among the five test areas even though they were located within an area having a 1½ mile radius. Unpalatable forbs and shrubs were more common on the grazed than on the protected counterparts. The total grass cover was slightly greater on the protected areas. Festuca idahoensis provided less cover on the grazed portions of the areas at which it was dominant. A similar trend was noted for Agropyron spicatum. Poa secunda was the only species persistently more abundant on the parts of the area open to grazing.

From their study, Evanko and Peterson concluded that leaf height, basal area of plants, and yield per clump or unit of plant area of important forage species appeared to furnish more reliable and usable criteria for evaluating range condition than did cover estimates.

The combined effects of climate and grazing by cattle upon the basal area of native vegetation was compared on areas protected from grazing with areas subject to grazing (Clarke, et al., 1947). Results of this 12-year study in southern Alberta and southwestern Saskatchewan indicated similar changes in both moderately grazed and ungrazed quadrats, an indication that climatic factors were more responsible for vegetational changes than was grazing. Data from the heavily grazed pastures, however, indicated that grazing was more influential than climate in effecting deterioration of plant cover.

Ecological studies

Wright and Wright (1948) located and analyzed the vegetation on ten different relict areas in southcentral Montana. In some cases, a comparison was made between the relict area and grazed pastures in the same locality. Basal cover of grasses and sedges was estimated in each area by the line interception method, while forbs and shrubs were listed in order of abundance. The vegetation of the relict areas was classified into five types: (1) Festuca idahoensis type, (2) Agropyron spicatum type, (3) Agropyron spicatum-Carex filifolia-Bouteloua gracilis type, (4) Bouteloua gracilis-Stipa comata-Koeleria cristata type, and (5) Bouteloua gracilis-Stipa comata type.

The Festuca idahoensis type occurred in the more mesic portions of the foothills of the intermountain regions; whereas, Agropyron spicatum was dominant in the drier portions of these regions. The two communities are favored by the relatively cool growing season of the intermountain region. Overgrazing has caused Festuca idahoensis to be replaced by Poa pratensis and Phleum pratense on the more moist sites; and by Artemisia tridentata on the deep, well-drained soils in drier regions. As a result of moderately heavy grazing, especially by cattle, Agropyron spicatum has been replaced by Koeleria cristata, Stipa comata, and Poa secunda. More severe grazing usually results in an increase of undesirable shrubs such as Chrysothamnus nauseosus, Artemisia tridentata, and Gutierrezia sarothrae.

The Agropyron spicatum-Carex filifolia-Bouteloua gracilis type is transitional between the bunchgrass zone of the foothills and the mixed grass prairies of the Great Plains, but in the drier phases of southcentral Montana, Koeleria cristata drops out. In the drier phase, Bouteloua gracilis increased in coverage on a grazed pasture and Stipa comata decreased.

Sturm (1954) compared soil cover and percentage composition of species on a relict area in northern Montana with the soil cover and composition of species on a pasture grazed year-long and one grazed only in the spring.