



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

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
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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-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 on 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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AND A STUDY OF THE
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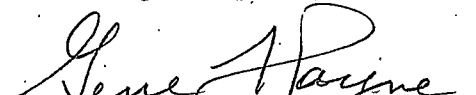
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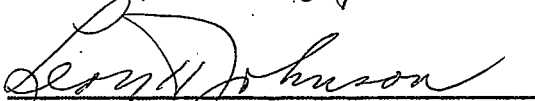
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ABSTRACT

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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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 Zealand, 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 appreci-

ably 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 Army (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 consistent 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. Sam-

pling 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 abun-

dance. 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.

Stipa comata was a dominant grass on the relict and Bouteloua gracilis a subdominant. On grazed range, Bouteloua gracilis became dominant and Stipa comata became a minor species. The relict area was characterized as climax for the shortgrass plains.

Daubenmire and Colwell (1942) found that the most evident effects of overgrazing in the Palouse prairie consisted of the removal of the tall, dominant bunches of Agropyron spicatum and their replacement by dwarf annuals. Poa secunda was only slightly injured by grazing animals and remained as the principal perennial associated with the annuals.

Response of plants to grazing

Reference will be made throughout this thesis to the response of plants to grazing and protection from grazing. The system of classification presented by Dyksterhuis (1949) is frequently used to describe the response of a particular plant species, or group of species, to grazing pressure on the range. Dyksterhuis classed the major plant species as (1) decreaseers: plants which decrease under grazing pressure, (2) increasers: plants which increase under grazing pressure, and (3) invaders: plants which invade under grazing pressure. The use of this classification with its implied meanings shall be used throughout this report.

DESCRIPTION OF THE EXPERIMENTAL AREA

Physical Characteristics

Physiographic features

Central Montana has been described as an area transitional between the main range of the Rocky Mountains and the vast continental slope of the Northern Great Plains. This area consists of frontal ranges, intermountain basins, tablelands, plains, badlands, and eroding stream banks. Geologists believe that the surface features over most of the area have resulted from the mountain-forming upheavals which occurred during Cretaceous and Tertiary periods and from subsequent erosion and deposition of colluvial and alluvial materials (Gieseke, et al., 1953).

Geographically situated in central Montana is an intermountain basin nearly encircled by the Big Belt, Little Belt, and Castle Mountains. This basin, drained by the Smith River and its tributaries, lies entirely within Meagher County. The area of study is located primarily in the foothills and benchlands that lie between the Smith River Valley and the Castle Mountains (Figure 1). The foothills of the Castles are largely short, gravel or stony capped ridges extending out from the mountains between the drainage courses. The grass covered slopes and ridges in the foothills are generally described as gently rolling or sharply rolling. The gravel capped benchlands rising above the Smith River on the east are smooth and gently sloping and range in elevation from 4800 to 5200 feet (Gieseke, 1944).

Soils

The principal soil unit found on the study area is Hilger loam and stony loam, undifferentiated. These dark-brown (Chestnut) soils occupy

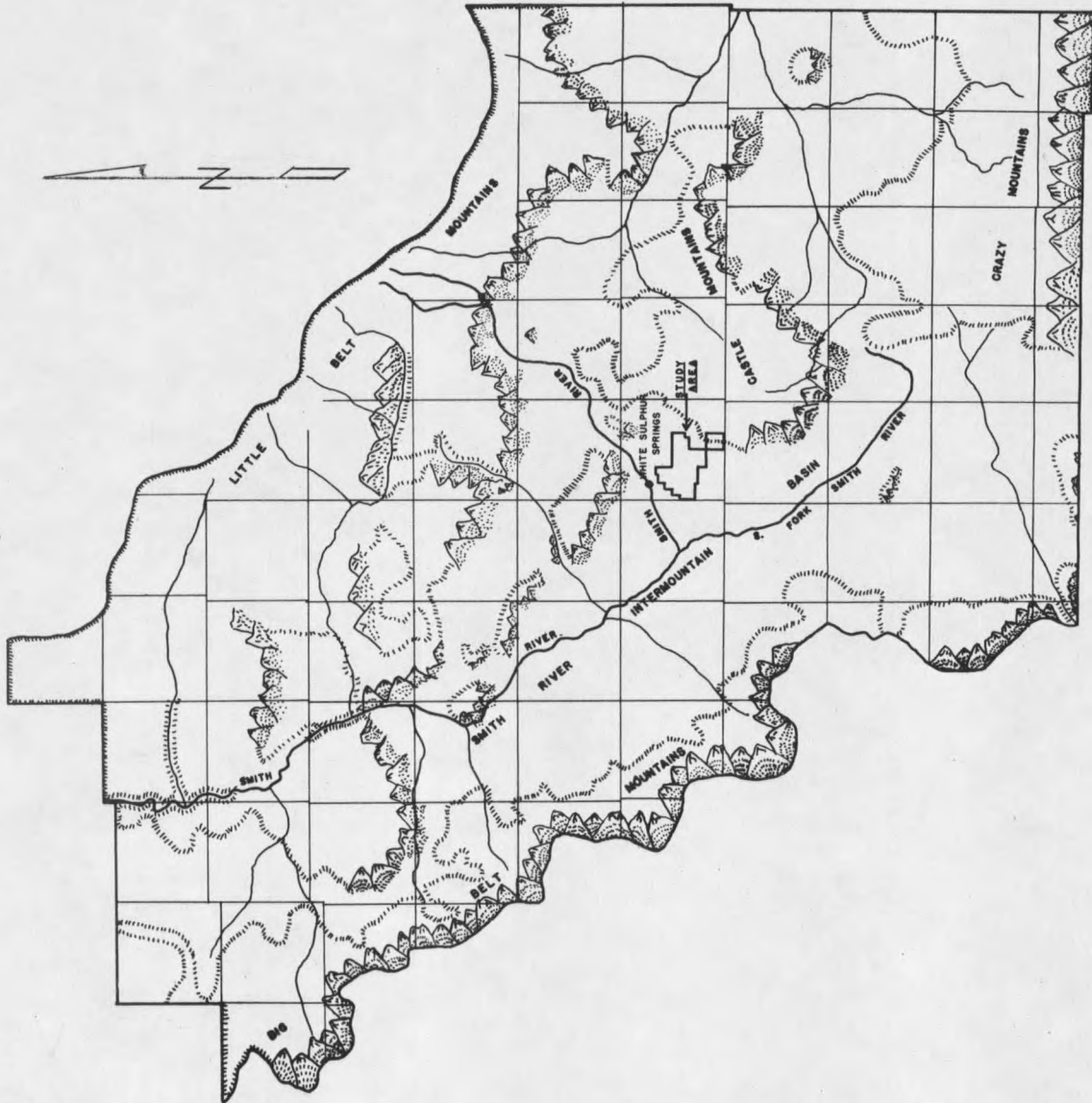


Figure 1. Map of Meagher County, Montana, showing the major physiographic features and location of the experimental area.

moderately to steeply sloping alluvial fans composed largely of gravelly and stony outwash materials derived from igneous and metamorphic rocks. These soils occur at the higher elevations and are mostly undulating to sharply rolling.

Two brown (Brown) soils occur to a lesser extent primarily at the lower elevations on the benchlands. These are (1) Crago gravelly loam and (2) Gilcrest loam and gravelly loam, undifferentiated. The Crago soils are of aeolian origin and underlain with stratified limestone gravel. Many of the Gilcrest soils are now under irrigation (Gieseke, et al., 1953).

Climate and weather

The climate of central Montana is mid-continental. Comparatively low rainfall, great extremes in temperature, many sunny days, and relatively low humidity characterize the intermountain basins. The midsummer temperatures are not oppressive because of low humidity, and the winter cold is sometimes tempered by warm "chinook" winds descending from the north and west. A local influence is exerted by the various mountain ranges and canyons on air drainage and paths of local storms. Consequently, some localized areas are more subject to early and late frosts, hail storms, or summer showers than are other areas only a few miles distant (Gieseke, et al., 1953).

Brisk south to southwesterly winds prevail in the vicinity of the study area. The winds occurring late in winter and in the spring are usually more intense and more constant than during other times of the year. Snow which falls during the winter period rarely lies in place in the lower agricultural and foothill area. The strong winds collect the snow in drifts on the leeward slopes of hills and ridges and in the coulees (Gieseke, et al.,

1953).

The temperature and precipitation information reported is taken from data collected at the weather station at White Sulphur Springs, Montana. The weather station is at an elevation of 5187 feet and located about three miles northwest of the study area. An incomplete weather record exists covering a 43-year period. The reported long-term means, especially for precipitation, may not, therefore, be an accurate indication of average precipitation over the entire 43-year period. In 1945, the Weather Bureau established the normal annual precipitation as 14.18 inches. This value was reported for comparative purposes through 1955. A new long-term annual mean of 18.83 inches was established in 1956; quite indicative of the relatively greater precipitation received during the years 1945 through 1955.

Precipitation data for the period, 1953-1957 inclusive, and long-term means, are shown in Table 1. Parts of the experimental area situated at elevations higher than the weather station would be expected to receive more precipitation than recorded at the weather station. The increased precipitation may, however, be quite small. For southwestern Montana, the average increase in precipitation is 2.5 inches per 1000 feet of rise in elevation (Baker, 1944). Temperature data for the same period are given in Table 2.

Total precipitation for 1957 was nearly equal to the long-term average. Intense rains of short duration occurred during late August and early September. These rains were frequently accompanied by hailstorms. The below average annual temperature for 1957 was primarily due to the colder than average temperatures during January. The number of days between dates of a temperature of 32 degrees or below was 110. During the 9-year period, 1948-

Table 1. Precipitation data from the White Sulphur Springs weather station in Meagher County, Montana. 1/

Month	Long-term means <u>2/</u>	Total Precip. 1957	Total Precip. 1956	Total Precip. 1955	Total Precip. 1954	Total Precip. 1953
January	1.00	.95	.60	.82	2.45	1.11
February	1.15	.90	.48	1.41	.90	1.35
March	1.73	1.71	.82	3.25	1.83	.70
April	1.38	.83	1.57	3.15	.87	1.27
May	2.35	2.41	2.19	2.65	1.22	3.47
June	3.41	4.92	1.13	2.73	3.13	3.31
July	1.39	.79	1.63	2.40	1.32	.39
August	1.36	2.35	1.46	1.37	1.13	1.00
September	1.52	.84	.61	1.22	1.52	.73
October	1.17	1.68	1.42	.88	.46	.39
November	1.16	1.06	.70	1.94	.13	.15
December	1.21	.53	.45	2.20	.26	1.43
Annual	18.83	18.97	13.06	24.02	15.22	15.30

1/ U. S. Dept. Commerce, Weather Bureau. Climatological Data, Montana, Annual Summaries 1953, 1954, 1955, 1956, 1957.

2/ Established in 1956.

Table 2. Temperature data from White Sulphur Springs weather station in Meagher County, Montana. 1/

Month	Long-term means <u>2/</u>	Avg. temp. 1957	Avg. temp. 1956	Avg. temp. 1955	Avg. temp. 1954	Avg. temp. 1953	Number of days in 1957 between dates with:
January	20.2	8.8	19.2	19.8	16.9	32.7	24 degrees
February	23.1	23.7	18.8	18.4	34.2	27.4	or below
March	28.4	29.0	29.0	20.5	22.5	32.8	160
April	40.9	39.0	38.4	36.3	37.8	35.7	
May	50.2	51.1	49.5	47.2	49.3	44.1	28 degrees
June	56.6	56.0	59.8	55.4	52.6	54.9	or below
July	65.5	64.9	64.3	63.3	66.2	65.4	145
August	63.6	63.4	59.5	65.1	61.6	65.6	
September	53.6	53.0	54.9	52.1	53.7	56.2	32 degrees
October	44.3	40.5	43.7	46.5	41.9	47.7	or below
November	31.5	29.4	30.3	19.9	39.3	38.5	110
December	24.1	30.7	28.2	20.0	26.8	27.2	
Annual	41.8	40.8	41.3	38.7	41.9	44.0	

1/ U. S. Dept. Commerce, Weather Bureau. Climatological Data, Montana, Annual Summaries, 1953, 1954, 1955, 1956, 1957.

2/ Established in 1956.

1956 inclusive, the average number of days between the 32-degree dates was 77. The shortest period of 23 days occurred in 1955.

Vegetational Characteristics

The native vegetation encountered within the study area is typical of the intermingling of the vegetational types of the Palouse prairie and the mixed prairie of the plains. Dominants of both of these grassland climaxes are prevalent in the study area (Weaver and Clements, 1938; Wright and Wright, 1948; Daubenmire, 1940; Heady, 1950).

Dominant grasses of the Palouse prairie that commonly occur on the study area include Agropyron spicatum and Festuca idahoensis. The latter species occurs on the more mesic north- and east-facing slopes at the higher elevations. Agropyron spicatum is most common on the drier sites and on south- and west-facing slopes. Grass dominants of the mixed prairie include Stipa comata, Agropyron smithii, Koeleria cristata, and Bouteloua gracilis. Other mixed prairie species common to the area of study are Calamagrostis montanensis and Carex eleocharis. Two grass species common to both of the grassland climaxes are also present. These are Poa secunda and Poa cusickii.

Some forbs that occur most frequently over the study area include Phlox hoodii, Astragalus spp., Chrysopsis villosa and Sphaeralcea coccinea. Other forb species present include Oxytropis sericea, Solidago missouriensis, Artemisia ludoviciana, Senecio canus, Paronychia sessiliflora, Erigeron spp., Lupinus spp. and Antennaria spp.

Two half-shrubs, Artemisia frigida and Gutierrezia sarothrae are common over much of the study area. Major shrub species occurring on the area are Artemisia tridentata, Artemisia cana, Chrysothamnus nauseosus and C. viscidiflora.

diflorus. Selaginella densa, a heterosporous plant belonging to the subdivision Lycopsidea, is abundant over much of the area.

A listing of the species encountered on the experimental sites is presented in Appendix Table I by latin and common names.

EXPERIMENTAL PROCEDURES

Location of Sites, Exclosures, and Line Transects

The field investigations were conducted on the Shaw Ranch 1/ near the town of White Sulphur Springs. A lease on the ranch had been acquired by the Montana Agricultural Experiment Station for experimental studies with range sheep. In September, 1953, five sites on the ranch were selected on which the detailed investigations were to be conducted. The five sites varied from one another with respect to physiographic, edaphic and vegetational characteristics. The five sites shall be referred to by the Roman numerals, I, II, III, IV, and V, throughout this report.

At each site, two adjacent areas (to be referred to as "locations" to delineate them from the "sites") were selected by visual observation for their similarity of slope, exposure, soils, and vegetation present. On one of the locations at each site a permanent range exclosure was constructed in September, 1953. Following construction of the exclosures, a group of five permanently marked line transects was established inside of each exclosure. On the other selected location at each site, a second group of five transects was similarly established and permanently marked. The latter "outside" locations were subject to seasonal grazing by sheep until May, 1957, when, prior to current season grazing by livestock, a temporary fence was constructed around each of the "outside" group of transects (Figure 2).

The line transects within the 75-foot square exclosures were each 50 feet long and placed in a parallel series with approximately 12 feet between them (Figure 3). No transects were, at any point, less than approximately

1/ Now the property of R. Bailey of White Sulphur Springs, Montana.

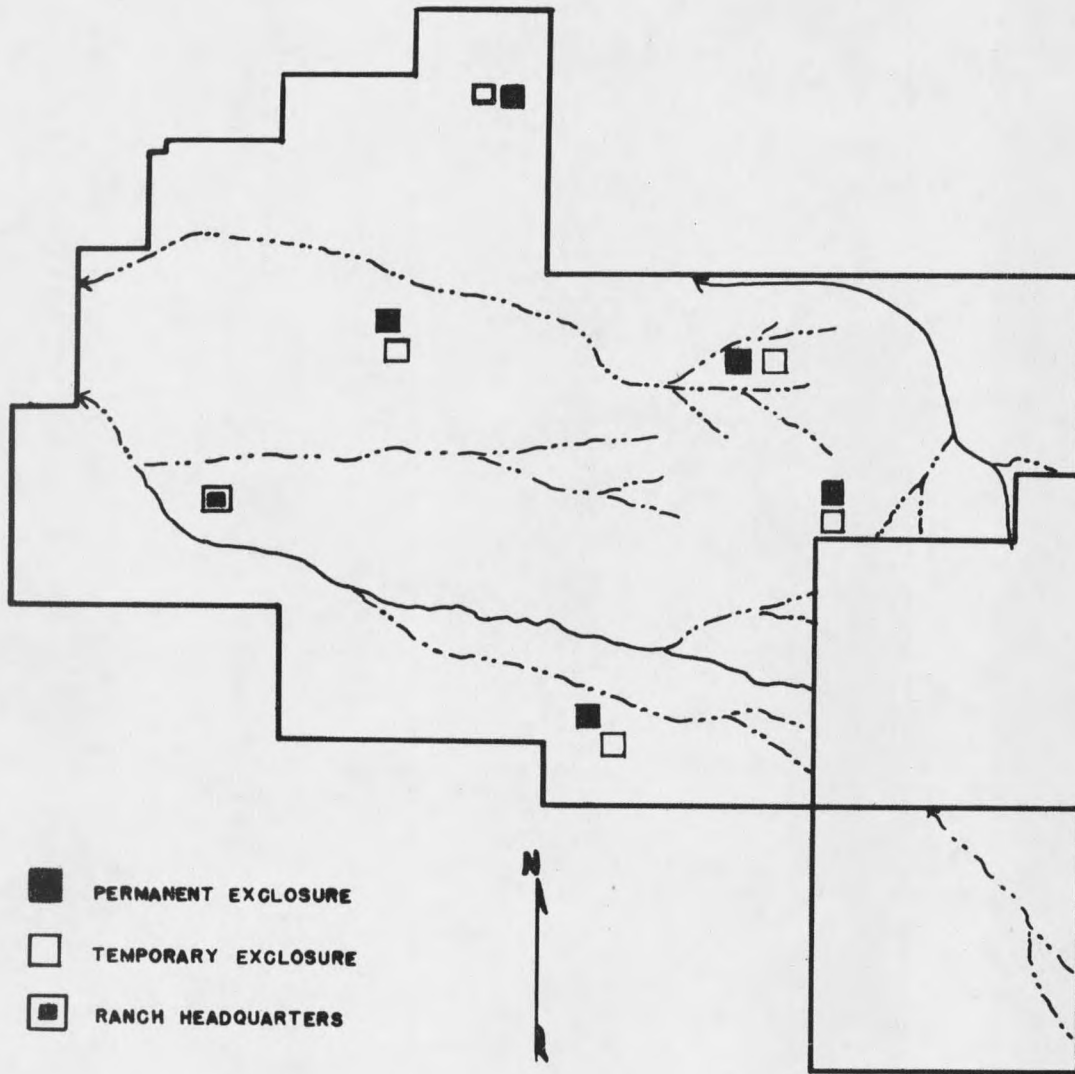
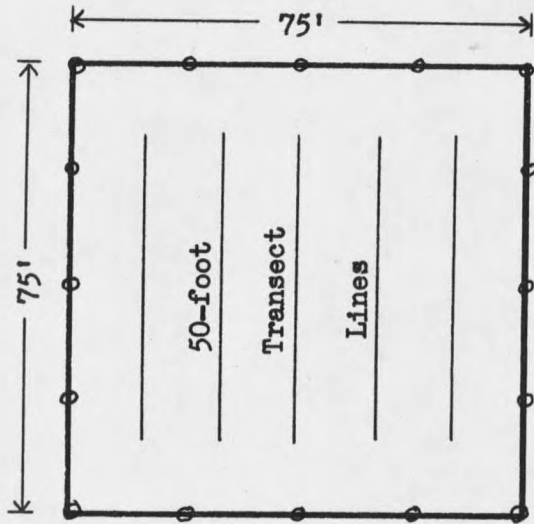
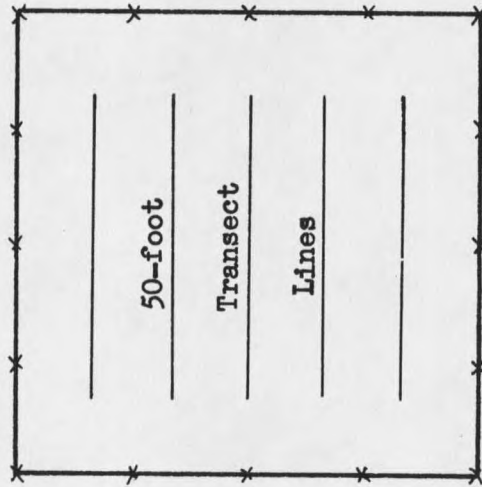


Figure 2. Map of the experimental area showing location of the enclosures.



Permanent Enclosure "Inside"
(Constructed 1953)



Temporary Enclosure "Outside"
(Constructed 1957)

Figure 3. Schematic diagram of a typical study site with enclosures and line transects.

12 feet from the enclosure fence.

Hereafter, the terms "inside" and "outside" may be used to denote the location of the permanent and temporary enclosures, respectively. Reference to these locations may also be made as non-grazed and grazed, denoting the type of grazing treatment prevalent during the period 1953-1957, inclusive. When referring to work done in 1957, the term "enclosure" will include both permanent and temporary enclosures, unless otherwise specified.

The permanent enclosures and line transects were established primarily as a means for studying the response of native vegetation to protection from grazing livestock. A determination of such effects were planned to be made from subsequent periodic observations and botanical analyses of the vegetation.

Analyses of the Vegetation

1953 point-quadrat analysis

The first detailed analysis of the vegetation was accomplished in September, 1953, by the point-quadrat method. Basal coverage and composition were estimated from a number of points along the ten transects at each of the five sites. The point apparatus used was an inclined frame containing 30 pins spaced one-inch apart (Figure 4). The pins were sharpened to a point on the lower end. Twenty consecutive placings of the frame were made along the edge of a steel tape tightly stretched between two stakes. Thus, a total of 600 point contacts were recorded along each 50-foot transect, totaling 6000 points at each site. On the basis of studies conducted in Canada (Clarke, et al., 1942) 6000 points were considered adequate for a reliable estimate of basal cover and composition of the vegetation at each

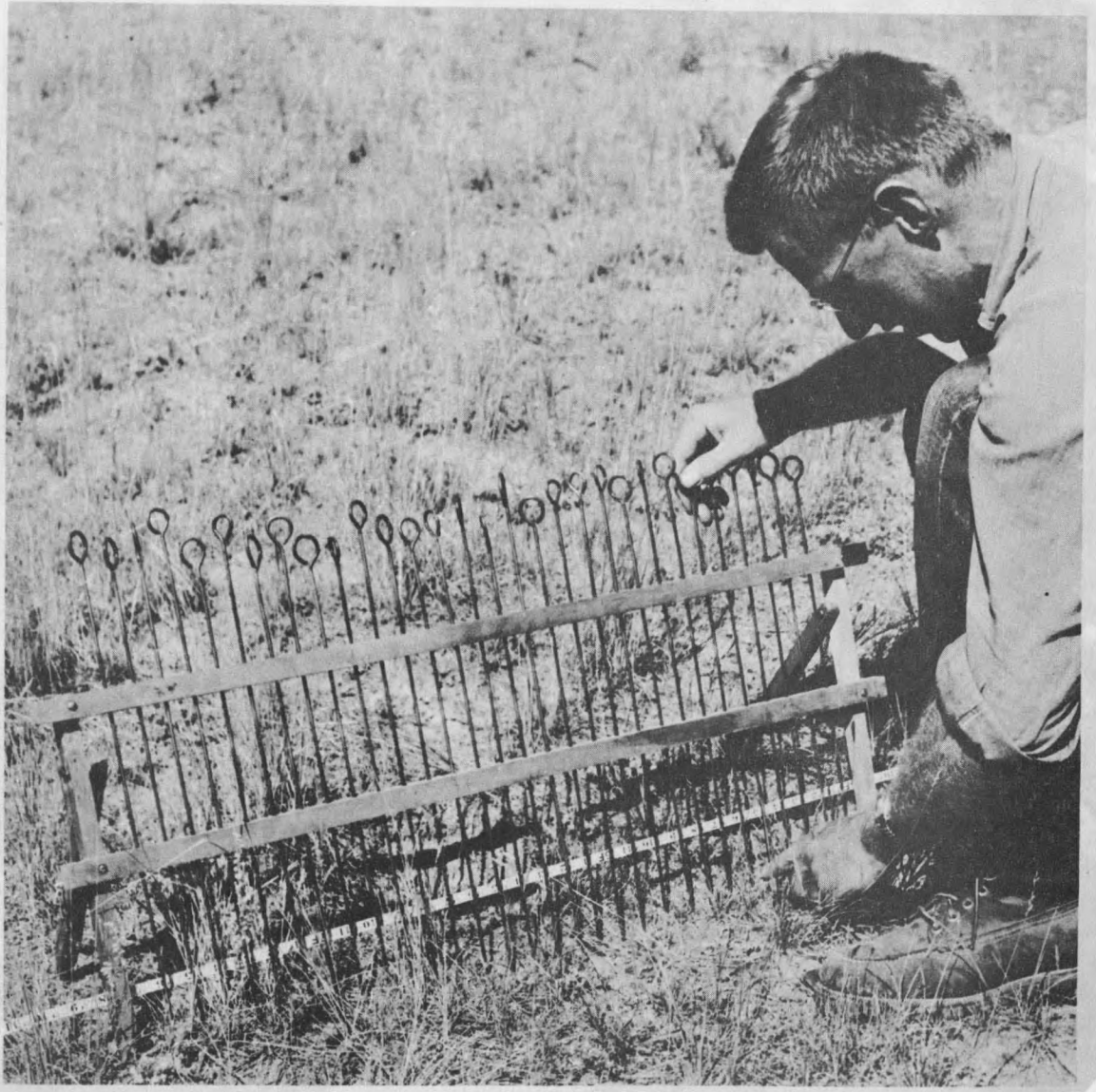


Figure 4. The point analysis frame used to estimate basal area and composition of the vegetation. The frame holds 30 pins which are spaced 1-inch apart. A total of 600 point readings were taken at 1-inch intervals along a 50-foot transect.

of the sites.

Contact of each point at the soil surface was recorded according to the item "hit". Basal "hits" were recorded on the stems of forbs, sod-forming grasses and sedges, or the crown of bunchgrasses. Hits on litter and bare ground, including rocks, were also recorded. An exception to recording only basal hits was made for shrubs and several mat-forming forbs. In recording hits on shrubs, the technique proposed by Coupland (1950) was employed. He proposed that contacts of the pins with the branches and foliage of shrub species should be recorded since the influence of shrubs on the habitat was considered to be more important than indicated by their basal areas. Hits on the foliage of mat-forming forbs such as Phlox hoodii, Antennaria spp., Astragalus gilviflorus and Selaginella densa were recorded since it was difficult to determine exactly the basal portion of these species. The point apparatus used in this study is similar to the one described by Mattox (1955), and the procedures for reading and recording hits are similar to those described by Johnston (1957). Tabulated results of the 1953 point analysis are presented in Appendix Table II.

1957 point-quadrat analysis

A subsequent point analysis along the line transects was conducted in August and September, 1957. The same apparatus and procedures as previously described were used except for several alterations in the recording of hits. Hits on rock, bare ground, and lichens were recorded separately at all sites. Due to an accumulation of sheep manure within the permanent enclosure at site IV, hits on the manure were recorded separately from hits on litter. A comparison of the amount of manure inside, with the amount outside

of the permanent enclosure, appeared of interest. A tabulation of the 1957 point analysis is presented in Appendix Table III.

Loop method

An analysis of the vegetation was made in 1957 by the loop method (Parker, 1951). The 3/4-inch loop readings were taken at 6-inch intervals along each 50-foot transect. A total of 100 readings per transect or 500 per enclosure were obtained. The loop was designed after the one described by Short (1953). The loop was placed so that its center was directly beneath the edge of the tightly stretched tape (Figure 5).

An observation and record was made of whatever occurred within the loop at the ground surface. If two or three species occurred within a loop, each species was given a value of one-half or one-third of a hit. As with the point method, aerial hits on shrubs and mat-forming forbs were recorded. When no vegetation appeared within the loop, a decision was made as to what characterized the loop. If more than half of the loop area was estimated to be covered with litter, it was recorded as such. Lichens were also recorded when they occupied over one-half of the loop area. This same procedure applied to hits on sheep manure at site IV. Selaginella densa, however, was recorded when present within the loop in any amount. Hits on rocks approximately 3/8 to 1/2 inch or more in diameter were recorded as "rock", whereas hits on rocks of smaller size were classed as bare ground. Tabulated results of the loop analysis are presented in Appendix Table IV.

Forage production

An estimation of forage production was determined from clipped plots. The grass, sedge, and forb components were clipped as close to the ground as

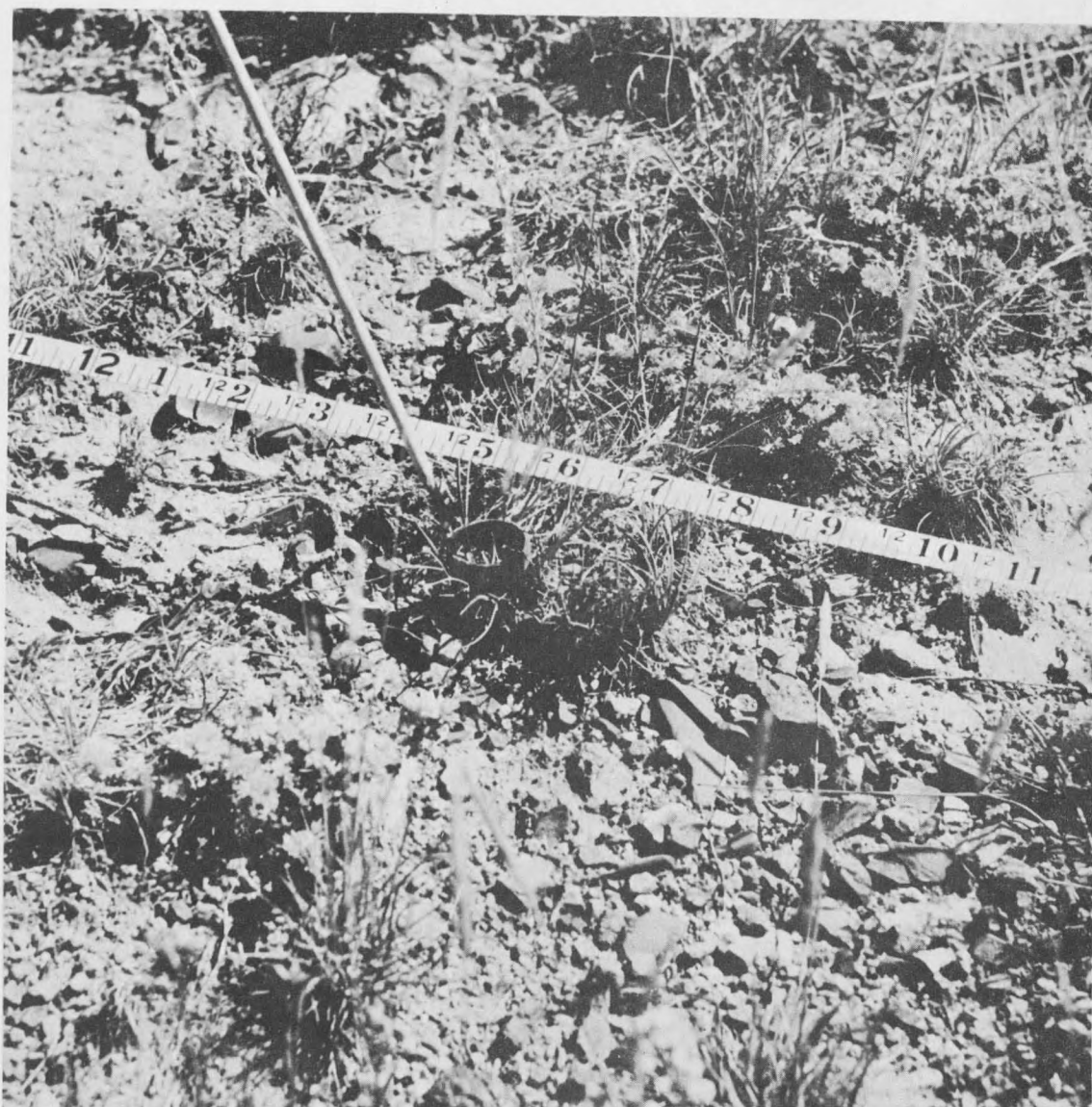


Figure 5. The 3/4-inch loop used to estimate composition of the vegetation. Loop readings were made at 6-inch intervals along a 50-foot transect.

possible and the current year's growth was removed from the shrubs and half-shrubs. Standing dead material was removed as completely as possible from the clippings in the field.

The harvested plant materials were permitted to air dry at room temperature and humidity for approximately a two-month period. All samples were then placed in an electric drying oven for a two-hour period at 105° C. and subsequently weighed to the nearest 1/100 of a gram. These samples shall hereafter be referred to as "oven-dry."

Forage production in 1953 was estimated from two, 9.6-square foot plots selected from among each group of transects. Weights in grams were recorded for Agropyron spicatum, other grasses, Artemisia frigida, shrubs, and forbs. Production data from 1953 are presented in Appendix Table V.

The forage production in 1957 was estimated from four, 1' X 6' plots clipped within each enclosure. Each enclosure was subdivided into four columns delineated by the five line transects. Each column was further subdivided into 24 plot positions. From each column of 24 plot positions one plot position was randomly selected in which the 1' X 6' plot was centrally placed. The vegetation was clipped by species and oven-dry weights determined for each species. The undecayed litter or mulch lying within each plot was also carefully collected and weighed. At site IV, sheep feces were also collected separately. Production data for 1957 are presented in Appendix Table VI.

Personnel

The majority of the work involved in collecting the data for the study was performed by two men. The 1953 data were collected by different observ-

ers than was the 1957 data. In 1957, all of the analyses by the point-quadrat method were performed by the same observer with the second man functioning as recorder. The two men then switched duties so that the second man made all of the observations by the loop method. Some of the bias resulting from familiarity with the vegetation along a given transect was thereby eliminated from the loop analysis.

Soil Sampling

Soil samples were taken in 1957 from four randomly selected locations within each enclosure and composited into one representative sample for the enclosure. The samples were taken from the zone of greatest root concentration which approximates the A horizon in the study area.

An excavation was made between the enclosures on each site to facilitate an examination of the soil profile (Figure 6). The thicknesses and depths of the A and B horizons were measured as was the depth at which effervescence with dilute hydrochloric acid was first detected. Mechanical analyses were performed on the composite samples and on those taken from the A and B horizons. The mechanical analyses were conducted by the hydrometer method of Bouyoucos (1936).

Grazing Patterns

No intensity-of-grazing records are available for the period covered by the study. Sheep were grazed on the ranch area primarily during the spring, fall, and winter, except during the summer of 1956, when part of the sheep band was left on the ranch. The movement of the sheep was controlled by herding. Grazing was considered to have been moderate over most of the ranch during the period of the lease, but lighter or heavier use probably

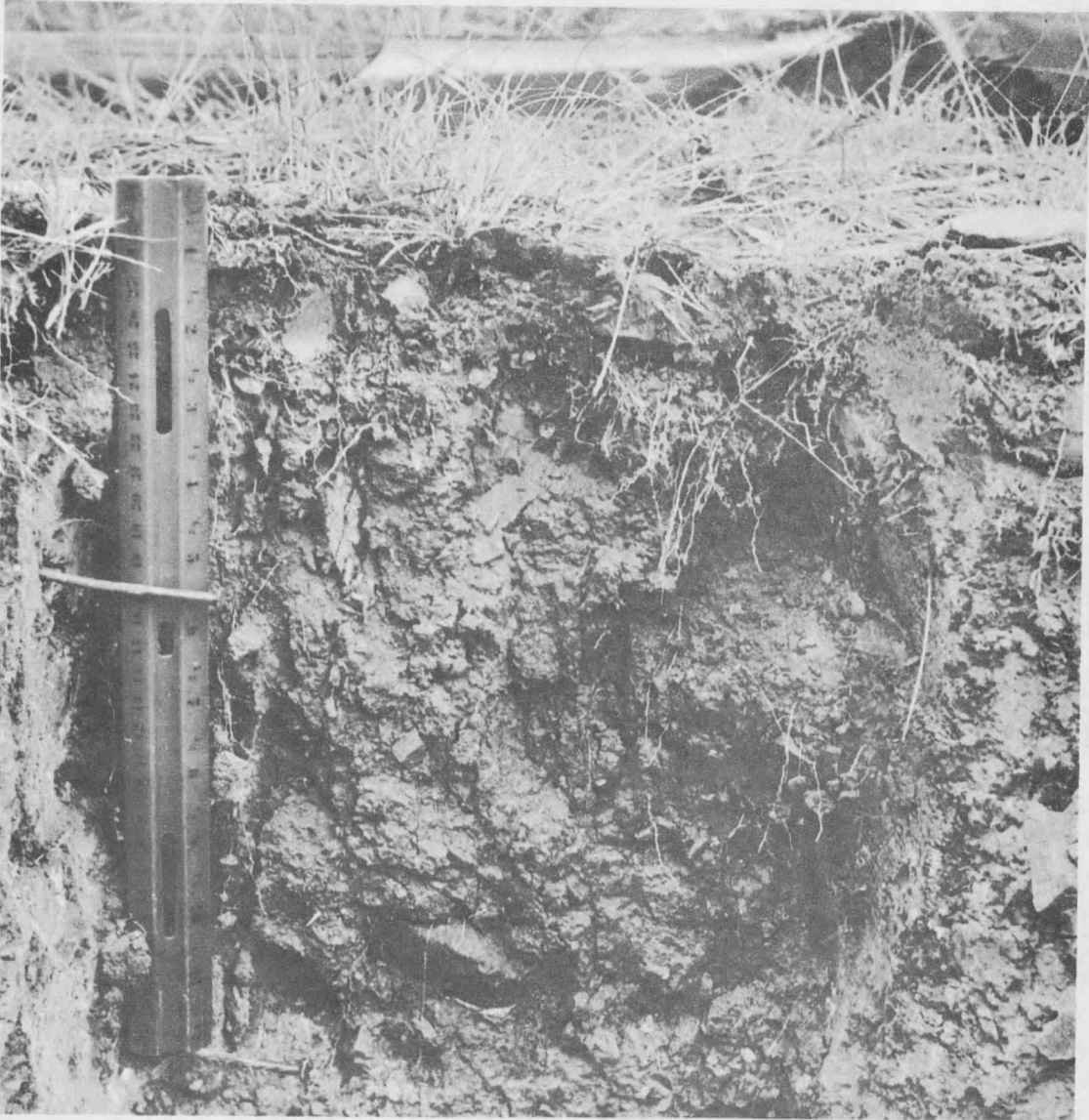


Figure 6. Excavation showing profile of the soil at site II. Horizon boundaries are marked by the nails placed by the ruler. The excavations were made between the permanent and temporary exclosures at each site.

occurred on some localized areas. The most intensive grazing probably occurred on the windswept ridge tops of the sections of the ranch that were sharply rolling, especially during the winter. Little is known by the writer about the history of grazing on this ranch prior to the lease by the Montana Agricultural Experiment Station. Grazing with both sheep and cattle was known to have been practiced for several years immediately prior to the lease.

RESULTS AND DISCUSSION

Physical and Vegetational Characteristics of the Experimental Sites

All of the variations of the physical and vegetational characteristics found within the boundaries of this foothill range area were not represented by the five selected sites. However, these sites represent much of the native rangeland in the area. Several edaphic and physiographic characteristics of the five sites are presented in Tables 3 and 4. The sites, I through IV, would probably be classified as "silty range sites" according to the Soil Conservation Service Technicians' Guide for Central Montana (1956). Site V would probably be classified as a "shallow site".

Table 3. Slopes and exposures at the five experimental sites.

Sites locations	I		II		III		IV		V	
	In	Out	In	Out	In	Out	In	Out	In	Out
Slope (percent)	3	5	2	2	4	4	2	2	9	9
Exposure (degrees from north)	280	270	275	275	255	310	15	15	220	230

The estimates of percent basal area presented in the following discussion of the individual experimental sites were obtained by the 1957 vegetational analysis with the point-quadrat technique. The estimates of percentage composition of weight contributed by the various species were derived from oven-dry weights of the vegetation harvested in 1957 from sample plots. Only the analyses from areas subject to grazing at each site were considered in describing the vegetation. The percentage basal area and percentage composition values presented for the five sites have been summarized from the data presented in Appendix Tables III and VI.

Table 4. Results of mechanical analyses of soil samples,^{1/} depths of soil horizons, and depths at which effervescence with dilute HCl was first detected.

Site	Horizon or Location	Depth in Inches	Depth to Lime Layer, Inches	Percentage Composition			Textural Description ^{5/}	
				Sand ^{2/}	Silt ^{3/}	Clay ^{4/}		
PROFILE SAMPLES	I	A	0.0- 4.0	64	31	5	Sandy loam	
		B	4.0-12.0	14	49	20	31	Sandy clay loam
	II	A	0.0- 4.0		60	25	15	Sandy loam
		B	4.0-12.0	12	46	33	21	Loam
	III	A	0.0- 6.5		44	37	19	Loam
		B	6.5-16.0	15	42	34	24	Loam
	IV	A	0.0- 4.0		54	32	14	Sandy loam
		B	4.0-11.0	10	51	34	15	Loam
	V	A	0.0- 4.0		49	35	16	Loam
		B	4.0- 8.0	8	47	39	14	Loam
COMPOSITED SAMPLES	I	In	4.0-5.0 ^{6/}	57	29	14	Sandy loam	
		Out	4.0-5.0	61	27	12	Sandy loam	
	II	In	4.0-5.0		61	28	11	Sandy loam
		Out	4.0-5.0		69	26	5	Sandy loam
	III	In	3.0-4.0		52	38	10	Sandy loam-loam
		Out	3.0-4.0		45	34	21	Loam
	IV	In	3.0-4.0		58	31	11	Sandy loam
		Out	3.0-4.0		52	35	13	Sandy loam-loam
	V	In	3.0-4.0		49	36	15	Loam
		Out	3.0-4.0		57	37	6	Sandy loam

^{1/} The portion of the sample passing through a 2.0 mm screen.
^{2/} Particles .05-2.0 mm in diameter.
^{3/} Particles .002-.05 mm in diameter.
^{4/} Particles less than .002 mm in diameter.
^{5/} Determined from triangle chart, Soil Survey Manual (1951).
^{6/} Approximate depth to which samples were taken. Represents zone of greatest concentration of roots.

Site I

This site is located on a lower part of the ranch in an area that is gently rolling. The soil sample taken at this site contained approximately 17 percent gravel by weight.^{1/} The estimated basal area of all plants, excluding Selaginella densa, at Site I is 13.4 percent as determined by the point-quadrat analysis. Selaginella densa had an estimated basal area of 1.8 percent.

Four species, Koeleria cristata, Phlox hoodii, Artemisia frigida, and Agropyron spicatum, listed in order of decreasing basal areas, occupied 77 percent of the total estimated basal area covered by all plants excluding Selaginella densa. Agropyron spicatum, Koeleria cristata, Artemisia frigida, and Phlox hoodii, listed in order of decreasing weight comprised nearly 76 percent of the total harvested vegetation.

Grasses and sedges, forbs, and shrubs and half-shrubs comprised 45.5, 30.0, and 24.5 percent of the estimated basal area, respectively; and 60.0, 16.0, and 24.0 percent of the total oven-dry weight of clipped vegetation. A greater variety of forbs were present on this site than on any of the other four sites. The more important of these were Senecio canus, Astragalus gilviflorus, Eriogonum flavum, Erigeron compositus, Arenaria congesta, Sphaeralcea coccinea, Townsendia exscapa, Liatris punctata, Hymenoxys acaulis, and Aster spp..

The season of grazing at this site was primarily spring-fall during the 5-year lease period. An observation of the immediate area, a study of the collected experimental data, and a sketchy knowledge of the history of graz-

^{1/} Particles larger than 2.0 millimeters in diameter.

ing and homesteading in Meagher County, would indicate that relatively intense use has been made of Site I by all classes of grazing livestock for many years prior to 1953.

Site II

Site II is the lowest in elevation of the five experimental sites. The topography in the vicinity of this site is gently rolling to nearly level. Gravel contributed 9 percent of the total weight of the soil samples taken at this site. The basal area of all plants was estimated as 13.5 percent. In order of importance, Koeleria cristata, Phlox hoodii, Artemisia frigida, and Bouteloua gracilis contributed 79 percent of the estimated basal area covered by all plants. Estimates of production indicate that Koeleria cristata, Artemisia frigida, Phlox hoodii, Calamagrostis montanensis, and Bouteloua gracilis comprised 75 percent of the vegetation. Selaginella densa is nearly absent at this site.

The estimated percentage of total basal area contributed by grasses and sedges, forbs, and shrubs and half-shrubs was 59.3, 21.5, and 19.2, respectively. Percentage composition by weight of clipped plants was 61.1, 16.5, and 22.4 percent for the three classifications, respectively.

Spring-fall use by sheep has been the grazing pattern on this site for the period 1953 to 1957. The evidence indicates that at sometime in the past, prior to 1953, this portion of the ranch was very heavily grazed by domestic stock. The study site, itself, is situated in an area that appears to have been a half-section homestead. A nearby abandoned field and the ruins of a homestead dwelling tend to support this hypothesis. The vegetation is largely composed of low-producing grasses and less desirable forbs

and shrubs. The rangeland near this site contained a greater concentration of Artemisia tridentata and Artemisia cana plants than did the two specific study locations.

Site III

Site III is located on the ridge of one of the lower finger-like projections extending out from the Castle Mountains. The surrounding topography is more sharply rolling than at site I. The loam soil contained 9 percent gravel by weight as estimated from the soil samples. The point analysis showed total basal area of plants to be 7.5 percent. Species estimated as contributing nearly 73 percent of the total basal area of plants are Koeleria cristata, Artemisia frigida, Poa secunda and Poa cusickii combined, and Phlox hoodii. Almost 78 percent of the harvested vegetation was composed of Koeleria cristata, Calamagrostis montanensis, Agropyron smithii, and Artemisia frigida. Festuca idahoensis became prevalent a short distance from the study site where the ridge sloped off toward the north, but was not present on the study site. The basal area of Selaginella densa was estimated as 9.4 percent.

The point-quadrat analysis indicated that 62.0, 12.0 and 26.0 percent of the estimated total basal area of plants was contributed, respectively, by grasses and sedges, forbs, and shrubs and half-shrubs. Percentage composition of the three categories on an oven-dry weight basis was 73.8, 7.5, and 18.7 percent, respectively.

Grazing at this site was primarily spring-fall and winter grazing by sheep. The ridge tops in this locality and at the higher elevations often blow free of snow in the winter and thereby permit the exposed vegetation

to be grazed. The history of grazing use in the locality of site III cannot readily be determined, but observation indicates that grazing may have been less severe than at sites I and II.

Site IV

Site IV is situated at a higher elevation than any of the other four sites. It was selected on the top, but near the lower end, of a long sloping bench extending out from the higher portions of the Castle Mountains. Gravel composed 15 percent of the sandy-loam soil samples by weight. The surrounding topography is sharply rolling.

The basal area of all plants on this site was estimated as covering 15 percent of the ground surface. Species composing 70 percent of this basal area were Festuca idahoensis, Poa secunda, Poa cusickii, and Agropyron dasystachyum. On a production by weight basis, Festuca idahoensis, Agropyron dasystachyum, Calamagrostis montanensis, Koeleria cristata, and Poa cusickii comprised an estimated 77 percent of the vegetation. The basal area of Selaginella densa was estimated as 4.6 percent.

Estimates of percentage composition of total basal area covered by plants were 78 percent for grasses and sedges, 14.9 percent for forbs, and 7.1 percent for shrubs and half-shrubs. Grasses produced 87.2 percent of the clipped vegetation; forbs, 10.4 percent; and shrubs and half-shrubs produced 2.4 percent.

This site had been rather heavily grazed during the 5-year lease period. It became, in effect, a natural bed-ground for the sheep, when they were grazing on this portion of the ranch. The sheep were not bedded here but they often sought out this ridge top for their rest periods during the day.

Also, during the night, some of the sheep would occasionally leave the main band and move to this ridge top site and bed for the remainder of the night. A corner of the boundary fence was present on the ridge top only a short distance from the permanent enclosure. These two fence structures may have had an attractive influence upon the sheep. Woolfolk (1949) conducted a study in eastern Montana with unherded sheep. He observed the tendency for sheep to bed near a fence or other obstruction which provided some real or fancied protection from enemies.

A considerable amount of sheep manure had accumulated within the permanent enclosure at site IV by 1957. It is assumed that the manure was blown across the enclosure by the force of the strong prevailing winds which occur in this area during the fall, winter, and spring. The tall, ungrazed vegetation within the enclosure served as a barrier in breaking the force of the wind and caused many of the manure particles to fall inside the enclosure. The vegetation appeared to be more influential in reducing the force of the wind than did the fence. The manure was well distributed over the entire enclosure area and not concentrated just beyond the fence on the windward side of the enclosure. A definite response of the vegetation to the effects of this added fertilizer and protection from grazing can be observed in this enclosure.

Site V

This site was located on top of and near the end of a long ridge projecting out from the Castle Mountains. The shallow loam soil contained 23 percent gravel by weight. The topography in this area is very sharply rolling. The total basal area of plants on this site was estimated as 12.3 per-

cent by the point-quadrat method of analysis. The site has the characteristics favorable for dominance of Agropyron spicatum. As a result of livestock grazing at this site this grass species has taken the form of large aggregated clumps.

Of the total basal area of all plants, 68 percent was contributed by Artemisia frigida, Agropyron spicatum, Poa secunda, and Koeleria cristata. An estimation of the percentage composition by weight indicates that Agropyron spicatum, Artemisia frigida, Koeleria cristata, and Stipa comata compose 84 percent of the vegetation. Selaginella densa, at this site, had an estimated basal area of 19.4 percent.

Grasses at this site contributed 57.7 percent of the estimated basal area of plants, forbs contributed 11.1 percent, and shrubs and half-shrubs 31.2 percent. By weight, grasses contributed 75.6 percent of the vegetation, forbs 6.8 percent, and shrubs and half-shrubs 17.6 percent.

The seasons of grazing in the vicinity of sites IV and V were spring-fall and winter during the period of the lease held by the Experiment Station. This area was well suited for winter grazing as many of the ridge tops were blown free of snow. No definite evidence exists from which assumptions can be made about the grazing history prior to 1953 in the immediate vicinity of site V.

Comparison of Methods of Vegetational Analysis

One of the major objectives of this study was to compare three methods of analyzing the percentage composition of the vegetation. These methods are the point-quadrat, 3/4-inch loop, and oven dry weight of harvested vegetation. The comparison of the three analytical methods was made over five

sites and two locations at each site. The five sites will be referred to as sites I, II, III, IV, and V. The two locations or grazing treatments at each site were the non-grazed areas inside the permanent enclosures, and the grazed areas outside the permanent enclosures. The percentage composition determined from the oven-dry weights of the clipped vegetation was used as the standard with which percentage composition determined by the point-quadrat and 3/4-inch loop methods was compared.

Statistical procedure

The statistical design used to analyze the comparison of methods data is a simple 3-way classification in which sites, grazing treatments, and methods were considered as the three variables. The mathematical model postulated for the data is outlined in Table 5. The model and test procedures for the design follow Ostle (1956). Tabulated "F" values used to test hypothesis were taken from tables presented by Pearson and Hartley (1956). The use of the mathematical model was made under the assumption that the sampled populations were normally distributed. Some workers have shown that many vegetational characteristics do not exhibit a normal distribution. This subject has been reviewed and discussed by Grieg-Smith (1957). However, the determination of appropriate tests for various distributions was not an objective of this study.

The point-quadrat and loop data used in the analyses were derived from four of the five line transects at each location. The purpose for using only four transects was to equalize or balance the number of observational units taken by each method. The four 1' X 6' plots used in the dry weight of clipped vegetation method were considered as four observational units.

Table 5. Analysis of variance model for comparison of methods.

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \epsilon_{ijkl}$$

$i = 1, \dots, 5$ (number of sites)
 $j = 1, 2$ (number of grazing treatments)
 $k = 1, \dots, 3$ (number of methods)
 $l = 1, \dots, 4$ (number of observational units)

Assumptions: $\sum_i \alpha_i = 0$; $\sum_j \beta_j = 0$; $\sum_k \gamma_k = 0$; $\sum_i (\alpha\beta)_{ij} =$

$\sum_j (\alpha\beta)_{ij} = 0$; $\sum_i (\alpha\gamma)_{ik} = \sum_k (\alpha\gamma)_{ik} = 0$; $\sum_j (\beta\gamma)_{jk} =$

$\sum_k (\beta\gamma)_{jk} = 0$; $\sum_i (\alpha\beta\gamma)_{ijk} = \sum_j (\alpha\beta\gamma)_{ijk} = \sum_k (\alpha\beta\gamma)_{ijk} = 0$;

$\epsilon_{ijkl} \sim \text{N.I.D. } (0, \sigma^2)$

ANALYSIS OF VARIANCE

Source of Variation	D.F.	Expected Mean Squares
Sites (S)	4	$\sigma^2 + 24/4 \sum_i \alpha_i^2$
Grazing vs. Non-grazing (G)	1	$\sigma^2 + 60/1 \sum_j \beta_j^2$
Methods (M)	2	$\sigma^2 + 40/2 \sum_k \gamma_k^2$
S x G	4	$\sigma^2 + 12/4 \sum_{ij} (\alpha\beta)_{ij}^2$
S x M	8	$\sigma^2 + 8/8 \sum_{ik} (\alpha\gamma)_{ik}^2$
G x M	2	$\sigma^2 + 20/2 \sum_{jk} (\beta\gamma)_{jk}^2$
S x G x M	8	$\sigma^2 + 4/8 \sum_{ijk} (\alpha\beta\gamma)_{ijk}^2$
Experimental Error	<u>90</u>	σ^2
Total	119	

It was considered more expedient to balance the statistical model by the elimination of one observational unit (transect) from each group of five than to handle the unwieldy mathematics involved in an unbalanced model. The transects that were eliminated were selected by a random procedure. The four remaining transects used in the statistical analyses are illustrated in Table 6. The necessity of making adjustments of observational units in this study clearly indicates the essentiality of fitting a proposed experiment to a statistical model rather than attempting to fit a statistical model to previously collected data.

Table 6. Randomly selected transects used in the comparison of methods analysis.

Treatment	Sites	I					II					III					IV					V				
	Transects	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Non-grazed		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Grazed		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

The arithmetic means of the comparison of methods data are presented in Table 7. These are the means of the percentage values computed from data presented in Appendix Tables III, IV, and VI. The arithmetic means vary slightly from the weighted means which can be computed from the raw data. A comparison of arithmetic means with weighted means indicated that the differences were small, therefore, both kinds of means were not presented in the table of means. The results of the analysis of variance presented in the form of calculated means squares for the three factors and their interactions are given in Table 8.

Nine different vegetation variables were considered in analyzing the comparison of methods data. The variables that were analyzed were those

Table 7. Means for comparison of methods data on a percentage composition basis. 1/

Site	Non-grazed				Grazed				Both treatments			
	Point	Loop	Weight	All Methods	Point	Loop	Weight	All Methods	Point	Loop	Weight	All Methods
AGROPYRON SPICATUM												
I	8.95	10.41	29.34	16.54	11.89	11.07	27.31	16.76	10.42	10.74	28.33	16.50
II	5.76	3.08	11.16	6.66	1.24	1.56	5.94	2.92	3.50	2.32	8.55	4.79
III	4.33	8.03	10.72	7.69	5.50	1.42	3.01	3.31	4.92	4.73	6.86	5.50
IV	1.95	1.02	1.12	1.36	3.09	1.48	4.64	3.07	2.52	1.25	2.88	2.22
V	16.92	13.44	42.82	24.40	13.24	11.19	44.38	22.94	15.08	12.32	43.60	23.67
All	7.58	7.20	19.03	11.27	6.99	5.34	17.06	9.80	7.29	6.27	18.04	10.53
KOELERIA CRISTATA												
I	31.48	40.82	17.13	29.81	27.42	32.08	23.98	27.83	29.45	36.44	20.56	28.82
II	40.72	50.88	35.35	42.32	32.05	43.48	32.83	36.12	36.39	47.18	34.09	39.22
III	18.92	13.46	14.02	15.47	27.53	34.69	26.58	29.60	23.23	24.08	20.30	22.53
IV	2.16	6.65	3.20	4.00	9.54	11.31	9.15	10.00	5.85	8.98	6.17	7.00
V	12.80	10.95	13.07	12.27	9.32	15.25	11.51	12.03	11.06	13.10	12.29	12.15
All	21.22	24.55	16.55	20.77	21.17	27.36	20.81	23.12	21.20	25.96	18.68	21.94
BUNCHGRASSES												
I	45.33	54.96	49.43	49.91	41.97	47.20	52.38	47.18	43.65	51.08	50.91	48.54
II	58.82	64.84	51.48	58.38	55.48	65.00	51.64	57.37	57.15	64.92	51.56	57.88
III	44.42	36.84	41.34	40.86	47.25	52.74	35.82	45.27	45.84	44.79	38.58	43.07
IV	70.41	60.39	65.96	65.58	65.52	60.22	51.77	59.17	67.97	60.30	58.86	62.38
V	62.70	63.36	81.30	69.12	45.90	55.83	71.01	57.58	54.30	59.59	76.15	63.35
All	56.34	56.07	57.90	56.77	51.23	56.20	52.52	53.32	53.78	56.14	55.21	55.04
SOD-FORMING GRASSES AND SEDGE												
I	1.40	5.43	4.22	3.68	2.60	6.99	8.12	5.90	2.00	6.21	6.17	4.79
II	5.48	10.78	17.94	11.40	4.58	9.36	9.95	7.96	5.03	10.07	13.94	9.68
III	19.13	44.18	46.10	36.47	15.66	25.22	38.40	26.43	17.40	34.70	42.25	31.45
IV	9.70	21.71	7.88	13.10	11.12	21.84	35.69	22.88	10.41	21.77	21.78	17.99
V	7.48	15.26	1.04	7.93	9.98	19.86	2.09	10.64	8.73	17.56	1.57	9.28
All	8.64	19.47	15.44	14.51	8.79	16.65	18.85	14.76	8.71	18.06	17.14	14.64

Table 7. (Continued)

Site	Non-grazed				Grazed				Both treatments			
	Point	Loop	Weight	All Methods	Point	Loop	Weight	All Methods	Point	Loop	Weight	All Methods
<u>ALL GRASSES AND SEDGE</u>												
I	46.73	60.38	53.65	53.59	44.58	54.19	60.50	53.09	45.65	57.29	57.08	53.34
II	64.30	75.62	69.42	69.78	60.06	74.37	61.58	65.34	62.18	75.00	65.50	67.56
III	63.55	81.01	87.44	77.33	62.91	77.96	74.23	71.70	63.23	79.49	80.83	74.52
IV	80.12	82.10	73.83	78.68	76.64	82.06	87.46	82.05	78.38	82.08	80.65	80.37
V	70.18	78.62	82.34	77.04	55.88	75.69	73.10	68.22	63.03	77.15	77.72	72.63
All	64.97	75.55	73.34	71.28	60.01	72.85	71.38	68.08	62.49	74.20	72.36	69.68
<u>PHLOX HOODII</u>												
I	15.44	11.65	26.82	17.97	20.55	17.30	6.91	14.92	17.99	14.48	16.87	16.44
II	20.22	12.34	9.84	14.13	19.80	7.79	10.26	12.62	20.01	10.06	10.05	13.38
III	8.79	5.53	2.44	5.59	10.40	2.68	6.01	6.36	9.60	4.11	4.23	5.98
IV	7.84	5.47	4.63	5.98	5.38	4.68	2.77	4.28	6.61	5.08	3.70	5.13
V	9.37	3.74	3.69	5.60	9.06	1.62	3.99	4.89	9.22	2.68	3.84	5.25
All	12.33	7.75	9.49	9.85	13.04	6.82	5.99	8.62	12.68	7.28	7.74	9.23
<u>ALL FORBS</u>												
I	20.06	18.05	36.98	25.03	31.01	27.88	15.50	24.80	25.54	22.96	26.24	24.92
II	22.91	15.15	17.78	18.61	22.25	10.36	16.11	16.24	22.58	12.75	16.95	17.43
III	9.63	6.90	3.92	6.82	11.14	3.12	7.28	7.18	10.38	5.01	5.60	7.00
IV	13.16	10.26	20.08	14.50	15.20	11.14	10.05	12.13	14.18	10.70	15.06	13.31
V	15.31	10.98	13.16	13.15	12.08	4.93	7.24	8.08	13.70	7.95	10.20	10.62
All	16.21	12.27	18.38	15.62	18.34	11.49	11.24	13.69	17.27	11.88	14.81	14.65
<u>ARTEMISIA FRIGIDA</u>												
I	18.27	10.41	3.64	10.77	18.45	14.68	14.26	15.80	18.36	12.54	8.95	13.28
II	9.62	9.23	2.78	7.21	15.98	14.10	17.44	15.84	12.80	11.66	10.11	11.52
III	6.44	3.30	0.80	3.51	21.64	17.10	14.70	17.81	14.04	10.20	7.75	10.66
IV	4.86	4.44	2.63	3.98	5.48	5.12	2.20	4.27	5.17	4.78	2.42	4.12
V	14.16	9.85	4.50	9.51	31.69	19.38	18.18	23.08	22.92	14.63	11.34	16.30
All	10.67	7.45	2.87	7.00	18.65	14.08	13.36	15.36	14.66	10.76	8.11	11.18

Table 7. (Continued)

Site	Non-grazed				Grazed				Both treatments			
	Point	Loop	Weight	All Methods	Point	Loop	Weight	All Methods	Point	Loop	Weight	All Methods
					ALL SHRUBS AND HALF-SHRUBS							
I	33.21	21.57	9.37	21.38	24.41	17.93	23.99	22.11	28.81	19.75	16.68	21.74
II	12.80	9.23	12.79	11.61	17.69	15.28	22.30	18.42	15.24	12.26	17.55	15.02
III	26.81	12.09	8.64	15.85	25.95	18.92	18.50	21.12	26.38	15.50	13.56	18.48
IV	6.72	7.63	6.09	6.82	8.16	6.80	2.48	5.82	7.44	7.22	4.29	6.32
V	14.50	10.40	4.50	9.80	32.04	19.38	19.66	23.69	23.27	14.89	12.08	16.75
All	18.81	12.19	8.28	13.09	21.65	15.66	17.39	18.23	20.23	13.92	12.83	15.66

1/ Only arithmetic means are presented.

Table 8. Mean squares for comparison of methods data on a percentage composition basis.

Variable	Sites	Grazing	Methods	S X G	S X M	G X M	S X G X M
<u>Agropyron spicatum</u>	2013.2**	65.0	1702.2**	41.7	410.5**	5.9	20.2
<u>Koeleria cristata</u>	3991.0**	164.5#	546.2**	371.1**	103.9#	47.9	55.3
Bunchgrasses	1898.5**	357.9#	56.3	213.6#	450.6**	96.2	87.5
Sod-forming grasses and sedge	2663.8**	1.8	1062.3**	330.6**	325.3**	97.3	164.6**
All grasses and sedge	2507.5**	308.2*	1584.3**	134.3	118.4#	24.5	101.1
<u>Phlox hoodii</u>	675.1**	46.1	359.3**	11.9	30.9	45.0	105.6**
All forbs	1138.3**	112.5	292.2**	27.5	26.3	224.8**	145.8**
<u>Artemisia frigida</u>	484.8**	2098.2**	433.6**	207.9**	36.2	38.4	26.8
All shrubs and half-shrubs	803.5**	793.2**	637.7**	204.8**	103.6#	119.1	77.0

** Significant at (P<.01)

* Significant at (P<.05)

Significant at (P<.10)

considered to be important in terms of dominance, abundance, grazing reaction, growth forms, or appropriate groupings of plants. Data for Selaginella densa were not included in the comparison of methods study, primarily because this species was not harvested at all sites and a percentage composition by weight could not be computed.

Effects of sites on estimates of percentage composition

The difference in percentage composition as determined by the three methods was highly significant among the five sites for all of the variables tested. This result could be expected since the five sites were selected to represent different vegetational characteristics. The characteristics of each site were previously discussed.

Effects of grazing treatment (locations) on estimates of percentage composition

The analysis of variance indicated that the two grazing treatments caused a statistically significant difference in the percentage composition of several of the analyzed variables when estimated by the three methods over all sites. These differences were significant at the .10 probability of type I error for Koeleria cristata and bunchgrasses; significant at the .05 level for the all grasses and sedge group; the highly significant (.01 level) for Artemisia frigida and the all shrubs and half-shrubs group. However, the effects of grazing and protection from grazing cannot be wholly determined from this part of the study because a comparison with previous vegetational analyses is not considered. The effects of grazing and protection from grazing will be discussed later in this section of the thesis.

Effects of methods on estimates of percentage composition

The primary purpose for testing this data by analysis of variance was to compare percentage composition as determined by the three methods of analyzing vegetation. The three methods, considered over the five sites and two locations, gave significantly different (.01 probability of type I error) estimates of percentage composition for all of the variables except bunchgrasses. No significant difference among methods was shown for the bunchgrasses variable.

Effects of methods on estimates of percentage composition of bunchgrasses, *Agropyron spicatum*, and *Koeleria cristata*

The close relationship of the estimates of percentage composition of the bunchgrasses variable by the three methods over all sites and locations is revealed in the table of means (Table 7). The close relationship appears to be a reasonable one in view of the results obtained from the two bunchgrasses that were individually analyzed. The point and loop methods gave nearly equal estimates of the percentage composition of *Agropyron spicatum*, but both estimates were about one-third of the estimate by weight. This was especially true on sites I and V where *Agropyron spicatum* was a heavy producer by weight. The estimates of percentage composition were nearly the same for all methods at site IV, where *Agropyron spicatum* is relatively scarce.

A reverse situation was true for *Koeleria cristata*, as both the point and loop methods estimated a higher percentage composition for this species than did the dry-weight technique. The point-quadrat method more nearly equalled the estimate by weight than did the loop. The loop gave a consid-

erably higher estimates of percentage composition. It appears that the influences of these two forms of growth habit--the greater weight per unit of basal area as characterized by Agropyron spicatum and the lesser weight per unit of basal area as characterized by Koeleria cristata--tend to nullify each other when combined. The remaining bunchgrasses that were not analyzed individually do not vary greatly from Koeleria cristata in growth form and would apparently tend to stabilize the close relationship of percentage composition for bunchgrasses as determined by the three methods of measurement. It seems reasonable to assume that Poa secunda and Bouteloua gracilis would be over-estimated by the point and loop methods. Estimates of Poa cusickii and Stipa comata by the three methods would probably be similar to the estimates for Koeleria cristata.

Festuca idahoensis was encountered only at site IV. The data was not subjected to analysis of variance, but a comparison of the composition percentages estimated by the three methods over both locations appears as follows: point, 40.7 percent; loop, 28.1 percent; and weight, 39.9 percent (derived from Appendix Tables III, IV and VI). The loop underestimated the percentage composition by weight at both locations. The point method over-estimated the weight of Festuca idahoensis on the grazed portion and underestimated its weight in the non-grazed enclosure. The Festuca idahoensis plants were taller and, consequently, produced more weight per unit of basal area in the enclosure than was produced on the grazed location.

Effects of sites X grazing interaction on estimates of percentage composition of bunchgrasses, Agropyron spicatum, and Koeleria cristata

The sites X grazing interaction for Koeleria cristata was shown to be

highly significant. The table of means show that the percentage composition of Koeleria cristata as indicated by the three methods was greater inside the permanent enclosure than outside the enclosure at sites I, II, and V, but less inside than outside at sites III and IV. The interaction for Agropyron spicatum was statistically non-significant and the interaction for bunchgrasses was significant at the .10 level. The effects of grazing at the different sites cannot be adequately determined from this analysis.

Effects of sites X methods interaction on estimates of percentage composition of bunchgrasses, Agropyron spicatum, and Koeleria cristata

The interaction of sites X methods was highly significant for Agropyron spicatum and bunchgrasses and significant at the .10 level for Koeleria cristata. Percentage composition of Agropyron spicatum was estimated in a relationship of approximately 1:1:3 by the point, loop, and weight methods, respectively, at sites I, II, and V. At sites III and IV, the relationship more nearly approached 1:1:1 for the three methods.

The plants of Agropyron spicatum at sites I, II, and V are, in general, in the form of larger and taller bunches than those encountered at sites III and IV. The more robust form of growth is particularly pronounced at site V. The weight of vegetation per unit of basal area of these bunches is expected to be greater than the weight per unit of basal area of the relatively smaller and shorter bunches of Agropyron spicatum.

A recheck of the field data, including some measurements taken to reflect vigor of Agropyron spicatum at the two locations on each site, leads the author to believe that another factor may also account for the difference in estimates among sites. The sites X methods interaction may be an

effect of plant distribution and the sampling procedure used. Greig-Smith (1957) states that there are two departures from a random distribution. A "contagious" distribution is one in which individuals tend to be clumped or aggregated together, the sampling of which gives an excess of blanks and high values compared with random expectations. The other distribution in which the individuals tend to be uniformly spaced has been termed as "regular."

The distribution of the larger bunches of Agropyron spicatum appears to be contagious with very few smaller plants of this species growing in the interspaces. This effect appears to be more prevalent on the grazed areas than on the exclosed areas. The contagious distribution of Agropyron spicatum is not so apparent on sites III and IV. The significant sites X methods interaction for Agropyron spicatum may be a result of inadequate or improper sampling in view of the apparent contagious distribution. The use of points and loops in a non-random procedure may also account for this interaction. A sampling procedure using randomly placed individual points and loops would perhaps be valuable for obtaining better estimates of percentage composition by the two methods over the five sites.

The relative pattern of the three methods in estimating percentage composition of Koeleria cristata was similar at all five sites. Estimates by the point method were higher than weight estimates at sites I, II, and III, but were slightly lower than the weight estimates at sites IV and V. The loop in all cases gave higher estimates of percentage composition than both the point and weight methods.

A close look at the means presented in Table 7 for bunchgrasses reveals

that no particular trend for estimating percentage composition by the three methods was common over any of the sites. However, as has been indicated, the non-significant mean square for "methods" reflects the similarity of estimates by all methods when the five sites are considered together.

The nearly equal estimation of percentage composition of bunchgrasses by the loop and weight methods at site I reflects the contrasting influences of the low estimate of Agropyron spicatum and high estimate of Koeleria cristata by the loop method. The lower estimate of Koeleria cristata by the point in relation to the loop influences the status of the point method at site I.

At site II, the relative amount of Agropyron spicatum was small and the high estimation of percentage composition of bunchgrasses by the point and loop reflects the influence of the point and loop estimates of Koeleria cristata. The loop estimated Koeleria cristata especially high and the point and loop both overestimated Poa secunda and Poa cusickii. Poa secunda is an especially low producer of vegetation for the basal area that it occupies.

The high estimate of percentage composition of bunchgrasses at site III by the point and loop methods reflects the influence of these two methods in estimating Koeleria cristata and Poa secunda.

The percentage composition of Festuca idahoensis was similarly estimated by both the point and weight methods at site IV. Overestimation of Poa secunda by the point method again influenced the higher estimate of bunchgrasses by the point method. The overestimation of Poa secunda by the loop was nullified by its underestimation of Festuca idahoensis.

The estimation of percentage composition of bunchgrasses at site V reflects the gross underestimation of Agropyron spicatum by both the point and loop methods. Koeleria cristata was estimated nearly the same by all methods at site V, but Poa secunda was estimated high by the point and loop methods. However, the dominance of Agropyron spicatum is still reflected in the very high estimation of percentage composition of bunchgrasses by weight.

Effects of grazing X methods interaction on estimates of percentage composition of bunchgrasses, Agropyron spicatum, and Koeleria cristata

The non-significance of the grazing X methods interaction would indicate that under the assumptions of the analysis of variance model the three methods tend to estimate percentage composition of Agropyron spicatum, Koeleria cristata, and bunchgrasses in about the same pattern or relationship to one another on both the non-grazed exclosures and the grazed area outside of the exclosures.

Effects of sites X grazing X methods interaction on estimates of percentage composition of bunchgrasses, Agropyron spicatum, and Koeleria cristata

No three-way interactions were indicated as significant for the three previously discussed variables. In the succeeding discussion, those factors and interactions which have non-significant mean squares will not be given consideration under a separate heading, unless the data appears to warrant discussion.

Effects of methods on estimates of percentage composition of sod-forming grasses and sedges

An examination of the table of means readily explains the highly significant difference among the three methods for estimating percentage composition of sod-forming grasses and sedges. The percentage composition of the

sod-formers is greatly underestimated by the point method and slightly overestimated by the loop method when the three methods are compared over all sites and both locations. This overall relationship should not be entirely accepted before consideration is given to the variations that occurred on the different sites, primarily because of the presence of different sod-forming species. These variations will be discussed later under the topic of effect of sites X methods interaction.

The reason for the high estimate of sod-formers by the loop method when compared with the point method should be apparent. The probability of a point striking the basal area of any given single-stemmed plant is quite small in comparison with the probability that the basal portion of that stem is included within a loop, 3/4-inch in diameter. The number of theoretical points within the area of a 3/4-inch loop could be infinite. In practice, however, the point used in the field is a tiny loop and some definite number could be fitted inside of the loop. Six times as many point readings as loop readings were taken in the field, but the number of points (or tiny loops) that would fit into the 3/4-inch loop would be many times six.

Effects of sites X grazing interaction on estimates of percentage composition of sod-forming grasses and sedges

When estimated by the three methods the sod-formers showed different reactions to grazing on the various sites. Again, these results should not be accepted as concrete evidence of the influence of protection from grazing upon the vegetation. This analysis does not consider comparisons with the 1953 data.

Effects of sites X methods interaction on estimates of percentage composition of sod-forming grasses and sedges

The estimates of percentage composition of the sod-formers obtained by the three methods was extremely variable among the five sites. The greatest extreme in variation existed at site V, on which both the point and loop exhibited much higher estimates of percentage composition than did the weight. This may be expected because Carex eleocharis comprised, almost entirely, the sod-formers present on the site. Carex eleocharis at site V was very small in stature and produced very little vegetation. This species makes its growth very early in the spring and by late summer the upper portion of the leaves have dried and often disappeared.

At site III, both the point and loop methods gave low estimates of percentage composition of the sod-formers and the point estimated only half as much as the loop. The sod-forming species of importance at site III are Calamagrostis montanensis and Agropyron smithii, both of which are major species on the site. Johnston (1957) considered the loop as nearly useless for estimating basal area of Agropyron smithii. His results showed that the estimates of basal area by the loop were from three to nearly five times as great as the estimates made by the point-quadrat method. In this study, estimates of basal area made at site III by the loop method were nearly eight times the estimates made by the point-quadrat method (Appendix Tables III and IV). However, as an estimator of percentage composition of Agropyron smithii and sod-forming species of similar morphology, the loop method appears to be more accurate than does the point-quadrat method. Results from the other sites tend to support this conclusion.

When considered over both locations, the point-quadrat method underestimated the percentage composition by weight of the sod-formers on site IV, but the loop estimated percentage composition equal with weight. A great variation among methods exists, however, when the two locations are considered separately. This variation between locations was one of the factors influencing a highly significant three-way interaction for the sod-forming grasses and sedges variable. The percentage composition of the sod-formers at the grazed location on site IV was underestimated by the point and loop methods. The estimates of sod-formers inside the enclosure at site IV presented a different comparison. Both the point and loop methods overestimated the percentage composition, the loop very decidedly so. The reason for the difference in estimates by the three methods between the two locations may be that the plants of Agropyron dasystachyum and A. smithii on the grazed area were more vigorous and contributed more weight per unit of basal area than did the sod-forming plants growing inside the enclosure. The vigor of the sod-formers on the non-grazed location was probably suppressed by the competition from Festuca idahoensis.

Three species comprised the major portion of the sod-formers at site IV. They were Agropyron dasystachyum, Agropyron smithii, and Calamagrostis montanensis. The two Agropyron species could not be delineated vegetatively so were considered as one species in recording hits. The two species of Agropyron made up a greater portion of the vegetation outside than inside the enclosure, but the same relationship existed in 1953 as determined by the point-quadrat method of analysis.

As an estimator of percentage composition by weight, the point was

again low at sites I and II. The loop estimated low at site II but nearly equal to weight at site I. From Appendix Tables III, IV and VI it can be shown that the point-quadrat method underestimated the percentage composition of Calamagrostis montanensis at both sites, Agropyron smithii at site I and, surprisingly, Carex eleocharis at site II. The loop gave low estimates of Calamagrostis montanensis at site II and Agropyron smithii at site I, but high estimates of Calamagrostis montanensis at site I and Agropyron smithii at site II. Carex eleocharis was overestimated by the loop at both sites.

Effects of sites X grazing X methods interaction on estimates of percentage composition of sod-forming grasses and sedges

The highly significant mean square for the three-way interaction would indicate that the three methods did not estimate percentage composition in a particular pattern or trend between the two locations and over the five sites.

The most consistent trend was for the point-method to greatly underestimate the percentage composition of the sod-formers. The loop method, in general, also underestimated the percentage composition of the sod-formers but to a lesser degree; and in several cases nearly equalled the weight estimates. Two departures from this trend were previously discussed under the sites X methods interaction for sites IV and V. Another inconsistency is the high estimates made by the loop method at site I.

The irregularities encountered in estimating percentages of sod-forming grasses and sedges are an indication of the variable production that can be expected from the several sod-forming species at various sites and under

different grazing practices.

Effects of methods on estimates of percentage composition of all grasses and sedges

The estimates of percentage composition of all grasses and sedges should reflect the combined results of estimates on bunchgrasses and sod-forming grasses and sedges. In the estimation of percentage composition by weight of all grasses and sedges, considered over all sites and locations, the point-quadrat method estimated nearly 10 percent low. The loop method estimated very close to the estimate by weight, being only about 2 percent high. The influence of low estimates of both bunchgrasses and sod-formers by the point method is apparent. Likewise, the influence of a slightly high estimate by the loop on both bunchgrasses and sod-formers is responsible for the similar effect on all grasses and sedges.

From this information, one might suggest the use of the 3/4-inch loop as a method for estimating percentage composition of all grasses and sedges as a group on an area similar to the one on which the experiment was conducted.

Effects of sites X methods interaction on estimates of percentage composition of all grasses and sedges

The statistical analysis indicates that the probability is nine chances in ten that an interaction exists between sites and methods (Table 8). This significance may not be great, but the interaction does warrant some consideration. The sites X methods interactions were highly significant for bunchgrasses, and sod-forming grasses and sedges, the two components of all grasses and sedges. The low probability of the sites X methods interaction for the all grasses and sedges variable is indicative of a counteracting or

equalizing effect resulting from the combination of its two component variables.

The relationship among estimates by the three methods was nearly the same on sites I, III, and V. On each of the three sites the point-quadrat method gave a low estimation of the percentage composition by weight of all grasses and sedges. The loop method gave nearly equal estimates at all three sites. An example of the equalizing influences can be shown at site V where the loop method gave a very high estimate of the sod-formers, a low estimate of the bunchgrasses, but a nearly exact estimate of weight of all grasses and sedges. Other similar comparisons can be made from the table of means.

The three methods gave the most uniform estimates of weight at site IV. The point estimated slightly low and the loop slightly high. The only appreciably high estimate of all grasses and sedges was made by the loop method on site II. This reflects on the high estimate, made by the loop, of the grass species at this site which produced a small amount of vegetation per unit of basal area. These grasses included Koeleria cristata, Bouteloua gracilis, Poa secunda, and Poa cusickii.

Effects of methods on estimates of percentage composition of Phlox hoodii and all forbs

Highly significant mean squares are indicated for Phlox hoodii and all forbs as a result of the different estimates of percentage composition made by the three methods. Phlox hoodii is the most abundant and persistent forb on the experimental area. With few exceptions, this prostrate, mat-forming species covers more ground area and produces more total vegetation by weight

than any other forb on the experimental sites. Its relatively high production cannot be attributed to its stature, but to its relative abundance on every site. Coupland (1950) lists Phlox hoodii as the second most abundant forb on the Canadian mixed prairie and classifies it as unpalatable and of little value for forage.

The percentage composition of both Phlox hoodii and all forbs was estimated in nearly the same relationship by the three methods. This seems reasonable in view of the relatively high proportion of Phlox hoodii in the composition of all forbs. The point-quadrat method overestimated the percentage composition of both Phlox hoodii and all forbs. The loop method made a low estimate of all forbs, but estimated Phlox hoodii nearly equal with weight.

The remainder of the forbs that were not analyzed separately were estimated equally by the point and loop methods, but both methods were low estimators of percentage composition by weight. Two of the unanalyzed forb species that contributed the most to the greater estimate by weight of all forbs were Astragalus striatus and Oxytropis sericea. Plant species of this growth form have a relatively large amount of vegetative weight per unit of basal area. Low estimates of these two species by the point and loop methods would be expected.

The first contact made by the point-quadrat with any portion of a plant of Phlox hoodii was recorded as a hit. Similarly, a loop which contained any part of the plant of Phlox hoodii was counted as a hit. It would seem reasonable, when aerial hits (first hits) were recorded, that both the point and loop methods would overestimate the percentage composition of Phlox

hoodii. This reasoning would appear to be supported by an assumption that the plants produced a low weight of vegetation per unit area of ground covered.

The estimates obtained by the point method verified the above assumptions with one exception. The exception will be discussed later. The loop method, however, estimated percentage composition rather inconsistently and, in general, gave a low estimate of weight. The higher estimate on Phlox hoodii by the point method (or the lower estimate by the loop) may be a result of sampling technique. The close spacing (1-inch interval) of the pins in the point-quadrat frame could allow for more than one hit on one plant of Phlox hoodii when aerial hits are recorded. If basal hits had been recorded, with the position of the frame unchanged, the same plant of Phlox hoodii may have been hit only once or not at all. Considering the loop method, it is unlikely that more than one aerial hit per plant would be recorded when readings are taken at 6-inch intervals, because the average diameter of the plants was usually less than 6 inches. Many of the same loop hits would be recorded by either basal or aerial contacts. The area of the loop would increase the chance that an aerial hit on a given plant would also include the basal portion of that plant. The chance is very small that an aerial hit by the point would also be a hit on the base of a given plant. The area of the pin point used in the field is very small in comparison to the area of the 3/4-inch loop. Therefore, when recording aerial hits as compared to basal hits, only a few additional hits may be encountered per line by the loop method, but the point method may pick up a greater number of additional hits per line.

Consideration of another factor may explain the nearly equal estimate by loop and weight. Phlox hoodii is a rather dense, compact plant and may weigh heavier for the volume of space occupied than is often the case with many species, especially shortgrasses such as Bouteloua gracilis or Poa secunda. The loop, then, instead of overestimating the weight as anticipated, may more nearly estimate it correctly; whereas, the point overestimates the weight because of additional hits obtained by aerial readings and close spacing of the pins in the frame.

It is surmised by the writer that the use of individual points and loops randomly placed over the sample area would tend to equalize the estimates of percentage composition of Phlox hoodii by the point and loop methods. An attempt to record only basal hits would probably cause the loop, and especially the point, methods to underestimate percentage composition of Phlox hoodii. The practice of recording aerial hits on Phlox hoodii and species of similar morphology is suggested on the basis of the results obtained in this study.

Effects of grazing X methods interaction on estimates of percentage composition of Phlox hoodii and all forbs

This interaction did not show statistical significance for Phlox hoodii although the loop underestimated percentage composition when considered over all of the non-grazed locations and gave a slightly high estimate on the grazed locations. The departure from the trend was caused by the estimates at site I which will be discussed under the heading of effects of the three-way interaction.

A highly significant interaction for grazing X methods was shown by the

statistical analysis for all forbs. Over all of the non-grazed locations, both the point and loop methods underestimated percentage composition; the loop more so than the point. When considering all of the grazed areas, the point method gave a high estimate of the weight of all forbs but the loop method gave an estimate equal with weight.

The effects of grazing and protection from grazing on the vigor and production of several forb species appears to be partially responsible for this interaction. Astragalus striatus and Oxytropis sericea were two forbs which were especially responsive to the effects of grazing and protection from grazing. The percentage composition by weight of these forbs was greater on the non-grazed locations, but the basal area as estimated by the point and loop methods was nearly the same on both grazed and non-grazed locations. This would indicate that protected plants of these species were more vigorous and produced more vegetation per unit of basal area than did plants of the same species that had been subject to grazing. Astragalus gilviflorus added considerably to the weight estimate on the protected area at site I, but was not encountered by either the loop or point methods. Astragalus gilviflorus is a short mat-forming plant which occurred in only a few scattered clumps on site I. It was a matter of chance that one clump fell into one of the clipped plots, but that no clumps were encountered along the line transects.

Effects of sites X methods X grazing interactions on estimates of percentage composition of Phlox hoodii and all forbs

Several factors apparently influenced the highly significant three-way interaction for these two variables. The preceding discussion pertaining

to the grazing X methods interaction for all forbs has explained, in part, the reason for the three-way interaction.

Perhaps the most noticeable inconsistency associated with estimates of percentage composition of Phlox hoodii occurred at site I. The table of means shows that both the point and loop methods gave high estimates at the grazed location. However, on the non-grazed location the estimates were markedly different in that both the point and loop gave low estimates of weight. This difference is unexplainable from the collected data. The total sample weight of Phlox hoodii was four times greater on the non-grazed location at site I than it was on the grazed location. The weight was quite uniformly distributed among the four sample plots inside the enclosure, although less so outside the enclosure. From the samples taken on the other four sites, no appreciable difference in total weight was found to exist due to grazing and non-grazing. No difference was observed in the stature of the plants as a result of protection from grazing. If protection from grazing were solely responsible, the same effect would have been expected at site II, where past grazing was thought to have been more severe. Soil texture and depth, precipitation, slope, and exposure are all comparable at sites I and II.

The sampling procedure was considered to be statistically sound and adequate for estimating the weight of the more common species present. The distribution of Phlox hoodii did not appear to be aggregated to such an extent that additional plots would be required to obtain a representative sample of its production.

At both locations on all sites, except site I, Phlox hoodii was consist-

ently estimated high by the point-quadrat method. The loop method estimated slightly high or nearly equal to weight on all non-grazed locations, except at site I, but underestimated Phlox hoodii on the grazed locations at sites II, III, and V. It may be possible that on the grazed locations at these three sites the weight per unit area of ground covered was greater than on the non-grazed location. The production data from sites II and III indicated that the total weight of the samples of Phlox hoodii were greatest from the grazed locations. This relationship was reversed at site V. The writer is unable to explain the reason for the apparent difference in estimates between the two locations when using the loop method.

Several explanations for the highly significant three-way interaction for all forbs have been made in the discussion of the methods X grazing interactions for all forbs and the three-way interaction for Phlox hoodii. The estimates of all forbs at site I reflect the unexpected results obtained from the estimates of Phlox hoodii.

Forbs other than Phlox hoodii which showed the most variation in weight between locations and among sites were Astragalus striatus at sites IV and V, Oxytropis sericea at site V, and Astragalus gilviflorus at sites I and II (Appendix Table VI). The harvested sample of Astragalus striatus from inside enclosure IV was three times heavier than the sample taken outside. Oxytropis sericea, sampled from inside enclosure V, was nearly 17 times heavier than the sample from the grazed location. These forbs were apparently selected by the sheep and their reduced vigor on the grazed areas indicated the results of repeated utilization by sheep.

At site I, the harvested sample of Astragalus gilviflorus from the non-

grazed location was 20 times as heavy as the sample from the grazed location. Neither the point or loop detected this species on the non-grazed location. Estimates by the three methods were nearly equal on the grazed portion. A sample of Astragalus gilviflorus was harvested only at the grazed portion of site II. Both the point and loop greatly underestimated its percentage composition by weight. This species was not encountered on the non-grazed portion of site II.

Effects of methods on estimates of percentage composition of Artemisia frigida and all shrubs and half-shrubs

Both variables, Artemisia frigida and all shrubs and half-shrubs (the latter term may subsequently also be referred to as "all shrubs" to simplify the wordage), were estimated in a similar relationship by the three methods. This similar relationship among methods for both variables seems reasonable since Artemisia frigida is, in most cases, the primary constituent of the all shrubs variable.

For both variables, estimates of percentage composition were about 1.7 times higher by the point than by weight. The loop method also estimated both variables high but to a lesser degree than did the point method.

All of the component species of the all shrubs and half-shrubs variable were, with one exception, recorded by aerial hits (first hits). The exception was Gutierrezia sarothrae. Only crown hits were recorded on this half-shrub. It was assumed that the vegetative portion of Gutierrezia sarothrae did not influence the area it covered in the same degree as did the other shrubs and half-shrubs. A reason for the overestimation of percentage composition of these two variables (Artemisia frigida and all shrubs) by the

point and loop methods has been presented in the discussion pertaining to overestimation of Phlox hoodii by these two methods. The same reasoning applies to the higher estimate by the point than by the loop. This reasoning was that several hits could be expected on one plant by the closely spaced points. Fewer total hits in proportion would be expected by the loop as only one hit per plant would be expected. In the case of the larger shrubs, two or possibly three hits could be made on one plant by the loop, but many more hits would be expected by the point method on the same plant.

A check through the data in Appendix Tables III, IV and VI indicates that both the point and loop methods gave low estimates of Gutierrezia sarothrae. The estimate by the loop was lower than the point for this species. It is believed that by recording only basal or crown hits, low estimates of percentage composition by weight would have been even more pronounced with the other shrubs and half-shrubs. It is conceivable that one plant may receive 15 or 20 hits by the point when recording aerial hits, but may receive no more than 2 or 3 hits if only hits on the basal or crown area were recorded. That the weight of the plant may be overestimated, in the case of the former, and underestimated, in the case of the latter, should be apparent.

Effects of sites X grazing interaction on estimates of percentage composition of Artemisia frigida and all shrubs and half-shrubs

The sites X grazing interaction was shown to be statistically highly significant for both variables. When considering the three methods collectively, estimates of percentage composition of Artemisia frigida were greater on the grazed than on the non-grazed locations at all sites. The amount

of difference between grazed and non-grazed locations, however, varied among sites. The percentage composition was only slightly greater on the grazed locations at site IV but was five times greater on the grazed than on the non-grazed location at site III.

The same general trend was apparent for all shrubs and half-shrubs but the difference between grazing treatments was less marked than it was for Artemisia frigida.

This data would indicate that the grazing treatments as determined by the three methods have influenced the difference in percentage composition of these species, especially Artemisia frigida. However, a definite conclusion about its reaction to grazing cannot be drawn from this data which does not present comparisons with any previous analyses. Grazing influence on Artemisia frigida will be discussed later in the thesis.

Effects of sites X methods interaction on estimates of percentage composition of Artemisia frigida and all shrubs and half-shrubs

The statistical analysis indicated a non-significant result for Artemisia frigida and significance at the .10 probability of type I error for all shrubs.

The relationship of the three methods was similar in the estimate of Artemisia frigida over the five sites with the exception of site II. At this site the point and loop methods closely estimated percentage composition by weight. The grazed location at site II is the only place at which the point and loop methods underestimated weight. Perhaps Artemisia frigida has been most favored at this site due to past grazing pressure.

The three methods estimated the percentage composition of all shrubs

in a similar pattern over all the sites except site II. Appendix Tables III, IV and VI show that Gutierrezia sarothrae was underestimated by the point and loop methods at both locations on this site. Artemisia tridentata was underestimated by the point and loop methods on the non-grazed location and Chrysothamnus nauseosus was underestimated on the grazed location. Recording only crown hits on Gutierrezia sarothrae chiefly accounted for its underestimation; however, inadequate sampling may have been responsible for the varied results between locations of the other minor species.

Effects of grazing X methods interaction on the estimates of percentage composition of Artemisia frigida and all shrubs and half-shrubs

This interaction did not appear statistically significant for either variable, but several comments may be applicable. The relationship of the three methods was similar over all sites for the non-grazed and grazed locations in that the point and loop both gave high estimates of percentage composition of Artemisia frigida by weight. The variation among methods was least on the grazed locations. This is an indication of the greater stature and vigor of the Artemisia frigida plants on the grazed area.

Weight appears to be the most sensitive measure for determining the effects of protection from grazing on Artemisia frigida. Of the three methods considered over all the sites, weight showed the greatest difference between grazing treatments. It would appear that under protection from grazing, production of the Artemisia frigida plants declines rapidly; whereas basal area appears to change more slowly.

Both the point and loop methods gave high estimates of weight of all shrubs on the non-grazed areas but only the point estimated high on the

grazed areas. As previously discussed, the loop apparently tends to estimate lower than the point on plants recorded by aerial hits. It is also possible that the number of loops employed in this study was inadequate to record hits on some of the minor and scattered species of shrubs; some of which had been encountered by the point and weight methods.

Effects of sites X grazing X methods interaction on estimates of percentage composition of *Artemisia frigida* and all shrubs and half-shrubs

The three-way interaction was not statistically significant. The relationship of the three methods to one another in estimating percentage composition at each location at each of the five sites was, in effect, quite similar. The variations from the trend have been discussed under the two-way interactions. The only place where the loop method estimated higher than the point method was on shrubs inside enclosure IV.

Number of species encountered by each method

The number of species encountered at each site by each of the three measurement methods is presented in Table 9. These data were not analyzed statistically. When considered over the five sites, the average number of species encountered was nearly the same for the three methods. A certain amount of bias may be present in the number of species encountered by the point and loop methods due to the procedure of taking the readings by both methods along the same line transects. Random placing of the points and loops over the study units would perhaps give a more unbiased estimate of the number of species present.

The results of a methodology study on grassland vegetation in southern Alberta, indicated that nearly the same number of grass and sedge species

were encountered by both the point and loop methods (Johnston, 1957). However, the point method encountered a greater number of forb and shrub species than did the loop. Similar results were obtained in this study by the point and loop methods on the grasses and sedge, but dissimilar results were obtained on the forbs and shrubs.

Table 9. Number of species encountered by each method at each site.

Vegetation class and site	Method		
	Point	Loop	Clipped plots
<u>Grasses and sedge</u>			
I	8	9	9
II	9	9	9
III	8	8	8
IV	10	9	10
V	8	7	6
Average	8.6	8.4	8.4
<u>Forbs</u>			
I	14	11	13
II	7	7	10
III	4	4	4
IV	5	6	9
V	5	6	7
Average	7.0	6.8	8.6
<u>Shrubs and half-shrubs</u>			
I	4	5	4
II	5	3	4
III	6	6	4
IV	3	3	4
V	2	2	2
Average	4.0	3.8	3.6

Changes in Vegetation Due to Protection from Grazing

The results of the comparison of the 1953 point analysis with a repeat analysis made in 1957 are to be discussed in this section. These results should reflect chiefly upon the response of the vegetation due to protection from grazing. It is also probable that changes in the vegetation have

occurred on the grazed areas. It seems reasonable to assume that prior to the period of lease by the Montana Agricultural Experiment Station, such factors as rate of stocking, season of use, class of livestock, and distribution of livestock were different than they were after the experimental area was leased.

Statistical procedure

The response of the vegetation to grazing and protection from grazing was determined from the differences between the number of hits made by the point-quadrat analysis in 1953 and 1957. The use of difference values is convenient because the direction of change between years can be immediately determined by the positiveness or negativeness of the value. The relative magnitude of the change among sites or between treatments can also be readily learned. The same type of information could be learned by using the actual values for both years, however, another item, years, would be entered into the analyses and the additional interactions would be difficult, if not impossible, to interpret.

The difference values for 19 variables were subjected to an analysis of variance using a simple two-way classification design. The statistical model for the analysis of variance is presented in Table 10. The model is used under the assumption that a normal population was sampled. The model and test procedures follow Ostle (1956). Tabulated "F" values for testing hypotheses were those presented by Pearson and Hartley (1956). The two factors considered in the analysis of variance for the difference in number of hits were sites and locations. The two locations correspond to the two grazing treatments--non-grazed inside the enclosure and grazed outside the

Table 10. Analysis of variance model for differences in the number of hits between 1953 and 1957 as determined by the point-quadrat method.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk}$$

$i = 1, \dots, 5$ (number of sites)
 $j = 1, 2$ (number of grazing treatments)
 $k = 1, \dots, 5$ (number of observational units)

Assumptions: $\sum_i \alpha_i = 0$; $\sum_j \beta_j = 0$; $\sum_i (\alpha\beta)_{ij} = \sum_j (\alpha\beta)_{ij} = 0$

$$\epsilon_{ijk} \sim \text{N.I.D. } (0, \sigma^2)$$

ANALYSIS OF VARIANCE

<u>Source of Variation</u>	<u>d.f</u>	<u>Expected Mean Squares</u>
Sites (S)	4	$\sigma^2 + 10/4 \sum_i \alpha_i^2$
Grazing vs. Non-grazing (G)	1	$\sigma^2 + 25/1 \sum_j \beta_j^2$
S x G	4	$\sigma^2 + 5/4 \sum_{ij} (\alpha\beta)_{ij}^2$
Experimental Error	40	σ^2
Total	49	

exclosure. The interaction of sites and locations is also considered. The data from all five transects at each location were used in the analysis of variance.

Table 11 presents the means of the differences between years for the 19 variables considered in this analysis. The results of the analysis of variance are shown in the form of the mean squares presented in Table 12. The differences between years were computed by subtracting the 1957 hits from the 1953 hits. Numbers preceded by a minus (-) sign in the table of means indicates that more hits were made in 1957 than in 1953. Numbers not preceded by a minus sign indicate that more hits were made in 1953 than in 1957. In the following discussion the difference between the number of hits made in 1953 and those made in 1957 may be referred to solely as the difference in hits without specifying the number of years.

Changes in *Agropyron spicatum*

Table 12 shows that the difference in the number of hits between 1953 and 1957 was statistically non-significant for sites, grazing treatment, and the two-factor interaction. *Agropyron spicatum* is classed as a climax 1/ dominant over much of the experimental area (Wright and Wright, 1948), therefore, some consideration will be given to the results of the analysis even though the results were shown to be statistically non-significant.

When considered over all sites and grazing treatments, only seven less hits were recorded in 1957 than in 1953 (difference values cited here and subsequently in the text are taken from Appendix Tables II and III). The

1/ This term is used as defined by the "Report of the Committee on Nomenclature of the Ecological Society of America."

Table 11. Means of differences between 1953 and 1957 hits on vegetation by the point-quadrat method.

Variable	Grazing treatment	Sites					All Sites
		I	II	III	IV	V	
<u>Agropyron spicatum</u>	NG <u>1/</u>	-0.6	<u>2/</u> -0.6	-0.4	2.8	-0.8	0.08
	G	-5.0	1.4	1.6	0.0	3.0	0.20
	Both	-2.8	0.4	0.6	1.4	1.1	0.14
<u>Koeleria cristata</u>	NG	-2.4	10.2	14.6	4.2	6.6	6.64
	G	6.2	5.4	19.6	-2.4	3.2	6.40
	Both	1.9	7.8	17.1	0.9	4.9	6.52
<u>Poa secunda & P. cusickii</u>	NG	-0.2	-4.2	-4.6	-9.2	-7.4	-5.12
	G	-1.6	-4.0	-1.4	-19.0	-7.0	-6.60
	Both	-0.9	-4.1	-3.0	-14.1	-7.2	-5.86
<u>Stipa comata</u>	NG	0.4	-1.8	0.2	-0.8	10.8	1.76
	G	0.2	-3.8	0.0	0.0	4.0	0.08
	Both	0.3	-2.8	0.1	-0.4	7.4	0.92
Bunchgrasses	NG	-2.2	7.6	9.8	-3.0	9.4	4.32
	G	0.0	1.4	19.8	-13.0	3.2	2.38
	Both	-1.1	4.5	14.8	-8.0	6.3	3.30
<u>Carex eleocharis</u>	NG	0.2	-0.6	0.4	0.0	0.4	0.08
	G	0.0	0.0	1.8	-1.2	-0.4	0.04
	Both	0.1	-0.3	1.1	-0.6	0.0	0.06
<u>Calamagrostis montanensis</u>	NG	0.4	6.8	11.0	2.4	0.4	4.20
	G	-0.4	4.0	7.0	0.2	0.8	2.32
	Both	0.0	5.4	9.0	1.3	0.6	3.26
Sod-forming grasses and sedge	NG	0.6	6.0	8.2	3.2	0.8	3.76
	G	-1.2	4.4	11.6	2.6	0.2	3.52
	Both	-0.6	5.2	9.9	2.9	0.5	3.64
All grasses and sedge	NG	-1.6	13.6	18.0	0.2	10.2	8.08
	G	-1.2	5.8	31.4	-10.4	3.4	5.80
	Both	-1.4	9.7	24.7	-5.1	6.8	6.94
<u>Phlox hoodii</u>	NG	-1.8	-6.6	2.0	-4.8	-2.2	-2.68
	G	-8.4	-11.6	-4.0	-2.2	-2.2	-5.68
	Both	-5.1	-9.1	-1.0	-3.5	-2.2	-4.18
All forbs	NG	-1.8	-7.4	2.2	-7.0	-0.6	-2.92
	G	-6.0	-8.6	-3.0	-2.6	-2.4	-4.52
	Both	-3.9	-8.0	-0.4	-4.8	-1.5	-3.72

