SOME METHODS FOR MONITORING RANGELANDS

AND OTHER NATURAL AREA VEGETATION

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Introduction

Vegetation monitoring has become an important component of range management on both private and public lands. Rangeland monitoring identifies and documents changes in vegetation over time providing information upon which to evaluate management practices. Data collected by rangeland monitoring can be used to evaluate effects of current management, modify management practices to best meet land objectives and document changes as a result of management or other factors.

The Public Rangeland Improvement Act of 1978 requires that range condition be reported for Forest Service and Bureau of Land Management operated public lands. Additionally other environmental legislation requires information which can only be acquired through range monitoring and surveys.

In Arizona, ranches and preserves often include State and/or Federal grazing permits in addition to privately owned land. The responsible agency will normally have range monitoring methods in place to document vegetation response to management. However, many Arizona ranchers and land managers have decided to collect data and keep their own records on range condition and trend. Ranchers have initiated monitoring programs designed to dove-tail with agency efforts and provide the baseline information needed to document changes that may occur on rangelands due to management techniques or climatic patterns. Managers of natural areas also require information on vegetation status. Active participation in range monitoring increases awareness of vegetation changes and improves understanding of the processes that effect those changes.

Chapter One

Considerations When Monitoring Rangeland Vegetation

E.L. SMITH AND *G.B. RUYLE*

The purpose of monitoring rangeland is to document change over time in vegetation or other aspects of the range as they relate to management and/or natural processes. Emphasis on change distinguishes monitoring from range inventories or surveys where the objective is to characterize all parts of a management unit or to estimate average values of certain attributes of the management unit (such as carrying capacity, range condition, plant cover, etc.). In selecting a monitoring method and monitoring locations the important considerations are to make sure that significant changes will be measured and that the changes measured are real and not just the result of sampling error or personal biases. Equally important, but often not adequately considered, is to try to explain why changes occurred or did not occur, because it is only by understanding of the causes that the manager can decide whether or how his management of the range should be modified.

What to Measure?

Management objectives and the type of vegetation involved influence the most useful attributes to measure. Time available and training of personnel may also influence this decision. There are many different attributes of vegetation (such as frequency, basal cover, canopy cover, production, density, height, etc.), soil, wildlife and livestock that can be measured or estimated. Some attributes are more useful or feasible to measure on certain types of plants than others, e.g. canopy cover may be good for shrubs, while basal cover is more appropriate for bunchgrasses. Cover is a good attribute to measure if one is interested in soil erosion, while production may be more useful for estimating carrying capacity. Some attributes are less subject to variation due to observer skill, sample size, or sample time than others, or may require less time to measure adequately than others.

The methods and attributes described in the following chapters are appropriate for a wide variety of vegetation types and management objectives and are fairly rapid and objective. Any one of the three can be used individually or they can be used in any combination to furnish additional information from the same set of quadrats. They will not be appropriate in all vegetation types or for all management objectives.

Where to Monitor?

In most situations it is feasible to monitor only a few locations representing a small part of the management unit (pasture, ranch or allotment). Consequently, selection of the areas to be monitored should be done carefully to ensure that useful information is obtained. Interpretation of the results from monitoring selected locations in terms of management effects on the whole management unit is a matter of judgment. How well this can be done is very dependent on good selection of monitoring locations.

The key area concept can be used in many situations to get maximum amounts of information from a minimum of monitoring locations. Key areas are places which reflect management (usually grazing) impacts on the management unit. Key areas should be sensitive to management changes and represent the most important ecological (range) sites within the unit.

When choosing key areas, transects should be located in ecological sites indicative of the management unit in general. They should be sites which produce a large portion of the forage and which have a chance of showing change in soil or vegetation due to the management employed in a reasonable length of time. Sites of very low productive potential or which are dominated by shortgrass sod should be avoided because change will likely be of minor extent and slow to happen on such sites. Stable areas, those not severely affected by erosion, will improve in plant cover or composition before unstable areas, and are therefore more sensitive to improved management. In areas of very poor range conditions, select monitoring locations where a remnant seed source for desirable perennial species still exists. Within a particular management area, try to monitor areas in several different range conditions and under different grazing management plans.

Critical areas, those with exceptional resource values or unusual susceptibility to disturbance, are also candidates for monitoring locations. For example, riparian areas or sites with highly unstable soils might be considered although they may not be extensive or reflect management impacts on the allotment as a whole. The distinction between key areas and critical areas is partly a question of management objectives, e.g. a riparian area could be a key area for wildlife but a critical area for livestock.

Another situation which could warrant monitoring, if available, is comparison areas. Comparison areas are areas which have been protected from grazing or grazed lightly and therefore show "natural" fluctuations in vegetation due to weather or other influences. Data collected in such areas may be useful in interpretation of data from key areas, although the vegetation and soil conditions on comparison areas do not necessarily represent the objective of management elsewhere. Another useful comparison area would be one on a similar ecological site under different management, such as on an adjacent ranch or allotment.

Where and How Often to Sample?

The best time of year to sample vegetation monitoring plots may depend on growing season and the time of grazing by livestock and/or wildlife. To reduce observer errors in species identification it is usually best to sample plots near the time of peak growing season when most plants have seedheads and have been relatively unaffected by grazing and weathering. It is important to sample at about the same season each year, that is the same growth stage, not necessarily the same calendar date. The amount of litter, presence of seedlings and annual plants, and some other vegetation characteristics may vary considerably from one season to the next.

Plots generally should be monitored as often as time and money permit. For typical range trend plots, sampling is recommended annually for at least the first 3-5 years. This provides an opportunity to develop consistency in species identification, to get a feel for the degree of variation to be expected from weather and sampling error inherent on the site, and to discover problems with the location selected (such as patches of atypical soil or plants or excessive heterogeneity that may result in rejection of the site).

Interpretation of Data

Data collected at each monitoring location represent an estimate of the situation within the area sampled only. In order to be able to reasonably interpret what the data mean in terms of management several criteria should be met.

The area sampled at each monitoring location should be as homogenous as possible in terms of slope, aspect, soil, and vegetation. The area should be large enough to encompass the normal patchiness in soil and vegetation without crossing onto another range site. Data collected across a mixture of range sites cannot be extrapolated to other parts of the unit. Collecting data on too small an area may only reflect small-scale variability within the plant community.

The area sampled should be described or marked sufficiently so the subsequent samples are drawn from the same area. The data collected apply only to the area sampled, and altering the size of the area sampled from one date to the next may introduce errors. Extrapolation of conclusions beyond the area sampled is a matter of professional judgement. The sample size (number of transects, quadrats, etc.) taken at each sampling location should be sufficient to reduce sampling variability between successive samples to an acceptable level. If the sample size is too small there is no assurance that differences obtained on successive dates are real and not just due to sampling variability. The use of statistical analysis to set confidence intervals on data will help establish the adequacy of sample size. In order to decide why observed changes occurred, or didn't occur, it is useful to try one or more of the following techniques. Collect "collateral" data, e.g. rainfall, utilization, stocking records, wildlife observations, etc., which may help explain why certain trends occur. Collect data often so that normal variation due to weather can be separated from management-related changes. Compare data on one location with other locations to see if trends are similar on different range sites, on comparison areas, on units managed differently, etc. It is not a good idea to average results from several sampling locations, at least not until initial interpretations are made.

Keep two points in mind:

1. The only thing that can be *measured* on rangeland are physical attributes of the vegetation, soil, and animals, i.e. number, cover, height, weight. Using these data to estimate carrying capacity, range condition, trend in range condition, or other value judgements depends on the knowledge, objectives and objectivity of the observer (i.e. professional judgement). These resource value ratings are interpretations, not measurements.

2. Statistical analysis can demonstrate how precise your data are and statistical comparison can tell whether changes from one sample date to the next are *statistically* significant. Statistical analysis cannot detect bias in the location of sample points or in the collection of data, nor can it tell you whether a change in the abundance or cover of certain species is of any practical significance or what caused it.

Chapter Two

Plant Frequency Sampling for Monitoring Rangelands

D.W. DESPAIN, P.R. OGDEN, AND *E.L. SMITH*

Federal and State land management agencies in the U.S. are actively involved in monitoring the effects of management practices and climatic fluctuations on western rangelands. A widely used method for monitoring vegetation changes on these rangelands is plant frequency sampling. Frequency has become popular primarily because it is relatively simple and objective.

Definitions

The concept of frequency as a parameter for quantifying vegetation is generally credited to the Scandinavian researcher, Raunkiaer (1909). Frequency is defined as the number of times a plant species is present within a given number of sample quadrats of uniform size placed repeatedly across a stand of vegetation (Mueller-Dombois and Ellenberg 1974, Daubenmire 1968). It is generally expressed as a percentage of total placements and reflects the probability of encountering a particular species at any location within the stand (Greig-Smith 1983).

Only species presence within the bounds of the sample quadrat is recorded, with no regard to size or number of individuals. Plant frequency is a function of quadrat size and reflects both plant density and dispersion. The sensitivity of frequency data to density and dispersion make frequency a useful parameter for monitoring and documenting changes in plant communities. If information is needed as to the specific attribute or attributes which contribute to the change, this must be accomplished by interpretation of data in the field or by collecting additional data which are specific for each attribute. Plant frequency, by itself, is useful for monitoring vegetation changes over time at the same locations or for comparisons of different locations. Plant frequency is less useful in descriptive studies except in conjunction with other parameters.

Sampling Procedures

Quadrat Size

Quadrat size is an important consideration in quadrat frequency sampling. The size of the quadrat influences the probability of each species occurring within the quadrat. Small quadrats result in low frequencies for most species and many uncommon species will not be sampled except with large samples. Large quadrats will include most species but will include the most common species in every quadrat. This eliminates the ability to detect changes in abundance or pattern for those species (Brown 1954).

The choice of a suitable quadrat size is primarily a function of the average abundance per unit area. A change in the size of the quadrat usually has the most effect on frequency values for species of intermediate abundance. Less influence of quadrat size is noted for species of high or low prevalence (Mueller-Dombois and Ellenberg 1974). Frequency values of 100% indicate quadrat size exceeds the maximum size of gaps between individuals (Daubenmire 1968). If quadrat size greatly exceeds this, then even a considerable decrease in the relative abundance of the species will not be detected. The best sampling precision is reached for a particular species when it is present in 40% to 60% of the quadrats sampled. This will provide the most sensitivity to changes in frequency. Good sensitivity is obtained for frequency values between 20% and 80%. Frequency values between 10% and 90% are useful but data outside this range should be used only to indicate species presence. Ideally, each plant species should be sampled with a quadrat size best suited for it. Obviously this is impractical. As a compromise, a quadrat size is selected which will adequately sample as many species as possible. Generally, quadrat size should be kept as large as possible without frequency of the most abundant species approaching 100%. At the very least, sampling those species in which one is most interested should result in frequency values between 20% and 80%.

Figure 1 shows the total number of species encountered and percent frequency values for several species using various quadrat sizes at 5 locations in Arizona. In general, quadrats larger than .10 m^2 are necessary to sample the most important species at each location. Roughly half of the species encountered occur in more than 5% of the quadrats. For the remaining species, frequency sampling indicates only their presence. Based on these

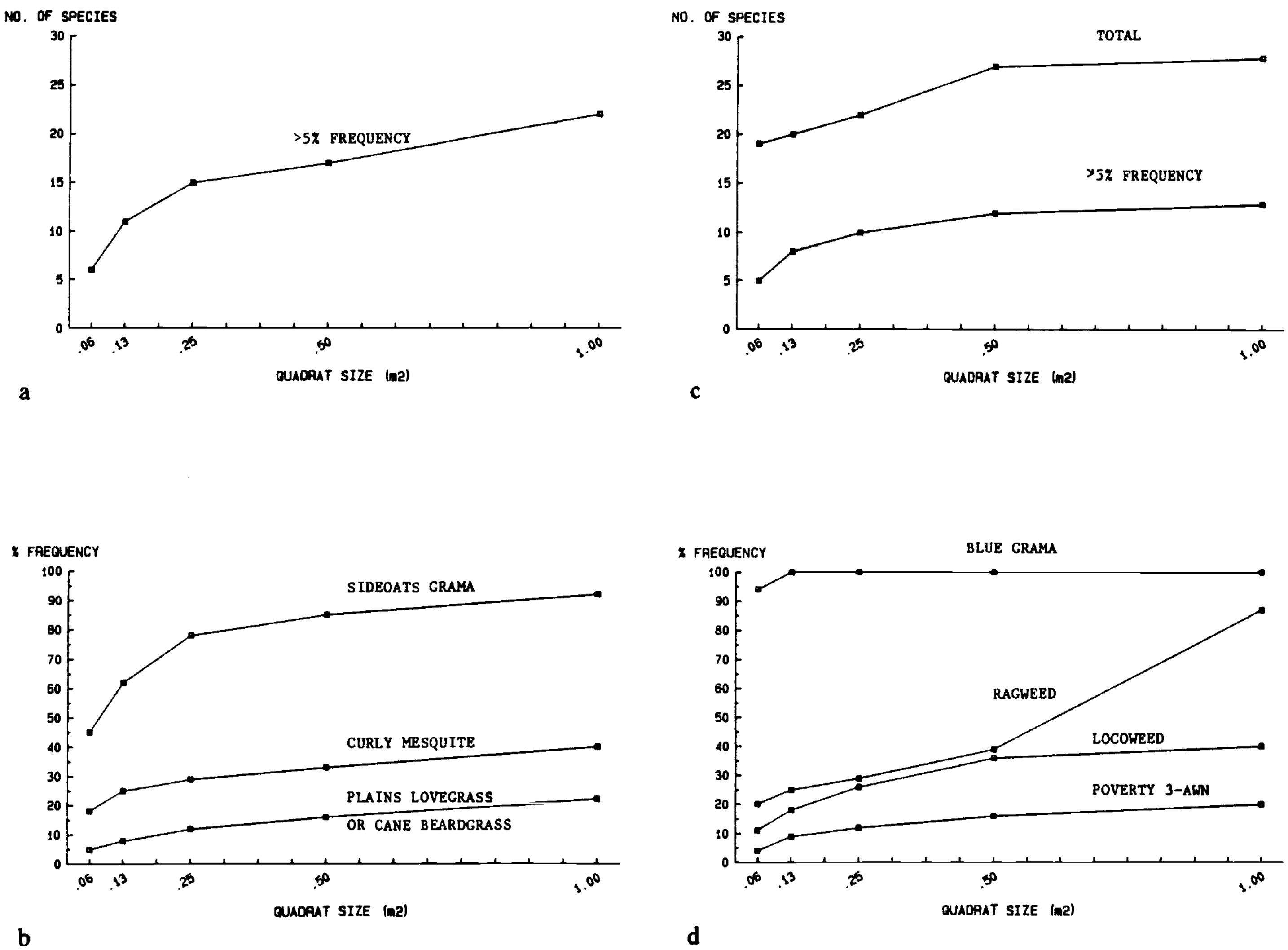

Figure 1. Number of species encountered and/or % of frequency for selected species at 5 locations in Arizona
a,b - Santa Rita Experimental Range near Tucson, AZ
c,d - Near Sonoita, AZ

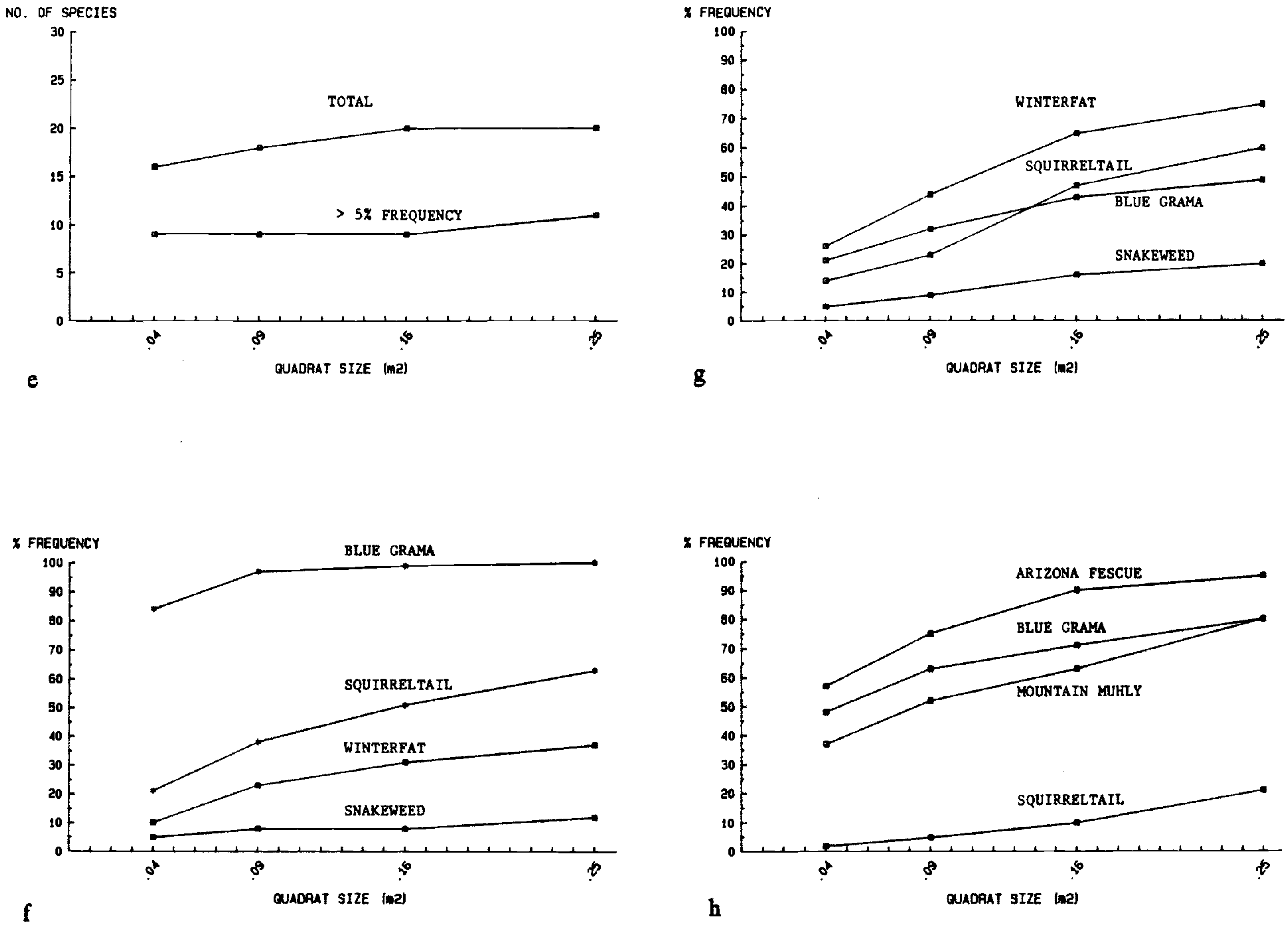

Figure 1. (cont.)

e,f,g	-	Near Meteor Crater, Az
h	-	Near Parks, AZ

examples and others, a square quadrat 40 or 50 centimeters on a side is generally appropriate and is easily handled in the field. Quadrats greater than 1 m^2 are unwieldy and are not recommended. If a species of primary interest is not sampled adequately (>10%) by a practical sized quadrat, a different method should be considered for documenting changes in that species.

Situations arise where one species is very abundant and occurs almost continuously throughout a community with small spacing between individuals. Examples of this are illustrated in Figures 1d and 1f. In Figure 1f, blue grama is highly abundant and dominates the stand. Other species such as squirreltail, a grass, and winterfat, a small woody plant, are common but not nearly as common as blue grama. In this case, a quadrat larger than .1 m^2 would be adequate for most major species, but too large for blue grama. A large quadrat would be necessary if there is concern for sampling a less abundant species such as snakeweed. A quadrat small enough to appropriately sample blue grama would be too small for winterfat. In this case, "nested quadrats" could be used. A small quadrat is nested in the corner of a large quadrat (**Figure 2**) and frequency of the most abundant species is recorded in the small quadrat at the same time other species are recorded for the large quadrat. More than two quadrat sizes will rarely be necessary.

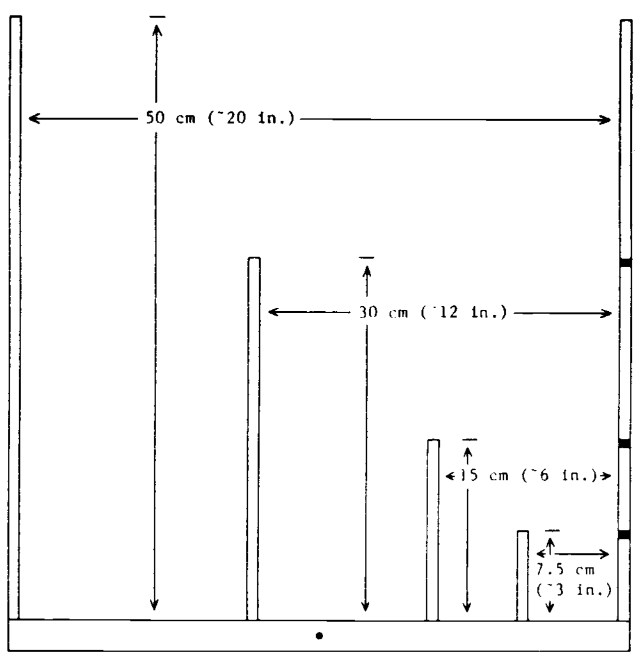

Figure 2: Nested quadrats.

Although a particular sized quadrat might be adequate at the beginning of a study or monitoring program, large increases in the abundance of plants may cause frequencies to approach 100% at some later date. At this point, the ability to track further increases in species frequency is lost and attention can be shifted to a smaller nested quadrat. By recording these species in both sizes of quadrats concurrently for at least one sampling period, time continuity in the data is maintained.

Quadrat Shape

Numerical results of frequency sampling are also dependent on quadrat shape, though to a lesser extent than size. Therefore, as with quadrat size, the same quadrat shape must be used for all sampling for which data are to be compared. Any conventional quadrat shape will provide satisfactory results (The term "quadrat" is loosely defined here to included circular sample units). However, there are some considerations.

Since individuals of a species tend to be symmetrical and often concentrate in patches, a rectangular frame is likely to assess a somewhat different frequency than an equally sized square or circular frame (Mueller-Dombois and Ellenburg, 1974). For sampling most vegetation parameters, a rectangular frame is generally considered the best shape because it least conforms to plant shapes and distribution patterns and samples more variability with each placement of the frame. However, a rectangular quadrat has a longer perimeter than a square or circular quadrat of equal area. Therefore, in frequency sampling, more judgement error is introduced in deciding if a plant is in or out of the quadrat boundaries. A circular frame has the least perimeter per unit area, but is probably the least preferred because the frame shape conforms to plant shape and distribution patterns. Also, a circular frame can be less practical in the field because one side cannot be left open to facilitate placement and still have plot boundaries easily defined. A square quadrat is recommended as a good compromise.

Basis For Recording Presence

The most common criteria for determining plant presence within a quadrat are a) rooted or basal frequency for which a plant must be rooted within the quadrat, and b) cover or shoot frequency for which a species is counted as present if any part of the plant hangs over or occurs within the bounds of the quadrat.

Some have distinguished rooted and basal frequency by defining rooted frequency as using the center of a stem or clump as the criterion of inclusion, and basal frequency as considering any part of the stem or clump. In practice, the distinction is rarely made. Generally, a plant is recorded as present if any part of the plant is rooted within the quadrat. Stoloniferous plants require some judgement as to whether to include rooted nodes or not. Rooted nodes are generally included because it is easier to be consistent and because an individual plant can develop from a rooted node in the event the stolons are severed.

Sample Size and Design

Experience with frequency sampling has shown that vegetation changes often occur as relatively large changes. Regular frequency measurements can provide the signal that a change has occurred, and field observation can determine if the signal is biologically realistic.

The number of quadrats to be sampled depends upon the objectives of the sampling and is usually determined as a balance between a practical number which can be sampled on a regular basis and a number which is statistically sensitive to changes. Two hundred quadrats appears to be a reasonable compromise between data needs for statistical rigor and needs to identify biologically meaningful changes. Generally, it is better to take samples of this size on a regular basis than to undertake a more ambitious sampling program which dies because too much effort is involved. One hundred quadrats is the minimum number recommended at each sample location. If frequency data are analyzed strictly on a statistical basis and the objective is to identify small magnitudes of change with a high degree of probability, large samples of 500 to 1000 quadrats may be required (Wysong and Brady 1987).

Sampling design or arrangement of quadrats at a sample location or macroplot also is a matter of both statistical validity and practical application. Frequency data are enumeration data (presence or absence) and are discrete. Such data fit a binomial population distribution and statistical analyses may utilize binomial confidence intervals or Chi-square analyses. The sampling unit in this situation is the individual quadrat and strict statistical theory requires that each quadrat be independent and randomly located within the macroplot. The macroplot may be divided into a limited number of blocks and each block sampled with random placement of quadrats.

If normal statistics (t and F tests) are used to evaluate the statistical validity of differences among blocks within macroplots, years or sample areas, a sampling design which groups quadrats into transects may be used with the transect mean or total used for analysis. In this case, data are continuous and transect means should approach a normal distribution. The design should maximize the number of transects (to maximize the number of degrees of freedom for error) but should include enough quadrats in each transect so that few transects have zero values for any species of interest. For 200 quadrats, 10 transects of 20 quadrats each is often a reasonable choice (Tueller et al. 1972). The transect is the sample unit for analysis, and statistical theory requires that transects be randomly and independently located within the macroplot to be sampled.

In the field, strict randomization of quadrats or transects is rarely practical. Generally, quadrats or transects are located systematically from random or systematic starting points. If quadrats are at least one or two paces apart, they probably very nearly meet the independence criterion (Yavitt 1979). Systematic sampling usually will yield data which are more precise than random sampling (Cochran, 1977). However, exact confidence limits are not known and systematic sampling can be criticized as incorrect for strict statistical interpretation.

A practical sampling design when using binomial statistics with the quadrat as the sample unit, is to divide a macroplot into about four blocks. Samples within each block should at least approach being random and independent. If normal statistics are to be used for analysis, the data may be collected by transects with starting points located systematically or randomly along a baseline. Orientation of the baseline and subsequent placement of quadrats should fit the area to be sampled.

Statistical analysis methods and examples are given in **Appendix A.**

Recording Data

The first time a location or macroplot is sampled, ground rules should be clearly established and recorded for future reference. Later adjustments should likewise be noted. Ground rules to consider include:

- Criteria for determining presence for each species or life form.
- Which species, if any, are to be lumped together (e.g., annual forbs or species difficult to distinguish such as 3-awns or some gramas).
- Whether to include seedlings and whether to separate any species into age classes. Seedlings, especially for species with low rates of seedling survival, may by excluded from the sampling or tallied separately to avoid wide fluctuations in the data which are season or climate related.
- Are annuals to be recorded, and if so, do they have to be alive and green or dry but rooted and standing.
- Sampling design, including any portions of the site to be avoided in sampling such as inclusions of atypical soil or vegetation.

Generally, data should be collected on a species by species basis. Consistency in species identification and use of criteria for determining presence or absence are essential. Rooted frequency is recommended for herbaceous plants and small shrubs and half-shrubs. Canopy frequency is suggested for larger shrubs. For intermediate sized shrubs or half-shrubs, the criteria for determining presence may depend on shrub density. Often, cover frequency is used for all shrubs in the interest of simplicity and consistency.

Summaries of data from previous sampling periods should be taken into the field for reference to assist in maintaining consistency in species identification. Having previous years data in the field also helps to interpret causes for observed changes while at the monitoring site. Recording species observed in previous sampling periods on field forms prior to sampling helps observers with consistency in identification. It also helps with on site comparison of current years data with previous years because species are in approximately the same order on the data sheets as on previous years summaries.

Perhaps the most common and significant problem in comparing data over time is in treatment of similar species. For example, two similar species may be separately identified on one occasion and combined as one species on another. Or, attempts may have been made to separate the species on each occasion, but the data reveal those attempts to be inconsistent. In these situations it is necessary to combine data for the two species and evaluate them as a complex. However, this can only be done if the data are collected on a quadrat by quadrat basis rather than tallied. When both species are recorded for the same quadrat, credit can be given for only one hit when the data are combined. Therefore, frequency values cannot be directly summed, but must be redetermined from the recorded hits for each individual quadrat.

Appendix D includes an example of a BLM form used for recording frequency on a quadrat by quadrat basis. This form does not allow for nested quadrats, but in combination with other examples in Appendix D, provides ideas for developing appropriate forms for particular needs. Data entry using hand held computers or data loggers may facilitate quadrat by quadrat entries and summary.

When nested quadrats are used, it is sometimes useful to collect data for the same species in both quadrats concurrently. In this case, a plant present in the nested quadrat can be recorded for the small quadrat only, as it automatically occurs in the larger quadrat. Frequency for that species in the large quadrat is then determined by summing the hits for the large and small quadrats. Appendix D includes a form used by the BLM for recording frequency in nested quadrats.

Analysis and Interpretation

An emphasis on interpretation of frequency changes while at the site of measurement has already been suggested. It is important to have data from previous years in a form that can readily be compared with current year data while at the monitoring location. A summary of data for the monitoring location, such as shown in **Appendix B**, is satisfactory for this purpose and is easily updated. A major benefit of a monitoring program is the discussion of data at the collection site by interested parties at the time the data are collected.

Data should be compared for frequency changes from one year to the next on a species by species basis. Binomial confidence intervals (**Appendix C**) can be utilized to help identify the magnitude of changes which indicate a change greater than what might be expected from sampling variation. For example, the data in Figure 3 (from Appendix B) are from a 200 quadrat sample at the 95% confidence level. Frequency of hairy grama for 1982 is 25% with confidence limits from 19% to 31%. In 1983, frequency of hairy grama was 36% with confidence limits of 29% to 43%. Confidence intervals overlap, so the difference could be due to sampling variation. Confidence intervals do not overlap at a probability of 80%. Statistical analyses of data for this species are detailed in **Appendix A**.

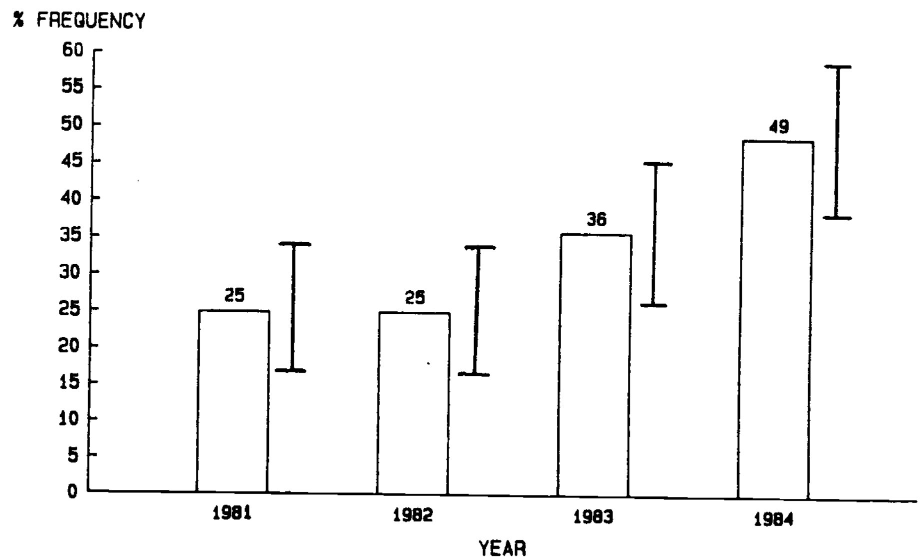

Figure 3: Four years of data for hairy grama from Slash S ranch monitoring site 2 (see Appendices A and B).

This change is large enough that observations of this species in the field should be made to determine if there might be some explanation for the change, such as an indication of new plants in the system. This was the case in this situation and a note was made that numerous young plants were observed. That these young plants probably maintained themselves and additional recruitment occurred is substantiated in the 1984 data where frequency of hairy grama increased to 49%. A similar observation was made for plains lovegrass for the 1982-1984 period (Appendix B). These changes were interpreted as a response to summer deferment of grazing in 1981 and 1982, heavy grazing with favorable precipitation in 1983, followed by summer deferment and favorable precipitation in 1984.

It was concluded that the changes were desirable and that the deferred rotation grazing system, utilization levels and favorable rainfall were providing for upward trend at the monitoring location.

As was pointed out, frequency is a combination of species attributes including density, dispersion and cover. The relationship of frequency to plant density is curvilinear. Frequency changes should not be expressed as percentage changes in density. A change in frequency at low values does not reflect density changes of the same magnitude as changes at high frequency values. For randomly distributed plants, the curvilinear relationship between frequency and density are given in **Figure 4**.

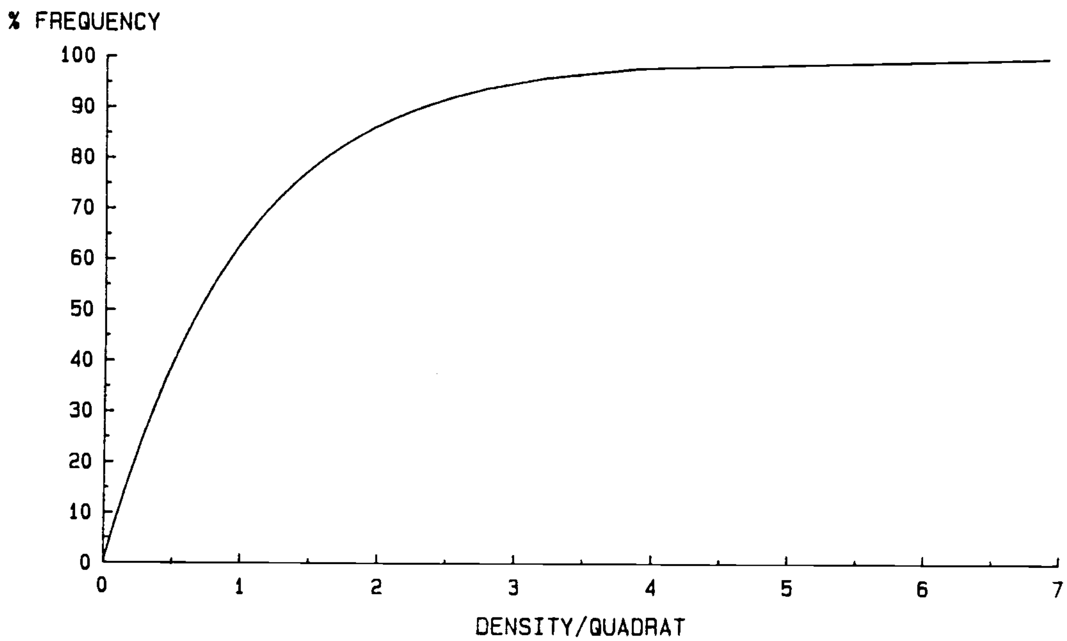

Figure 4: Relationship between density and frequency for a random population.

Advantages and Disadvantages

As with all vegetation sampling methods, the frequency approach has both advantages and disadvantages.

Advantages

1. **Objectivity**
   No estimation or subjective evaluation is necessary. The only decisions made by the observer is whether a particular plant is present within the quadrat and the identity of the plant. Objectivity provides better repeatability of results over time and among different observers.

2. **Rapidity**
   Quadrat frequency is a relatively rapid approach to monitoring vegetation changes with respect to value of the data collected.

3. **Simplicity**
   Relatively little training or practice is necessary for consistent application of frequency procedures and the data obtained are easily summarized and evaluated.

4. **Low sensitivity to periodic fluctuations**
   Rooted frequency data are relatively insensitive to periodic fluctuations in vegetation structure due to grazing or changes in phenology. This is less true for cover frequency.

5. **No distinction of individuals**
   There is no need to distinquish individuals in frequency sampling which can be a problem with indefinite individuals such as sod-forming grasses. This is an advantage only in comparison with density techniques.

6. **Function of both density and dispersion**
   Frequency values depend upon both the density and the dispersion or distribution of individuals. Therefore, frequency will detect changes in plant distribution as well as abundance. This can also be a disadvantage as pointed out below.

Disadvantages

1. **Function of both density and dispersion**

   Sensitivity of frequency to both density and dispersion can be a disadvantage as well as an advantage. It is difficult to determine which characteristic is indicated by changes observed in the data without supporting data from other parameters. Long term range health is, overall, more a concern of abundance than of dispersion. Frequency data can show significant changes in percentage values where no real changes in abundance actually exist. This problem arises more often when comparing two stands for differences than when observing one stand for changes over time.

2. **Data are non-absolute**

   Though often correlated, frequency does not necessarily relate directly to more concrete parameters such as density, weight, height, volume or any criteria related to the amount of a species present at a location. Species frequency data are not generally useful for evaluating vigor, production, or dominance. This limits the use of frequency to comparisons in space or time such as monitoring trends in abundance related to loss and recruitment (confounded with changes in distribution patterns). Also, different species cannot be readily compared with each other unless their size and structure are similar, or when frequency is combined with other data or knowledge relating to size of the plant.

3. **Values dependent on quadrat size**

   Frequency values are dependent upon the size of the quadrat used in sampling. Therefore, data collected with different sized quadrats are not comparable.

4. **Not well suited to larger shrubs**

   Because of wide spacing of large species, a quadrat large enough to adequately sample these species becomes unwieldy or impossible to use. Use of shoot or cover frequency can often be useful for evaluating shrubs, but where individual plants are widely scattered, may still be inadequate. The same can be said about uncommon, small species, but the issue of large shrubs is usually more important because of potentially strong influence on the community despite fewness of numbers. Quadrat frequency procedures are generally not well suited to shrubland vegetation types such as chaparral or Sonoran shrub types.

Appropriate Use of Frequency for Range Monitoring

Each parameter sampled and each method used to sample it have their advantages and disadvantages and have purposes to which they are most suited. The same is true of frequency data. Plant frequency data are useful because they are relatively easy and fast to collect, can be statistically evaluated, and indicate changes in species abundance and distribution. Because frequency data are non-absolute, they only indicate a change is occurring and which species are changing. The nature of those changes is not very well established from frequency data alone.

Frequency is an appropriate "indicator" of range trend, but unwarranted conclusions should not be drawn from frequency values alone. Other parameters provide more information than frequency alone and should be used where necessary. Frequency combined with other parameters is especially useful. However, other parameters are more expensive to obtain and are not always practical for wide spread monitoring.

A good analogy has been used to describe the appropriate use of frequency monitoring. A doctor monitors a patients blood pressure for indication of heart problems. When an increase in blood pressure is detected, the doctor does not immediately perform open heart surgery. Rather, additional tests are run to confirm and pinpoint the cause of the rise in blood pressure. Then appropriate action is taken.

Frequency monitoring should be considered in range management in a similar way as blood pressure monitoring is used by a doctor. When a consistent change in frequency of one or more species occurs, it may be necessary to take a closer look to determine the nature and cause of those changes. This may require performing additional "tests" such as more intensive monitoring of additional parameters. Lack of consistent trends in frequency values indicate little change in the vegetation and efforts can be concentrated elsewhere where frequency values are changing.

Frequency should be used only in those vegetation types and situations where it is appropriate (RISC 1983). Results should not be inappropriately extrapolated beyond the location sampled.

Comparison with Other Monitoring Methods

How does frequency sampling using quadrats compare with other methods commonly used to monitor rangelands? There is not as much difference as it may seem for many of these methods. Some of the most common methods used by range managers now and in the past can be compared with frequency to assist in understanding use of the method. Also, the use of ground cover sampling popularly included with frequency sampling will be briefly discussed.

Point Methods

Various "point" sampling procedures, such as the "step-point" and "Parker 3-step" methods, have been used extensively by land management agencies for monitoring trends in range condition. The basic concept behind these procedures is essentially the same as that of quadrat frequency except that a point is used as the sample or sub-sample unit rather than a quadrat. In fact, data collected with point sampling methods can be evaluated as frequency data; i.e. the number of hits on a plant species as a percentage of the total number of points read. However, because a point is essentially dimensionless, the data are usually used as absolute measures of cover, basal area or whatever the criteria used for determining "hits".

There are advantages to the direct quantitative information provided by point procedures as opposed to the relative nature of frequency data. However, disadvantages of point sampling often out-weigh the advantages. The main disadvantage of point procedures is the large number of sample points usually required for an adequate sample size. Large sample sizes are required because many placements of the point encounter no plants at all. Another disadvantage of point methods relates to lack of repeatability over time and between observers. It is difficult to place a point without any bias. The slightest shifting of a point may change the reading and two observers may see it differently anyway.

Point Frame

One approach that is occasionally used to help overcome disadvantages of point sampling is to place a series of pins in a frame. These "point frames" allow for rapid sampling of points by providing several sample points at each placement of the frame. At the same time, the pins are held rigid in position such that there is less bias in the placement of the pin for sampling. The main drawback to this approach is that the sample points within each group or frame placement are so close together as to lack independence. In other words, the points are not independent of each other as related to size of a plant or patterns of plant distribution. For example, all or a portion of the points in the frame may hit the same shrub. This can cause biased sampling results with the principal bias in favor of large or aggregated species.

Step-Point

Another common attempt to remedy the drawbacks of point methods is to record the nearest plant to the sample point whenever a direct hit is not made. This gives a recorded hit each time the point is placed, reducing the number of points that must be sampled and reducing observer inconsistencies or errors in reading the hits.

This approach has several problems stemming from the fact that the method is not really a point method. It is a quadrat based frequency method except that the quadrat varies in size with each placement of the point (quadrat). The size of the quadrat at each placement is determined by the distance to the nearest plant. The quadrat is circular in shape, or a half-circle when only plants in front of the point are considered (such as when the tip of the boot is used as the point). If the closest plant is determined based on any plant part, it is cover frequency. If the criterion is the closest plant at its rooting point, it is rooted frequency.

There are three problems with nearest plant frequency data. First, each "quadrat" is of a different size such that the data have no meaning until combined for determining composition. Second, when composition is determined, the data for each species are no longer independent. A change in the density of one particular species will cause a change in data values for other species regardless of whether the abundance of the other species has changed or not. This means it is impossible to determine which species are changing and whether they are increasing, decreasing, or some of each. Third, small, dense species such as some grasses and small annual forbs are greatly overemphasized.

Parker 3-Step

The Parker 3-step method (Parker 1951), widely used by the USFS, is another attempt at overcoming disadvantages of point sampling. In the Parker method, the size of the "point" is increased to 3/4 inches in diameter to reduce error in determining hits. The "point" is kept consistent in size and is kept small so that the data can be evaluated as cover data. Increasing the size of the "point" such that it has dimensions creates a bias in the data when interpreted as cover data. Thus, an estimate of cover by the Parker method is considered a biased estimate of cover. This bias is generally not considered high enough to cause significant problems in interpreting the data, although at times it can be significant. A major disadvantage of the small 3/4 loop used in the Parker method is that although slightly increasing the size of the "point" helps increase repeatability in sampling, it does not greatly reduce the sample size required for adequacy of sample. The 300 points typically sampled are often inadequate.

Since only species presence or absence is recorded, data collected with the Parker method using a 3/4 loop can appropriately be analyzed as frequency data. However, the 3/4 inch loop is too small for most species to be useful for frequency data.

Ground Cover

A popular addition to monitoring plant frequency has been point sampling of ground cover. Usually, one or more points are marked on the quadrat frame. At each placement, the type of ground cover occurring beneath each point is recorded. Cover type categories are usually general, e.g. bare ground, rock, litter, etc.. Although a reading is obtained at every placement of a point (unlike plant cover), point sampling of ground cover still often requires a larger sample size than quadrat frequency. One remedy is to read more than one point per placement of the quadrat. This results in a clustered sampling and may result in bias due to lack of independence between points.

Ground cover data are useful, and may also indicate changes in range trend. Ultimately, ground cover or other soil features may be the best indicator of long term site stability and potential productivity. However, our current understanding of what parameters to monitor and how to monitor them is still limited.

It should be emphasized that point sampling of ground cover involves a different parameter and is a procedure additional to, rather than a part of, plant frequency sampling. Therefore, the proper sampling and evaluation of ground cover must be considered separately from frequency in selecting the best methods. Then it can be considered how best to simultaneously handle the two procedures most effectively in the sampling scheme.

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Chapter Three

The Dry-Weight Rank Method of Estimating Plant Species Composition

E.L. Smith and D.W. Despain

Desirable sampling techniques for range inventory and monitoring should have several characteristics. The first is that they should provide for an accurate and repeatable characterization of a plant community. Because of the variability in range vegetation this requirement implies a large sample size, therefore a method which sacrifices accuracy for speed of individual observation to obtain increased sample size usually produces better information for a given sampling time than one which requires more time per observation. The second is that different observers should get similar results, i.e. the procedure should be objective and simple to minimize personal bias. Third, methods should be adaptable to a variety of sampling situations without the need for extensive calibration. Fourth, the data must provide useful information, that is, they can be interpreted as a basis for decision making.

Frequency meets the first three requirements very well. It may not provide all the information needed for certain purposes, however. Although it provides an excellent record for monitoring trend in abundance of individual species, there are some important limitations on interpretation of frequency data. One is that data obtained from different quadrat sizes are not comparable. Another is that frequency does not always relate well to the ecological importance or contribution to forage production of a species, especially where different life forms are involved. Finally, frequency of different species cannot be added together to form simple categories (such as forbs, grasses, shrubs) unless the data are recorded separately for each quadrat, and even then the significance of such data may be unclear.

For some purposes it is desirable to have estimates of species composition on a dry weight basis. Composition by weight is probably the best measure of the relative importance of a plant in the community, and for this reason is used in some methods for evaluating range condition. When combined with forage value ratings of individual species, it can be used to indicate relative forage supplying capability of a stand.

Species composition may be estimated by experienced observers by an overall assessment of a stand or mapping unit. Such estimates are adequate for most management decisions, but are highly subject to personal bias and provide no measure of precision of estimate. Composition may also be estimated in a number of sample quadrats and the results averaged for the stand. Use of quadrats reduces observer bias by focusing attention on a small area, and it provides a measure of precision for the mean estimate. However, deciding on percentages to assign to each species in a number of quadrats is time consuming, especially if there are several species in each quadrat.

The dry-weight-rank (DWR) procedure was developed in Australia for estimating species composition by weight in pastures (Mannetje and Haydock, 1963). It is similar to direct estimation of composition by species in quadrats except that in DWR the observer only ranks the three species which contribute the highest percentage to the weight of the quadrat. Since it is not necessary to rank all species and because it is usually easier to decide the order of species than to assign percentages to each, this method is faster than direct estimation of composition. It easily can be combined with any method using quadrats, such as frequency or canopy-cover estimates. If actual weight (pounds/acre or kilos/hectare) of each species is desired, percent composition by weight may be multiplied times total dry matter yield obtained by the comparative yield method (see Despain and Smith, this volume) or other techniques.

Since 1982, the DWR method has been extensively tested by the University of Arizona in a variety of vegetation types. It has also been tested on rangeland in other areas, such as Colorado (Hughes, 1969), Oklahoma (Gillen and Smith, 1986), Africa (Kelley and McNeill, 1980), and Australia (Friedel, et al. 1988). Although research done in Colorado concluded that it was not satisfactory for research purposes, the general conclusion elsewhere has been that it is a rapid and useful technique for range inventory and monitoring.

In this paper we describe the procedure for using the technique, assumption and constraints in using it, and the results of some of our testing of the method in Arizona.

Procedure

Training

Our experience is that very little training is necessary for observers to accurately rank species in order of dry weight. Furthermore, it is not usually feasible to do training in the field since the ranking is done on dry weight and not field weight. However, some experience in weight estimate is highly desirable so that observers have some "feel" for differences in plant weight associated with moisture content, plant morphology, and phenology. If vegetation is relatively mature and dry this can be approximated by clipping and weighing different plants in the field.

The main training needed for people experienced in weight estimate is to get them to: (1) break the habit of trying to assign percentages and to think in terms of rank, and (2) not agonize over close calls but to assign a rank and get on with it.

Quadrat Size, Layout and Sample Site

Quadrat size is fairly flexible. In most of our use of this method the quadrat size has been determined to meet the requirements for techniques used in combination with DWR (such as frequency) and it has given acceptable results. Quadrats may be located in any manner – random, systematic grid, or in transects. As with any other sampling method, some type of randomization is needed for statistical analysis of the data.

The number of sample units (quadrats or transects) depends on the variability of the vegetation with respect to quadrat size and shape. We have not tested optimum sample size for DWR because, so far, we have not done statistical tests or set confidence intervals on the data obtained. Usually we have made observations on 100-200 quadrats per sample location because that is the number of quadrats desired for frequency sampling. It is likely that in fairly uniform vegetation, 25-50 quadrats may give a repeatable estimate of composition of the major species.

Data Collection

At each quadrat the observer simply decides which three species in the quadrat have the highest yield on a dry matter basis. The highest yielding species is given a rank of 1, the next highest 2, and the third highest a 3. All other species present are ignored, although they may be recorded for frequency.

The portion of a plant which contributes to the ranking of weight is any part of the plant occurring within a vertical projection of the quadrat perimeter. Plants do not have to be rooted in the quadrat.

The data may be recorded in two ways. If it is desired to record the data separately for each quadrat they may be recorded as shown in **Figure** 1 and 2. Otherwise, the ranks for each species may be tallied for all quadrats in the sample, or in a transect, as shown in **Figure** 3. Unless it is desired to weight individual quadrats by their yield (as explained later) there is no reason to record the data on a quadrat by quadrat basis.

If some quadrats have less than three species, two alternative procedures may be followed. One is to merely assign a rank to the species present and ignore the rank of 3 (or 2 and 3 if only 1 species is present) (see Figures 1 and 3). We call this the method of *single ranks*. An alternative is the method of *multiple ranks*, which involves assigning more than one rank to some species (see Figure 2 and 3). In effect, the DWR method assumes that a rank of 1 corresponds to 70% composition, rank 2 to 20%, and rank 3 to 10%. Therefore if only one species is found in a quadrat it may be given rank 1, 2 and 3 (or 100%). If two species are found one may be given ranks 1 and 2 (90%), ranks 1 and 3 (80%), or ranks 2 and 3 (30%) depending on the relative weight of the two species.

Species	Dry-Weight-Rank Quadrat Number																									Rank Tally			Weighted	Percent Composition
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	1	2	3		
A	1	2	1	1	3	2	1		1	1	3	3	1	2	1	2	1	3	2	1		1	1	3	2	12	6	4	100	43
B	2	1	3	2	1			3	2	2	2	1	3		2			1	1	2				2		5	8	3	54	24
C	3		2		2	1		2		3	1		2	1		1	2		3						3	4	5	4	42	18
D		3		3				1				2			3		3				1					2	1	4	20	9
E																									11	2	0	0	14	6
Total																										25	20	15	230	100

Figure 1. Dry-weight-rank data on individual quadrat basis. Not all quadrats have three species, single ranks assigned.

Species	Dry-Weight-Rank Quadrat Number																									Rank Tally			Weighted	Percent Composition
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	1	2	3		
						2	1															1	1							
A	1	2	1	1	3	3	2		1	1	3	3	1	2	1	2	1		2	1		2	2	3	2	12	9	9	111	44
							3															3	3							
									2									1												
B	2	1	3	2	1			3	3	2	2	1	3		2			2	1	2				2		5	9	5	58	23
																		3												
C	3		2		2	1		2		3	1		2	1		1	2		3						3	4	5	5	43	17
														3																
																					1									
D		3		3				1				2			3		3			3	2					2	2	6	24	10
																					3									
E																								1	1	2	0	0	14	6
Total																										25	25	25	250	100

Figure 2. Dry-weight-rank data recorded in 25 individual quadrats. Not all quadrats with three species, multiple ranks assigned.

Spp	SINGLE RANK METHOD: Rank Tally			Weighted	Compos. %	MULTIPLE RANK METHOD: Rank Tally			Weighted Σ	Comp. %
	1	2	3			1	2	3		
A	(12)	(6)	(4)	100	43	(12)	(9)	(9)	111	44
B	(5)	(8)	(3)	54	24	(5)	(9)	(5)	58	23
C	(4)	(5)	(4)	42	18	(4)	(5)	(5)	43	17
D	(2)	(1)	(4)	20	9	(2)	(2)	(6)	24	10
E	(2)	(0)	(0)	14	6	(2)	(0)	(0)	14	6
Total	25	20	15	230	100	25	25	25	250	100

Figure 3. Dry-weight-rank data tallied for 25 quadrats using single or multiple ranks.

Calculations

Figure 4 shows the method of calculation of percent composition using either single or multiple ranks. The procedure involves calculation of a weighted average and is the same in either case:

1. For each species record the number of 1, 2, or 3 ranks received in the sample. (In the example the number of quadrats observed was 25).

2. For each species multiply the number of ranks of 1, 2 and 3 by 7, 2, and 1 respectively and record under the appropriate weighting column. Add the weights and record under weighted.

3. Total the weighted column across species. If multiple ranks are assigned the total of this column will always be ten times the number of quadrats. If single ranks are assigned and some quadrats have less than three species the total of the weighted column will be lower.

4. Divide the value recorded for each species in the weighted column by the total of the weighted column to get percentage composition for each species. Percent composition, by definition, should total 100 percent.

Single Ranks								
Species	Rank Tally			Weighting			Weighted	% Composition
	1	2	3	7	2	1		
A	12	6	4	84	12	4	100	43
B	5	8	3	34	16	3	54	24
C	4	5	4	28	10	4	42	18
D	2	1	4	14	2	4	20	9
E	2	0	0	14	0	0	14	6
Total	25	20	15				230	100

Multiple Ranks								
Species	Rank Tally			Weighting			Weighted	% Composition
	1	2	3	7	2	1		
A	12	9	9	84	18	9	111	44
B	5	9	5	35	18	5	58	23
C	4	5	5	28	10	5	43	17
D	2	2	6	14	4	6	24	10
E	2	0	0	14	0	0	14	6
Total	25	25	25				250	100

Figure 4. Calculation of percent composition using hypothetical dry weight rank data with either single or multiple ranking. Data are same as in Figures 1-3.

Assumptions and Constraints

Multipliers

The original research on this method (Mannetje and Haydock, 1963) derived the multipliers (or weighting factors) empirically based on a number of data sets. The factors published were rank 1 = 70.19%, rank 2 = 21.08% and rank 3 = 8.73%. The sum of these is 100%. These weightings were used when all ranks were assigned, i.e. when all quadrats had three species or multiple ranks were used. If single ranks were used and some quadrats had less than three species the ranks were weighted by a ratio of the percentages shown above. In this case Rank 3 = $^{8.73}/_{8.73}$ = 1; Rank 2 = $^{21.08}/_{8.73}$ = 2.41; and Rank 1 = $^{70.19}/_{8.73}$ = 8.04.

Some people have questioned whether these same multipliers should be extended to other vegetation types, and some have empirically derived and published their own multipliers. In each case these multipliers differed slightly from those of Mannetje and Haydock (1963). We have not derived any multipliers based on our own data. However, we have tested several sets of published multipliers on our data sets and found that it makes very little difference in the composition estimates. Our conclusion is that the published multipliers may be used with very minor effects on accuracy of estimates. This conclusion was also reached by Kelley and McNeill (1980).

Since the precise value of the multipliers does not seem of major concern, we usually use the values of 70%, 20% and 10% which are approximately the same as the published values. In this case the ratios among multipliers are the same as the percentages, i.e. Rank 3 = ${}^{10}/_{10}$ = 1; Rank 2 = ${}^{20}/_{10}$ = 2; Rank 3 = ${}^{70}/_{10}$ = 7. Thus the same weightings can be used whether simple or multiple ranks are assigned.

Accurate Ranking of Quadrats

For the DWR method to work it is necessary that most quadrats be accurately ranked. In other words the observer must be able to pick the three top species in correct order. This requirement is obviously important if estimates by DWR for one sample location are to be acceptably similar to estimates produced by clipping or weight estimate at the same time and location. It is also important to know that different observers will produce comparable results, especially in monitoring where data are often collected by different people at different times.

Based on a number of tests we have concluded that errors due to faulty rankings and to difference among observers are negligible. Furthermore, observers can achieve good results with minimal training and experience.

Usually the distinction between Rank 1, 2, and 3 is quickly obvious. In those cases where it is not, observers should be instructed to not worry about a wrong decision. The advantage of this method is speed which allows a large sample size. A few erroneous rankings are not serious in a large sample. Of course misplaced rank would have greater effect in the estimate in a small sample than in a large sample.

Three Species per Quadrat

A basic assumption is that there should be at least three species encountered in a high percentage of quadrats, preferably all of them. Whether three species occur in a quadrat depends on the size and density of plants relative to the size and shape of quadrat used. In any given situation, the larger the quadrat the higher the percentage of quadrats with three or more species. Theoretically, a rectangular quadrat should provide a higher number of species per quadrat than square or circular quadrats, since they are less apt to be occupied by one large plant or clump of plants of the same species. Although we have not tested quadrat shape, the effect is likely to be practically insignificant in our judgment.

Most of the work we have done with DWR has been in 40 x 40 cm quadrats (16 x 16 inches) which is the size commonly used for frequency (Despain, Ogden and Smith, this volume). With this quadrat size the assumption of most quadrats having three species is usually not met, especially in sparser vegetation types. Tests of different quadrat sizes ranging from 40 x 40 cm to 100 x 100 cm ($1m^2$) showed that the percentage of quadrats having three or more species could be increased to about 60%, which is still not a very high percentage. A quadrat larger than $1m^2$ does not seem practical to use in most situations.

The work on quadrat size also showed that estimates of species composition based on nested quadrats of 40 x 40, 50 x 50, 50 x 100 and 100 x 100 cm did not differ significantly. Therefore, we concluded that the percentage of quadrats with three species is not very important.

When less than three species are found in a quadrat, multiple ranks can be assigned as described earlier. Although our work has shown that the use of multiple ranks does not change composition estimates very much, we recommend multiple ranking as standard practice.

Correlation of Ranks with Yield

Another assumption of the DWR method is that the rank of a given species is not correlated with total quadrat yield, that is, a species does not tend to occur mainly in high or in low yielding quadrats. The weighting factors (70, 20, 10%) used in calculating percent composition treat all quadrats as if they weigh the same. If species A tends to be ranked mainly in above average quadrats and species B tends to be ranked mainly in low- yielding quadrats, then the composition of A in the community will be underestimated and that of B overestimated.

If this situation occurs it can be corrected by weighting the ranks assigned to each quadrat by the yield of the quadrat (Jones and Hargreaves, 1979). Quadrat yield can be estimated in grams or can simply be ranked on a 3 or 5 point scale as is done in the comparative yield method (see Despain and Smith, 1987). Using this procedure composition for a given species is based on not only the number of quadrats in which its composition is estimated as 70%, 20%, 10% or 0%, but also the relative yield of those quadrats. Composition of a species which tends to occur in high-yielding quadrats will then increase.

In tests on a number of different sample areas, we found that weighting the ranks by plot yield did not often change by very much the similarity of species composition estimates based on DWR to those based on actual clipping and weighing. It is easy to visualize situations where the correlation in species occurrence and quadrat yield would occur and cause significant error. For example in a community characterized by large bunchgrasses (e.g. sacaton or big galleta) intermixed with sparse annuals or forbs, the bunchgrass would tend to get ranking of 1 (or even 1, 2 and 3) in quadrats where it occurred. Forbs or annuals would be ranked in the others. Since the bunchgrass dominated plots might yield several times more than the others, the composition of bunchgrass could be grossly underestimated. There are two drawbacks to weighting by quadrat yield. One is that an additional rating must be made, which requires extra time and is itself subject to error. The second is that data must be taken on an individual quadrat basis rather than by simply tallying. Although these problems are not difficult to solve, the extra time and complication of the data collection required have not been worth the effort in our opinion, since the problem of correlation of ranks and yield has not been too significant in most of our sampling. In communities where the problem obviously exists, weighting by yield is advisable.

Where is the DWR Method Useful?

The DWR method has shown very good results for characterizing herbaceous vegetation, with or without a mixture of half-shrubs. There is no theoretical reason why it could not work where the vegetation is composed mainly of larger shrubs. There are two practical reasons why it probably will not work very well. One is that unless shrub cover is very dense, a large percentage of small quadrats will be vacant of shrubs, and in those where shrubs occur only one species will likely be encountered. Thus it is not practical to use a quadrat large enough to make the method work in stands of large shrubs. The other reason is that it is difficult to determine how to rank shrubs and even more difficult to check these estimates by clipping or estimating. Usually we wish to estimate "current growth" of shrubs, not total standing crop. On evergreen species and succulents, e.g. juniper, cholla, yucca, prickly pear, this is next to impossible by any method.

In very sparse desert shrub vegetation the DWR method may not work too well. This is because the small quadrat size will result in many quadrats where nothing occurs. This does not invalidate the procedure, as it would in frequency, or invalidate statistical analysis, as it would for weight or cover data. However, since blank quadrats furnish no data, it does make the procedure inefficient. The only solution is to increase quadrat size. Anyone who has carried a large quadrat or tried to objectively place one on the ground in desert shrub situations knows there are limits to quadrat size.

We therefore think that DWR is a good method to characterize grassland/small shrub types (including sagebrush) and understory of mesquite, juniper, ponderosa pine or other wooded types. It probably is not very useful in chaparral or very sparse desert shrub types.

Field Tests of the DWR Method in Arizona

Accuracy of the Method and Composition of Observers

A number of tests were done to see if the DWR method would produce composition estimates comparable to those derived from clipping and weighing the same quadrats. The DWR estimates were made independently by several observers to see how well they compare.

Table 1 shows a typical trial. In this case three observers rated each of 100 plots 40 x 40 cm in size. The plots were then clipped by species and weighed. The percentage composition could then be calculated based on: (1) the clipped weight, (2) the true ranking of species based on clipped data, and (3) the estimated ranking by three observers. The results show that the composition of the community was 90% similar when "clipped composition" was compared to "actual DWR". The three observers ranged from 95-98%

similar to "actual DWR". This table shows the estimated composition of each species, and thus gives an idea what these similarity values mean. It can be seen that the three observers and actual DWR are closer to each other than they are to the clipped composition. This indicates that observers are quite accurate in ranking species. Most of the error is in the method, not among observers.

Table 2 shows data from five additional locations with two or three observers. The figures show the percent similarity of estimates by DWR for each observer to those estimated from clipped data. In parentheses, the similarity to DWR estimates based on clipped data is shown. Again it can be seen that there is more difference between clipped and DWR estimates than among observers. In interpreting the percent similarity figures, it may be useful to know that some ecologists have stated that similarity in excess of 75% probably indicates that samples are drawn from the same population.

Tables 3 and 4 show a comparison of three observers using DWR in two very different vegetation types. Table 5 shows similarity among observers for nine locations in different vegetation types in southern Arizona.

From these tests we concluded that the DWR procedure produces composition estimates very close to those calculated by clipping, drying and weighing the same quadrats. Furthermore, most of the difference between DWR and actual composition was due to the method itself and not to inability of observers to accurately use the method.

Table 1. Comparison of percent composition by DWR to clipped plots and comparison of difference among observers. Based on 100 quadrats of 40 x 40 cm.

Spp	DWR Est.			Actual DWR	Clipped Wt.
	Obs. 1	Obs. 2	Obs. 3		
Black grama	34	30	28	33	41
False mesquite	17	20	22	19	21
Rothrock grama	19	18	18	18	12
Perennial forbs	12	11	12	11	9
Slender grama	6	6	7	5	4
Sideoats	3	4	4	4	3
3-awns	2	2	2	3	3
Tanglehead	2	2	2	2	3
Annual grass	2	2	1	2	1
Az. cottontop	1	2	2	2	1
Bush muhly	1	1	1	1	1
Annual forbs	1	1	1	1	1
% similarity to: Actual DWR	97%	98%	95%	--	90%
% similarity to: Clipped wt.	87%	86%	85%	89%	--

Table 2. Similarity of composition estimates by individual observers using DWR to those obtained by direct calculation using clipped data from the same quadrats and to those calculated by DWR from clipped data in the same quadrats (in parentheses).

Location	Similarity Index (%)		
	Observer 1	Observer 2	Observer 3
Oracle Wildlife Refuge -- grazed	94 (94)	93 (5)	93 (95)
Santa Rita Exp. Range -- grazed	60 (80)	60 (83)	--
Santa Rita Exp. Range -- ungrazed	87 (97)	86 (98)	85 (95)
Sonoita Highway -- limey site	87 (94)	87 (93)	--
Rosemont Allotment	89 (96)	90 (95)	--

Table 3. Comparison of composition estimates by three observers using DWR in 100 quadrats in a stand determined by Lehmann lovegrass.

Species	Observer 1	Observer 2	Observer 3
Lehman lovegrass	54	54	52
False mesquite	32	32	33
Rothrock grama	1	7	1
Perennial forbs	8	9	10
Ocotillo	2	2	2
Opuntia	2	2	2

Table 4. Comparison of composition estimates by three observers using DWR in a desert grassland dominated by burroweed. Based on 100 quadrats.

	% Composition - DWR - 100 Quadrats		
Spp	Observer 1	Observer 2	Observer 3
Burroweed	22%	23%	19%
Rothrock grama	21	19	23
Arizona cottontop	7	7	7
Slender grama	22	21	20
Prickly pear	2	2	2
Annual forbs	T	T	T
Three awns	12	10	10
Perennial forbs	10	13	12
Mesquite	T	1	1
Cholla	T	1	1
Lehmann lovegrass	T	T	T
Tanglehead	2	2	4

Table 5. Similarity of species composition among different people observing the same set of quadrats.

Location	Similarity Index (%)		
	Observer 1/Observer 2	Observer 1/Observer 3	Observer 2/Observer 3
Oracle Wildlife Refuge -- grazed	95	95	95
Oracle Wildlife Refuge -- grazed	99	95	96
Oracle Wildlife Refuge -- ungrazed	97	95	98
Santa Rita -- ungrazed	94	--	--
Santa Rita -- grazed	99	98	97
Santa Rita -- ungrazed	95	94	93
Santa Rita -- grazed	98	--	--
Rosemont Allotment	96	--	--
Sonoita Highway -- Limey Site	95	--	--

Quadrat Size

The DWR method assumes the quadrat is of sufficient size to have three species in most quadrats. We examined this question at four locations at the Santa Rita Experimental Range. Locations were selected to provide a variety in total plot yield, dominant species and species diversity.

Table 6 shows the percentage of quadrats having three or more species for four quadrat sizes. The percentage increases with quadrat size but all quadrat sizes have a substantial percentage of quadrats with less then three species. Table 7 shows the percentage similarity of composition estimates by each quadrat size to that estimated by the largest quadrat at the four locations. It can be seen that community composition did not differ much as a result of quadrat size. The greater the species diversity, the more difference due to quadrat size, e.g. compare location 1 and 4.

Table 8 shows the estimated percent composition of the three most important species at each of the locations. Since these three species make up 60-99% of the composition, it can be seen that for purposes of rating range condition or carrying capacity, quadrat size makes little practical difference.

Therefore our conclusion is that quadrat size is fairly flexible and, when frequency, canopy cover, or comparative yield methods are combined with DWR, the requirements of these methods should govern selection of quadrat size.

Table 6. Percentage of quadrats having three or more species for different quadrat sizes based on 50 quadrat transects at four locations on the Santa Rita Experimental Range.

Location	Quadrat Size (cm)			
	40 x 40	40 x 50	50 x 100	1008 x 100
1	2	4	8	10
2	18	20	36	64
3	14	18	48	56
4	16	22	48	66

Table 7. Percentage similarity (SI = composition estimates from smaller quadrats to those from 100 x 100 cm quadrats).

Location	Quadrat Size (cm)			
	40 x 40	40 x 50	50 x 100	100 x 100
1	98	98	99	100
2	92	92	92	100
3	93	93	93	100
4	86	86	92	100

Table 8. Effect of quadrat size on estimated percentage composition for the three major species at each of four locations on the Santa Rita Experimental Range.

Location	Quadrat Size (cm)			
	40 x 40	40 x 50	50 x 100	100 x 100
1. Lehmann lovegrass	79	79	78	77
Black grama	19	18	19	20
Mesquite	T	T	T	--
2. Burroweed	54	54	54	60
Lehmann lovegrass	22	21	23	17
Three awns	12	13	13	11
3. Burroweed	65	64	63	66
Three awns	13	13	12	9
Lehmann lovegrass	10	10	10	8
4. Sideoak grama	35	32	33	35
Three awns	17	19	19	18
Tanglehead	15	18	22	24

Single vs. Multiple Ranks

When some quadrats have less than three species, multiple ranks may be assigned. We calculated the similarity of composition obtained from clipped plots to that calculated by DWR procedures with ranks assigned from clipping data (no observer error) using single or multiple ranks. The results are in Table 9. It can be seen that using multiple ranks did not change the similarity of composition estimates to those obtained by clipping.

Table 9. Similarity (I.S. = 2w/a+b x 100) of species composition calculated by procedures using clipped weights and either single or multiple ranks to direct calculation from clipped weights from 14 desert grassland location.

Location Sampled	No. of Quadrats	No. of Species	Similarity %	
			Single Rank	Multi Rank
1. Oracle Wildlife Refuge -- ungrazed	40	12	93	90
2. Oracle Wildlife Refuge -- ungrazed	30	24	86	87
3. Oracle Wildlife Refuge -- grazed	40	24	90	89
4. SRER - Excl. 22 -- grazed	40	19	96	95
5. SRER - Excl. 22 -- ungrazed	50	18	84	84
6. SRER - near Excl. 22 -- grazed	30	10	54	57
7. SRER - Huerfano Butte area	100	13	90	--
8. SRER - IBP site -- grazed	40	12	80	78
9. SRER - IBP site -- ungrazed	47	18	83	84
10. Empire Ranch -- grazed	40	18	86	86
11. Empire Ranch -- ungrazed	40	16	84	84
12. Rosemont Allotment -- grazed	100	10	92	91
13. Sonoita Highway -- grazed	100	9	85	86
14. Northern Arizona -- grazed	72	20	87	89

Weighting Plots by Yield

A basic assumption is that species ranking is not correlated with quadrat yield. To see the effect of violating these assumptions refer to Table 1. In this test the most significant departures of composition estimate by DWR compared to clipped weights were black grama and Rothrock grama. Black grama was underestimated while Rothrock grama was overestimated. That is because black grama, because of its growth form and tendency to occur in clumps, is ranked mainly in high-yielding quadrats. Rothrock grama, on the other hand, occurs as individual plants which are usually small. When Rothrock grama occurs it is likely to be in a low-yielding quadrat. In this case, the error produced in composition estimates is not very significant.

Table 10 shows the results of 12 tests comparing similarity of species composition using weighted and unweighted quadrats to the composition obtained from clipped data. In only three out of 12 trials was any substantial difference in similarity found. The results of these tests indicate that, although the problem of correlation of species ranks with yield does not occur in most desert grassland communities, it occurs often enough to be considered.

If it is suspected that this situation will occur, it is necessary to: (1) make an estimate of plot yield for each quadrat taken to use as a weighting factor or (2) decide that the possible error produced is probably not significant to any management decisions likely to be based on the data.

Table 10. Percentage similarity of actual species composition based on harvesting to that estimated by DWR with and without weighting of ranks by quadrat yield.

Number of Observers	Number of Quadrats per Observer	Number of Species Found	Similarity to Actual Composition		
			Unweighted	Weighted	Difference
			%	%	%
3	40	11	92.4	92.4	0
2	30	8	59.1	88.7	+ 29.6
2	100	9	87.0	87.8	+ 0.8
2	100	10	86.5	83.0	- 3.5
1	40	15	83.2	91.9	+ 8.7
1	40	13	83.6	84.9	+ 1.3
1	40	14	88.8	91.6	+ 2.8
1	40	14	88.6	88.7	+ 0.1
1	40	17	85.9	92.2	+ 6.3
1	40	11	86.6	87.9	+ 1.3
1	40	9	78.4	92.7	+ 14.3
1	40	15	82.8	95.0	+ 12.2
		x =	83.6	89.7	+ 6.1

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Chapter Four

The Comparative Yield Method for Estimating Range Production

D.W. DESPAIN AND E.L. SMITH

The "comparative yield method" (Haydock and Shaw, 1975) is a useful method for estimating vegetation yield or standing crop on rangelands or improved pastures. This method, developed in Australia, has not been widely used in the U.S. It is a relatively rapid and simple method, yet provides better documentation in support of yield estimates than visual estimations alone. The method is similar to the double-sampling technique of Wilm et al. (1944) which is widely used by range managers in the western U.S. However, relative ranks are given to each quadrat rather than estimating weight directly which reduces training time as well as time spent in sampling.

The comparative yield method is used for estimating total biomass or production. Where yield by species is desired, the method can be combined with the "dry-weight-rank" method for determining species composition by weight (Smith and Despain, this volume). In this case, sampling time is reduced even further than that required by typical double-sampling approaches because direct species by species estimates of weight are not necessary, and it is not necessary to clip calibration plots on a species by species basis.

The comparative yield and dry-weight-rank methods are useful additions to plant frequency sampling where more information is required than that provided by frequency alone (Despain et al., this volume). Little time is added to the sampling scheme except for setting up standards and clipping calibration quadrats for the comparative yield method.

Procedures

The comparative yield method begins with the establishment of a set of reference quadrats to which sample quadrats are compared and rated. These reference quadrats are selected to represent the range in dry weight of standing crop or yield (ignoring occasional extremes) likely to be encountered on individual quadrats during subsequent sampling. Each sample quadrat is than ranked according to the standard quadrat to which it is most similar in terms of biomass. Sufficient quadrats are both ranked and harvested to provide a calibration of ranks to quadrat weight using typical double sampling techniques.

Establishing Standards

Before using the comparative yield method, it is necessary to have several frames made for setting up reference standards. They can be simple 3-sided frames made of any material. There is no need for handles and they need not be as durable as the frame that will be used for sampling. They must, however, be the same size as the sampling frame. If small diameter material is used, the frames should be painted or flagging tied to them so that they can be spotted easily in the grass.

Prior to sampling, a number of reference quadrats or "standards" are subjectively located to represent the range of quadrat yield that is expected to be *commonly* encountered during sampling. Usually, five standards are established. Standards 1 and 5 are located first. A frame is subjectively placed in a low yielding spot to represent low yielding situations that will commonly be encountered during sampling (excluding bare or nearly bare quadrats). This becomes standard 1. Standard 5 is located by placing a frame on a high yielding situation, excluding unusually dense patches of vegetation or situations that have a rare chance of being encountered during sampling. Standard 5 should contain approximately 5 times the yield of standard 1. It is a good idea to clip and weigh both standards 1 and 5 to confirm their relative weights. If standard 5 is more than about 5 times standard 1, then new standards should be selected to adjust the relationship. It is more common to pick standard 5 too high than to pick standard 1 too low, so take care that standard 5 doesn't represent a rarely occurring situation.

When satisfied with standards 1 and 5, standard 3 is located by placing a frame in a situation that is considered to be half-way between standards 1 and 5 in terms of dry weight of plant material encompassed by the frame. Standards 2 and 4 are then similarly selected to represent quadrat yield mid-way between standards 1 and 3 and standards 3 and 5, respectively.

All 5 quadrats are then clipped and weighed to see how close the selections are to a linear distribution of quadrat weights. The process is repeated with appropriate adjustments until the weights of the standards are approximately linear and all observers are confident of their ability to place quadrats in situations representative of each rank standard. If standards are not properly or consistently selected, such that ranks are not linear, precision in the method will be reduced.

A common tendency is to establish standard 5 at a level that is too high. This usually results in very few ranks of 5 being given during sampling and often results in non-linear standards. Another tendency is for the weight interval between 0 and standard 1 to be less than that between other ranks. This is not a problem as long as few ranks less than 1 are given during sampling, including 0 or empty quadrats. If many empty quadrats (more than about 5%) are anticipated, then a larger quadrat size should be used even if the standards are linear with respect to 0.

In low yielding situations (less than about 500 kg/ha) it will be difficult to distinguish between ranks when using small quadrats (such as those typically used in frequency sampling) because differences among quadrats are only a few grams. One solution is to use fewer standards, i.e. a 3 point rather than 5 point scale but a preferable solution is to use a larger quadrat. Figure 1 shows the relationship between yield and the approximate difference in grams among ranks that must be distinguished with different sized quadrats using 5 standards. A large quadrat does not necessarily improve the ability to distinguish ranks because it may be more difficult to distinguish small differences in larger quadrats. Once all observers are confident of their ability to pick similar quadrats at all rank weight intervals, the frames may then be placed in situations representative of each rank and left in place for reference during sampling. All observers should agree that each reference standard so placed is representative of the rank it is intended to represent.

This process of establishing standards serves as training for observers as well as ensuring better consistency between observers. The process may take a while the first few times the comparative yield method is applied, but will require less time as observers gain more experience in selecting standards. One set of standards may be used for all sampling done in an area as long as vegetation structure and yield are homogenous. The standards should be located where they can be referred to during sampling as necessary.

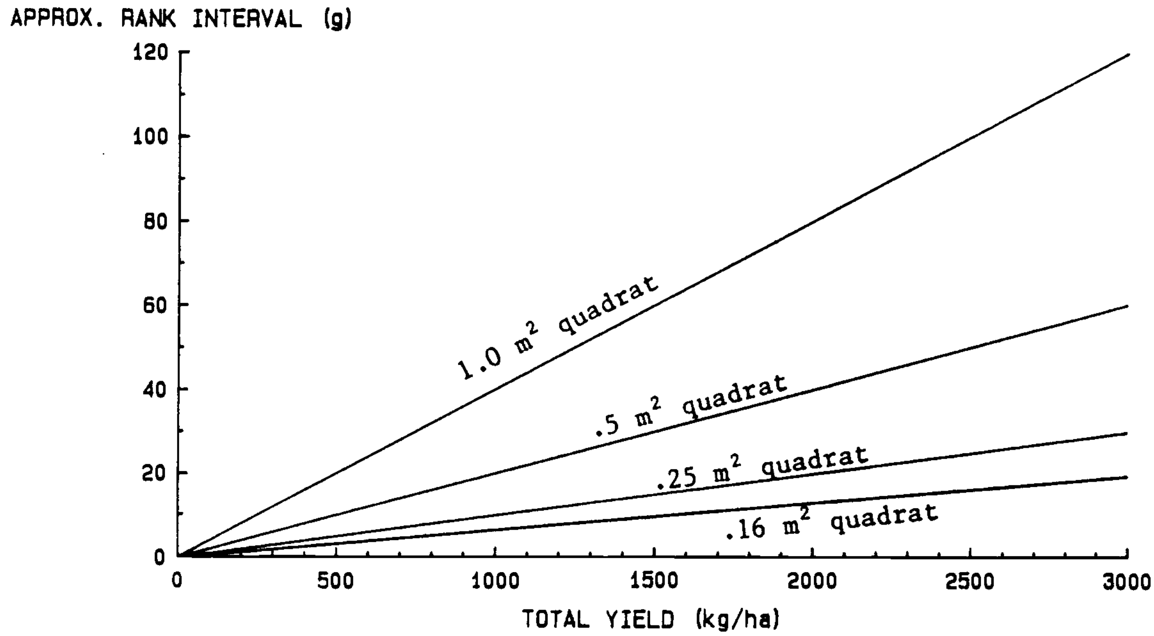


Figure 1: Approximate weights of rank intervals at various levels of yield for four quadrat sizes.

Sampling

Sampling may be conducted in conjunction with observations of other attributes, such as frequency and dry-weight-rank. At each quadrat placement, the quadrat is mentally or directly compared to the standards and given a rank corresponding to the appropriate standard. If yield of a quadrat appears intermediate between two standards, an intermediate rank may be given (such as 2.5 if yield appears between that of standard 2 and standard 3). Subdividing ranks into more intervals than half-ranks is not useful in most situations.

In the event a quadrat is encountered in which yield greatly exceeds the yield of standard 5, a higher rank may be estimated. For example, if yield appears to be about 50% more than that of standard 5, the quadrat may be given a rank of 7 or 8. This kind of situation will arise most commonly in very diverse vegetation or where a large, robust grass occurs widely scattered throughout the area. If many quadrats are given a rank greater than 5 during the course of sampling, then the standards were not properly established.

On the other hand, it is common for standard 5 to be established such that a quadrat of rank 5 is rarely encountered. In this case, most quadrats will be given ranks of 1 and 2 indicating that standards were not properly established.

Calibration of Ranks

A certain number of quadrats representing each rank are selected and harvested to provide a calibration of ranks to weight. These may be selected and clipped during sampling from among the regular sample quadrats, or they may be subjectively located and ranked after sampling is completed. The latter approach is often the preferred method so as to avoid carrying clippers and bags throughout regular sampling. Quadrats should be selected for harvesting to cover the range of ranks given during sampling. If the standards have been regularly referred to throughout sampling, they may be included among the quadrats harvested. Otherwise, independent quadrats should be harvested so that ranks of harvested quadrats agree as closely as possible with ranks given during sampling.

Clipping and weighing about 10 to 15 quadrats is recommended. Typically, two or three quadrats are harvested for each integer rank (10-15 total). Quadrats representing half-ranks may be ignored and quadrats representing rarely occurring ranks, such as those greater than 5, should be excluded. A larger number of quadrats may be clipped to improve the calibration.

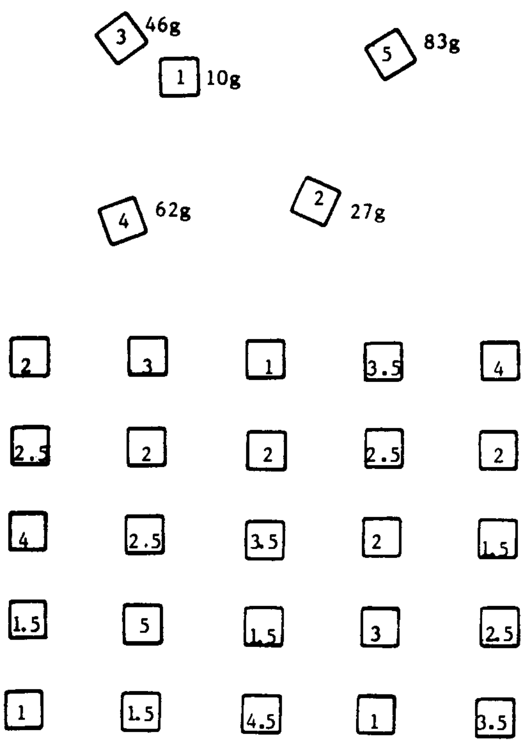
Separate calibration samples should be harvested for each distinct sampling period, such as morning vs. afternoon or separate days. This procedure helps reduce problems created by a shift in perception of ranks as sampling proceeds. Periodic reference to the original standards will also help reduce this problem. New calibration samples must be taken whenever the standards are changed. If there is more than one observer, either a separate set of calibration quadrats should be harvested for each observer, or all observers should independently rank the quadrats to be harvested.

The total yield of each calibration quadrat is clipped and bagged without regard to species. Whether total current years growth or total standing crop is harvested depends on the purpose of sampling and the way in which the main sample quadrats were ranked. Generally, total standing crop is most easily dealt with for herbaceous species, and foliage only for woody plants. Bags may be weighed in the field to get an average green weight if an immediate estimate of yield is necessary. All bags are later dried and weighed to provide a conversion factor from field weight to dry weight.

Standard double-sampling techniques are used to convert ranks to dry-weight for an estimate of total yield on a total area basis (Cochran 1977, Cook and Stubbendieck 1986).

Example

A hypothetical example of application of the comparative yield method is given in **Figure 2**. In this example, five standards are established prior to sampling, representing a range of quadrat yield from 0 to more than 83 grams. The weight interval between 0 and standard 1 is significantly less than the intervals between other ranks, but in this case it does not matter because no 0 or .5 ranks were given during sampling.



LOCATION: Example				
SAMPLE QUADRATS			HARVESTED QUADRATS	
RANK	TALLY	TOTAL X RANK	RANK	WEIGHT
0	0	0	1	10
.5	0	0	2	27
1	3	3	3	46
1.5	4	6	4	62
2	5	10	5	83
2.5	4	10		
3	2	6		
3.5	3	10.5		
4	2	8		
4.5	1	4.5		
5	1	5		
	Σ	63	15	228
	MEANS	2.52	3.0	45.6

Figure 2: Hypothetical example of application of the comparative yield method.

Sampling design consists of 25, systematically located quadrats (in practice, samples of 100 to 200 quadrats are recommended). The first quadrat (upper left hand corner) appears most similar in terms of total yield to standard number 2 and so is given a rank of 2. Yield of the second quadrat appears to be mid-way between that of standard 2 and 3 and is given a rank of 2.5. Sampling continues likewise for all 25 quadrats. For purposes of this example, the standards are used for the calibration quadrats and the weight of each of these quadrats is shown next to it. Figure 2 shows a typical field data form filled out for this example. The mean rank of the main sample is 2.52 and the mean rank of the harvested set of quadrats is 3. The mean dry weight of the harvested set is 45.6 grams/quadrat.

Calculations

Mean yield may be estimated either by a ratio estimate or a least-squares regression technique. The ratio estimate is useful for a quick calculation in the field. The least-squares method is recommended for final data analysis and setting of confidence intervals.

Ratio Estimate

The mean rank of the 5 clipped quadrats is 3.0 and the mean weight of the clipped samples is 45.6 grams (**Figure 2**). Each rank therefore corresponds to an additional 15.2 grams per quadrat:

$$(45.6\ g/quadrat)/3.0 = 15.2\ g/quadrat/rank$$

The mean rank of all quadrats estimated in the sample is 2.52. Multiplying this mean rank by the mean rank interval gives an estimate of the mean yield per quadrat for the sample:

$$2.52 \times 15.2\ g/quadrat/rank = 38.3\ g/quadrat$$

If the quadrat size is 40 x 40 centimeters (.16 m^2), the mean yield per quadrat in grams should be multiplied by 62.5 to convert yield in grams per plot into kilograms per hectare: (62500 quadrats/ha)/(1000g/kg) = 62.5. For this example: 38.3 g/quadrat x 62.5 = 2394 kg/ha.

Other conversion factors can be calculated for different quadrat sizes or to convert to pounds per acre. If calculations are done in the field, the weight used is field weight rather than dry weight. The field weight may be converted to dry weight by multiplying by an estimated dry weight percentage.

Regression Estimate (least squares)

The ratio estimate assumes that the line expressing the relation between ranks and yield passes through the origin, i.e. a rank of zero corresponds to weight of zero. Although this is logical, the line calculated by ratio does not usually give the best fit of the line to the data because most of the ranks of interest are greater than zero. A least squares regression line best fits the data (**Figure 3**).

In the example shown in Figure 2, the 5 clipped plots are used to calculate the regression. The X (independent) variable is ranks and the Y (dependent) variable is weight. If the regression is calculated after drying the samples, dry weights are used. If field weights are used, the results should be adjusted by multiplying by an estimated dry weight percentage.

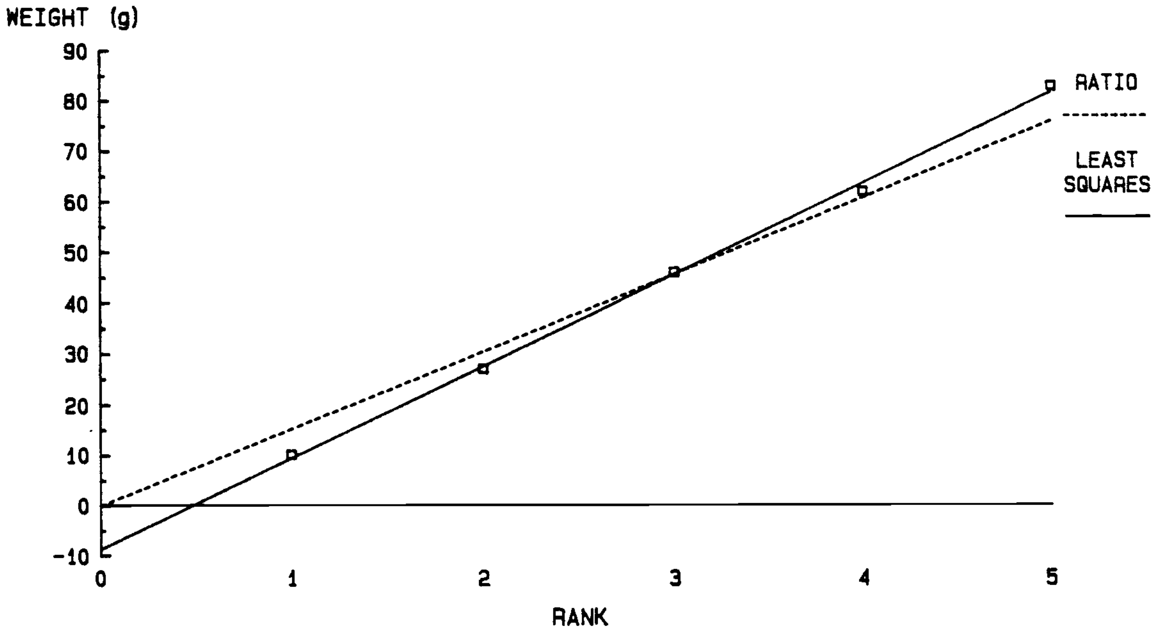


Figure 3: Comparison of the fit of ratio estimates and regression estimates to the harvested quadrat data in Figure 2.

The regression equation is:

$$\bar{Y} = a + b\,\bar{X}$$

where:

$$\bar{Y} = \textit{mean yield of clipped quadrats} = 45.6\ g$$

$$\bar{X} = \textit{mean rank of clipped quadrats} = 3.0$$

$$a = \textit{Y intercept} = -8.7$$

$$b = \textit{slope of the regression line} = 18.1$$

Substituting the average rank of the samples (2.52) in the equation gives:

$$\hat{\bar{Y}} = -8.7 + 18.1(2.52)$$

$$\hat{\bar{Y}} = 36.9 \text{ grams/quadrat}$$

Note that the estimated sample yield (36.9 g/quadrat) is somewhat different than the ratio estimate (38.3 g/quadrat). Note also that the estimated value of a rank of zero is the Y intercept, "a", which in this case is - 8.7. This does not cause a problem as long as ranks less than 1 are seldom given.

The estimated yield per quadrat can be converted to an area basis by an appropriate conversion factor:

$$36.9 \text{ g/quadrat} \times 62.5 = 2307 \text{ kg/ha}$$

Calculations used for setting confidence intervals on the mean sample yield using the regression approach are shown in the appendix.

Test Results

Comparisons of estimates of yield by the comparative yield method with results from harvesting all quadrats were made at several locations in Arizona. The results for 6 locations are shown below. Four locations are on semi-arid grasslands of southern Arizona and two within the pinyon-juniper woodland zone of northern Arizona.

Study Areas

Location A is a limey upland range site (about 12 inches average annual precipitation) with a mixed grass and low shrub vegetation of relatively low productivity. Dominant grasses include black grama and three-awns with lesser amounts of slim tridens, fluffgrass and Lehmann lovegrass. Small shrubs and suffrutescent plants occur scattered across the site including parthenium, paper flower and smaller amounts of desert zinnia and false mesquite.

Location B is a loamy slopes site (about 14 inches average annual precipitation) representing a somewhat more productive grassland at higher elevations. Dominant grasses include curly mesquite, side-oats grama and black grama. Shrubs are largely absent but widely scattered oak and one-seed juniper occur.

Location C, a loamy upland range site (about 15 inches average annual precipitation), is the most productive of the sites and is a nearly pure stand of the introduced Lehmann lovegrass which has invaded and almost completely taken over the site.

Location D is a deep sandy loam site (about 14 inches average annual precipitation). This area is dominated by slender grama, tanglehead, Arizona cottontop and three-awns. Several other native grasses are common. Woody plants are scattered throughout including mesquite and burro weed.

Location E is a 30 year old crested wheatgrass seeding established following fire which removed the overstory of pinon and Utah juniper.

Location F is located adjacent to E in an unburned stand of mature pinon and juniper with an understory dominated by muttongrass and blue grama.

Methods

On locations A through D, a total of 100, 40cm by 40cm quadrats were ranked by two observers relative to a scale based on 5 standard quadrats. All 100 quadrats were harvested by individuals other than the observers. On locations E and F, 50 quadrats each were similarly ranked and harvested. However, because of the low level of productivity of the understory beneath the pinon-juniper overstory on location F, 3 standards were used instead of 5. Yield rarely exceeded just a few grams per quadrat and it was found too difficult to distinguish 5 ranks without going to a larger quadrat.

Results

Figure 4 summarizes the results of sampling on all six locations. The comparative yield method produced results very similar to harvesting on all locations for all observers. Comparative yield estimates were generally within 10% of the harvested estimates with a maximum deviation of 19%. Typical of biomass sampling, confidence intervals are quite wide.

Comparative yield estimates exhibit a higher variance than harvested estimates in all cases except on the crested wheatgrass seeding (site E). This is partially a function of the contribution of variance by the regression component of comparative yield calculations that is not a part of harvested estimates. The degree to which quadrat size affects variance of the means was not tested.

No observer estimates are significantly different than the clipped estimates (P=.05). At each location except the pinon-juniper understory (F), the precision of estimates by the comparative yield method are within typical guidelines of land management agencies. For example, the Bureau of Land Management recommends that yield estimates be within 20% of the true mean with 80% confidence.

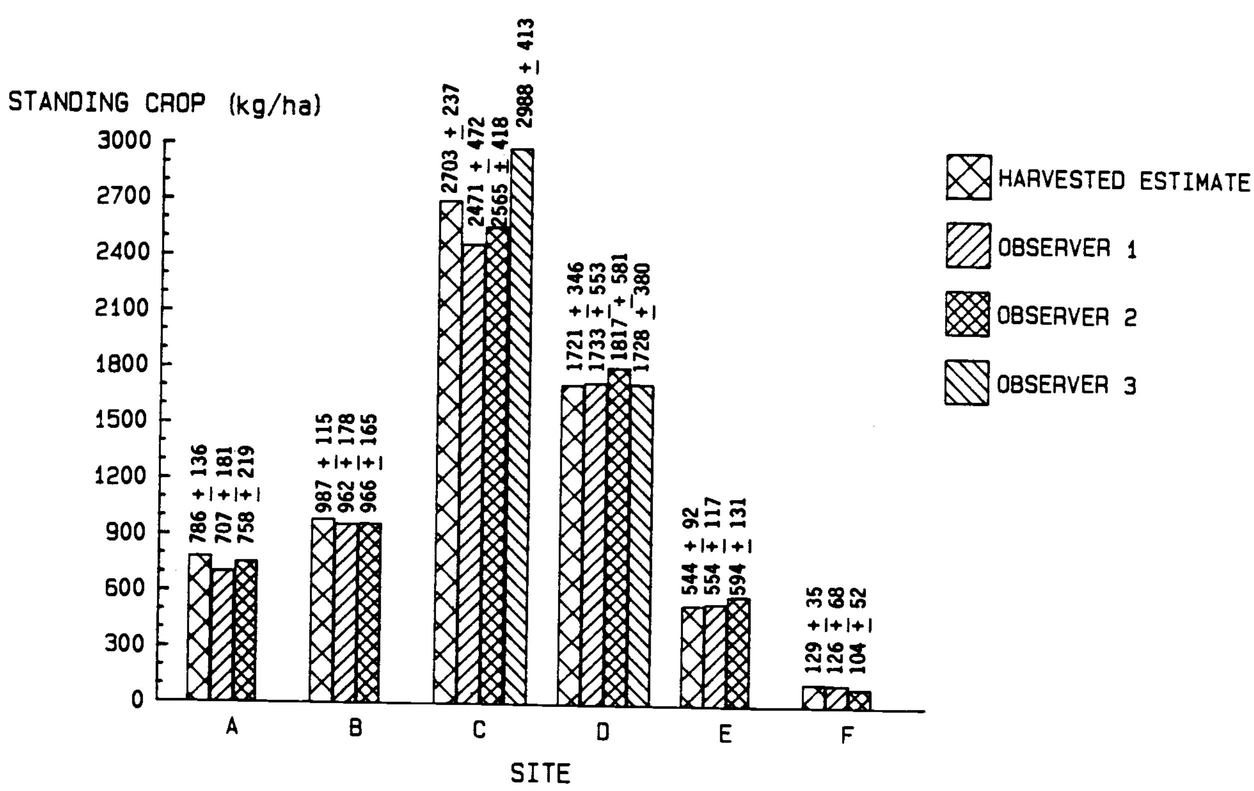


Figure 4: Comparison of mean yields estimated by harvesting and by several observers using comparative yield on the same set of 50-100 quadrats at 6 locations in Arizona. Confidence intervals shown are for P=.05.

Appropriate Application of the Comparative Yield Method

The comparative yield method, like most other biomass estimation techniques, is best suited to herbaceous vegetation. Small shrubs or half-shrubs can also effectively be included. Large shrubs or trees are not well adapted to this procedure. Quadrats of feasible size (up to $1m^2$) show high variances for shrubs and trees unless the stand is very dense. If current annual yield is desired, it is difficult to estimate or consistently harvest current growth of shrubs. It is practically impossible with evergreen shrubs and succulents. This problem is not limited to the comparative yield method but applies to any method using quadrats. Other techniques should be used for shrub biomass.

Estimates of biomass by any method are subject to large variances and lack of consistency. Whether sampled by the comparative yield method or any other method, biomass data have high potential for seasonal and yearly variation. At best, biomass estimates represent peak standing crop of some species in the plant community. A one-time sample of biomass does not measure annual production. Such data should not be used to establish stocking rates. They may be useful for comparing relative production in different pastures or communities or in response to different treatments. If "production" data are required, the comparative yield method is of comparable precision and requires less time and training than most techniques.

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Appendix A

Statistical Analysis: Procedures and Examples

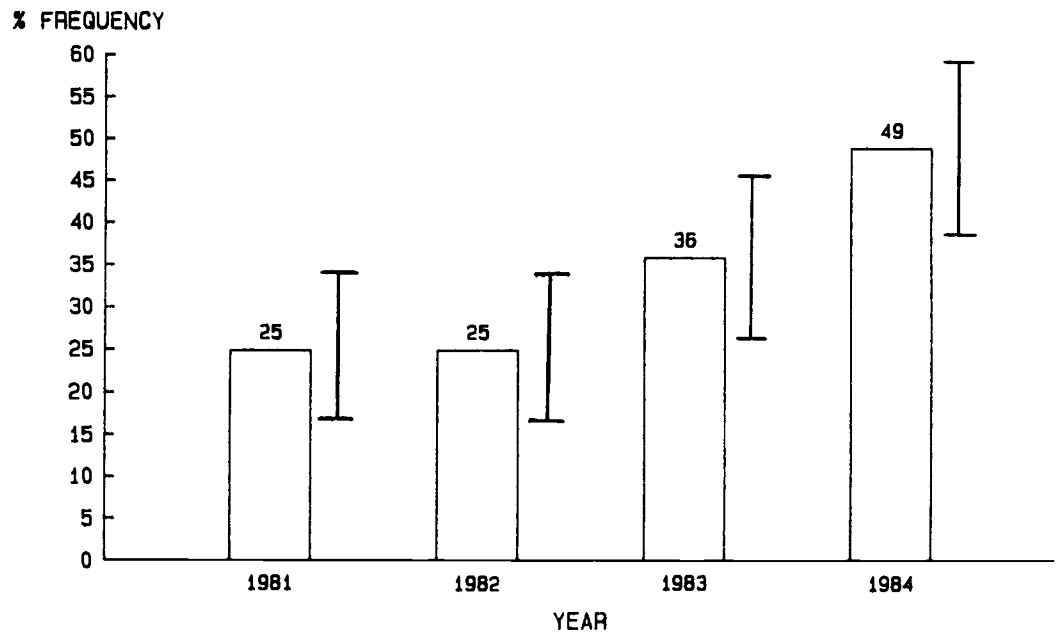
The discussion on statistical analyses of frequency data which follows utilizes four years (1981-84) of frequency data for hairy grama at monitoring Site 2 on the Slash S Ranch which is located in the Dripping Springs area south of Globe, Arizona. Summary data for this monitoring location (1979-85) are presented in **Appendix B**. Monitoring on this location was established in 1979 to provide data on vegetation response to a change in livestock management, a change from yearlong grazing to a deferred-rotation grazing system. Sampling has utilized 200, 40- x 40-cm quadrats located systematically at one-pace intervals along four 50-quadrat transects. The transects are systematically arranged 2 paces apart and parallel to a macroplot centerline. The systematic arrangement provides for convenient relocation of the macroplot area to be sampled and recording of the field data. By strict statistical standards, neither quadrats nor transects are random. Systematic sampling may provide a more precise estimate of a mean than random sampling but probability levels for the systematic sample can not be assigned. Probability levels based on random samples can only be considered as approximate when applied to the systematic samples.
A summary of data by transects is given in **Appendix Table** 1.

Appendix Table 1. Number of quadrats containing hairy grama in 50-quadrat transects at monitoring site No. 2, Slash S Ranch.

Year	Transect 1	2	3	4	Total	Mean	% Frequency
1981	13	8	14	14	49	12.5	25
1982	13	9	9	18	49	12.5	25
1983	19	12	23	18	72	18.0	36
1984	27	24	22	25	98	24.5	49

Binomial Confidence Limits

This analysis assumes that the quadrats are the sample unit and they are randomly and independently distributed over the macroplot. The advantage of binomial confidence limits to evaluate differences among frequency means is that for a given sample size and level of probability, the confidence intervals may be obtained from tables and no calculations are needed. This is convenient for interpretations made in the field. The frequency values to be compared and their appropriate confidence limits are located in the appropriate table and the observation made as to whether or not the confidence limits overlap. If the confidence limits of the two frequencies to be compared do overlap, they are not significantly different. **Appendix Fig. 1** shows a display of frequency of hairy grama and 95% confidence limits for four years of data from Appendix Table 1. It should be pointed out that the 95% probability applies to the statement that we may be 95% confident that the population mean lies within the confidence interval specified for each frequency. When comparing means using confidence intervals, we are conservative as to the number of means declared significantly different for a specified probability level.



Appendix Fig. 1. Mean frequency and 95% confidence intervals for hairy grama at monitoring Site 2 on Slash S Ranch for 1981-84.

Chi-square Analysis

Statistical comparisons of frequency data between any pair of years may be made by a chi-square test utilizing a 2 x 2 contingency table. For example, the change in frequency of hairy grama between 1982 and 1983 from Appendix Table 1 may be evaluated for difference by testing the null hypothesis of independence of data sets. To account for sample site, the total number of times hairy grama is present per 200 quadrats is used for the analysis rather than percent frequency.

Appendix Table 2. Contingency table of observed presence and absence of hairy grama data for 1982 and 1983.

Year	Present	Absent	Total
1982	49 (a)	151 (b)	200
1983	72 (c)	128 (d)	200
Total	**121**	**279**	**400**

Chi-square is calculated as:

$$\sum \frac{(observed - expected)^2}{expected}$$

Where:

$$Expected\ a = \frac{200 \times 121}{400} = 60.5$$

$$Expected\ b = \frac{200 \times 279}{400} = 139.5$$

$$Expected\ c = \frac{200 \times 121}{400} = 60.5$$

$$Expected\ d = \frac{200 \times 279}{400} = 139.5$$

And:

$$\chi^2 = \frac{(49 - 0.5)^2}{60.5} + \frac{(151 - 139.5)^2}{139.5} + \frac{(72 - 60.5)^2}{60.5} + \frac{(128 - 139.5)^2}{139.5} = 6.27$$

Only one value within the four cells of the contingency table is independent, so there is only one degree of freedom for the χ^2 test. The tabular χ^2 at .05 level of probability and one degree of freedom is 3.85. The calculated value is higher than the tabular value, so we reject the null hypothesis and conclude that the two means are independent (a significant change between years).

Since frequency data are discrete data and the chi-square distribution is continuous, there is a bias in χ^2 probabilities read from the chi-square tables. There is a tendency to reject the null hypothesis too often. A correction for continuity may be made to correct for this bias if the analysis is with one degree of freedom. The correction is to add 0.5 to observations less than expectation and subtract 0.5 for observations greater than expectation. For the data above, the corrected chi-square is:

$$\chi^2 = \frac{(49 + 0.5 - 60.5)^2}{60.5} + \frac{(151 - 0.5 - 139.5)^2}{139.5} + \frac{(72 - 0.5 - 60.5)^2}{60.5}$$

$$+ \frac{(128 + 0.5 - 139.5)^2}{139.5} = 5.73$$

The adjusted chi-square value is smaller than the unadjusted value, but in this case is still larger the tabular value for the .05 level of probability, so we reject the null hypothesis as above.

Analysis of Variance

If an analysis of variance is to be used for the statistical analysis, the transects are the sample unit and should be randomly located. Sample data should approach a normal distribution. Sample units should not produce frequent zeros, and the absolute values are more appropriate for the normal statistics analysis than percentage values. If percentage values are used, an appropriate transformation may be necessary to obtain normally distributed data.

For the analysis of frequency change of hairy grama from 1982 to 1983 (data from Appendix Table 1) the following analysis of variance may be calculated:

Source	DF	Sum of Sqs	Mean Sqs	F value
Year	1	66.12	66.12	3.40
Transect/Year	6	116.75	19.46	
Total	7	182.87		

Appendix Table 3. Analysis of variance for hairy grama frequency data for 1982 and 1983.

$$\textit{Year} \sum \textit{of Sqs} = \frac{(49)^2 + (72)^2}{4} - \frac{(121)^2}{8} = 66.12$$

$$\textit{Total} \sum \textit{of Sqs} = (13)^2 + (9)^2 + (9)^2 + (18)^2 + (19)^2 +$$

$$(12)^2 + (23)^2 + (18)^2 - \frac{(121)^2}{8} = 182.87$$

$$\textit{Transect/Year} \sum \textit{of Sqs} = \textit{Total} \sum \textit{of Sqs} - \textit{Year} \sum \textit{of Sqs}$$

The tabular F at a probability of .05 and 1 and 6 degrees of freedom is 5.99. The calculated F is smaller than the tabular F, so we accept the null hypothesis that there is no difference between frequencies of hairy grama in 1982 and 1983. The F test calculated here is not sensitive to identify the change, as there are few degrees of freedom in the error term. More transects are needed for a larger sample number to improve the sensitivity of this analysis to identify true differences among years.

To compare the four years of data for hairy grama as given in Appendix Table 1 and using normal statistics and the transects as sample units, an analysis of variance may be done for data over the four years (Appendix Table 4).

Source	DF	Sum of Sqs	Mean Sqs	F Value
Years	3	408.5	136.17	10.57
Transects/Years	12	154.5	12.88	
Total	15	563.0		

Appendix Table 4. Analysis of variance for hairy grama frequency data for years 1981 to 1984.

The tabular F value at the .05 level of probability with 3 and 12 degrees of freedom is 3.49. The calculated F exceeds the tabular value, so we reject the null hypothesis of no difference among year means.

We then must go to an appropriate test among the year means to determine which means are significant from one another. Since error rates between Type I and Type II errors and individual event and experiment-wise error rates differ among the various multiple range tests, it is beyond the scope of this discussion to recommend the appropriate test.

A Least Significant Difference (LSD) may be calculated, and although the Type I error rate is only applicable when testing between two means, a general feel for differences which are statistically meaningful may be obtained by comparing the four yearly means using an LSD calculated as:

$$LSD = t\, s_x^2$$

And for our example with a t at .05 level of probability and the 12 degrees of freedom associated with the error term in Appendix Table 4:

$$LSD = 2.179 \times 12.88/4 \times 2 = 5.5$$

The mean frequencies of hairy grama by years on a 50-quadrat transect basis are:

Year	1981	1982	1983	1984
Mean Frequency	12.25	12.25	18.0	24.5
Difference		0	5.75	6.5

The hairy grama frequency in 1983 was statistically higher than it was in 1982 and there was an additional change upward between 1983 and 1984.

Summary

There are several ways that frequency data may be analyzed statistically. The appropriate analysis should match the field design which most closely approximates the assumptions on which the analysis is based. Choose the method of analysis which is preferred and design the sampling to best fit the analysis assumptions. The statistics are simply a tool to help distinguish between sampling variation and real differences as an aid to identifying biologically significant changes.

Appendix B

Data Summary for 7 Years of Frequency Data on the Slash S Ranch near Globe, Arizona

FREQUENCY MONITORING DATA

ALLOTMENT: SLASH S   SITE: 2

GROUND COVER		79	80	81	82	83	84	85	86
BAREG	Bare ground	22	9	23	20	14	15	18	
GRAVEL	Gravel			24	14	11	8	12	
ROCK	Rock			22	26	38	33	21	
LITTER	Litter			12	14	12	19	25	
PBASAL	Plant basal area			20	29	25	23	28	

TREES		79	80	81	82	83	84	85	86
ACGR	catclaw acacia	T	1	4	3	4	T	2	
JUNIP	juniper	T						0	
PRJU	mesquite		2		2	T		1	

SHRUBS & HALF-SHRUBS		79	80	81	82	83	84	85	86
AGAVE	agave	2	4	2	5	3	2	3	
CAER	false mesquite	54	76	68	68	76	78	67	
DASYL	sotol		1		1			0	
ECHIN3	hedgehog cactus	4	5	6	8	4	6	3	
ERWR	shrubby buckwheat			1	2	1	1	2	
GUSA2	broom snakeweed	34	43	40	54	42	26	27	
MIBI3	wait-a-minute	T		1		1	1	0	
OPPH	prickly pear	12	12	7	14	9	10	10	
OPWH	whip cholla				1				

PERENNIAL GRASSES		79	80	81	82	83	84	85	86
ARIST	three awn	2	5	18	22	25	28	25	
BOBA3	cane beardgrass	3	2	1	2	2	4	8	
BOCU	sideoats grama	44	43	47	47	45	47	60	
BOHI2	hairy grama	30	21	25	25	36	49	48	
DICA8	Arizona cottontop		2		1			1	
ERIN	plains lovegrass	12	17	10	13	22	40	40	
HIBE	curly mesquite	22	14	8	11	22	11	19	
LEDU	green sprangletop		1	1	1	1	2	1	
SIHY	squirreltail	1				1		1	

FREQUENCY MONITORING DATA

ALLOTMENT: SLASH S SITE: 2

ANNUAL GRASSES		79	80	81	82	83	84	85	86
BRRU2	red brome	82	74	51	45	20	3	6	
PANIC	witchgrass						T		
VUOC	six weeks fescue	62	96	52	83	84	3	66	

PERENNIAL FORBS		79	80	81	82	83	84	85	86
AMBRO	ragweed	2	1	3	3	2		3	
ASTER	aster	T	32	3	2	3	1	2	
AYEMI	mouse shelter							1	
CAKE	desert mariposalily				3	1		1	
CARLO	carlowrightia		6					0	
ERIGE2	daisy	48		1	4	10	17	6	
EUPHO	spurge	T	1	2	5	4	1	1	
EVPI	evolvulus	3		16	17	29	16	38	
MALVA	mallow				1			0	
MASP4	spiny haplopappus	6	6	3	8	9	12	10	
QULO2	groundcherry	1						0	
SELAG	club moss	68	89	82	85	76	80	88	
SIDA+	sida			1				0	
TRADE	spiderwort		2		1			0	

ANNUAL FORBS		79	80	81	82	83	84	85	86
AMSIN	fiddleneck		1					1	
BRASS2	mustard	10						0	
COMPOS	composite	1						6	
DAPU3	rattlesnake carrot		1		1			6	
ERCI6	redstem filaree			17		38		0	
LEPID	pepperweed		1		13			1	
LUPIN	lupine				18			0	
PLPA2	indian wheat	86	93	66	52	18	4	45	
PORE4	portulaca				2	3	2	2	
SILEN	catch fly							5	

Appendix C

Tables of Binomial Confidence Intervals

CONFIDENCE INTERVALS FOR BINOMIAL POPULATIONS--100 QUADRATS

Approximate 95% and 80% confidence intervals for percentage frequency observed for 100 quadrats. Confidence intervals were calculated as:

$$\sqrt{\frac{pq}{100}}\; t_{\alpha(2)99} \;;\; \text{where } t_{95} = 1.98 \text{ and } t_{80} = 1.29$$

Freq. %	Conf. P=.95 %	Inter. P=.80 %	Freq. %	Conf. P=.95 %	Inter. P=.80 %	Freq. %	Conf. P=.95 %	Inter. P=.80 %	Freq. %	Conf. P=.95 %	Inter. P=.80 %
0	0-4	0-2									
1	0-5	0-4	26	17-35	20-32	51	41-61	45-57	76	68-84	70-82
2	0-7	1-5	27	18-36	21-33	52	42-62	46-58	77	69-85	72-82
3	1-8	1-6	28	19-37	22-34	53	43-63	47-59	78	70-86	73-83
4	1-10	2-8	29	20-38	23-35	54	44-64	48-60	79	71-87	74-84
5	2-11	2-9	30	21-39	24-36	55	45-65	49-61	80	72-88	75-85
6	2-12	3-10	31	22-40	25-37	56	46-66	50-62	81	73-89	76-86
7	3-13	4-11	32	23-41	26-38	57	47-67	51-63	82	74-90	77-87
8	3-14	4-12	33	24-42	27-39	58	48-68	52-64	83	76-90	78-88
9	4-15	5-13	34	25-43	28-40	59	49-69	53-65	84	77-91	79-89
10	4-16	6-14	35	26-44	29-41	60	50-70	54-66	85	78-92	80-90
11	5-17	7-15	36	26-46	30-42	61	51-71	55-67	86	79-93	82-90
12	6-18	8-16	37	27-47	31-43	62	52-72	56-68	87	80-94	83-91
13	6-20	9-17	38	28-48	32-44	63	53-73	57-69	88	82-94	84-92
14	7-21	10-18	39	29-49	33-45	64	54-74	58-70	89	83-95	85-93
15	8-22	10-20	40	30-50	34-46	65	56-74	59-71	90	84-96	86-94
16	9-23	11-21	41	31-51	35-47	66	57-75	60-72	91	84-96	87-95
17	10-24	12-22	42	32-52	36-48	67	58-76	61-73	92	85-96	88-96
18	10-26	13-23	43	33-53	37-49	68	59-77	62-74	93	86-97	89-96
19	11-27	14-24	44	34-54	38-50	69	60-78	63-75	94	88-98	90-97
20	12-28	15-25	45	35-55	39-51	70	61-79	64-76	95	89-98	91-98
21	13-29	16-26	46	36-56	40-52	71	62-80	65-77	96	90-99	92-98
22	14-30	17-27	47	37-57	41-53	72	63-81	66-78	97	92-99	94-99
23	15-31	18-28	48	38-58	42-54	73	64-82	67-79	98	93-100	95-99
24	16-32	18-30	49	39-59	43-55	74	65-83	68-80	99	95-100	96-100
25	16-34	19-31	50	40-60	44-56	75	66-84	69-81	100	96-100	98-100

Values for frequencies 0-9% and 91-100% are "exact" binomials according to Owen (1962).

CONFIDENCE INTERVALS FOR BINOMIAL POPULATIONS--200 QUADRATS

Approximate 95% and 80% confidence intervals for percentage frequency observed for 200 quadrats (binomial distribution). Confidence intervals were calculated as:

$$\sqrt{\frac{pq}{200}}\; t_{\alpha(2)199} \;;\; \text{where } t_{95} = 1.97 \text{ and } t_{80} = 1.29$$

Freq. %	Conf. P=.95 %	Inter. P=.80 %	Freq. %	Conf. P=.95 %	Inter. P=.80 %	Freq. %	Conf. P=.95 %	Inter. P=.80 %	Freq. %	Conf. P=.95 %	Inter. P=.80 %
0	0-3	0-2									
1	0-4	0-3	26	20-32	22-30	51	44-58	46-56	76	70-82	72-80
2	0-5	0-4	27	21-33	23-31	52	45-59	47-57	77	71-83	73-81
3	0-6	1-5	28	22-34	24-32	53	46-60	48-58	78	72-84	74-82
4	1-7	2-6	29	23-35	25-33	54	47-61	49-59	79	73-85	75-83
5	2-9	3-7	30	24-36	26-34	55	48-62	50-60	80	74-86	76-84
6	2-10	4-8	31	25-37	27-35	56	49-63	51-61	81	76-86	77-85
7	3-11	5-9	32	26-38	28-36	57	50-64	52-62	82	77-87	78-86
8	4-12	5-11	33	26-40	29-37	58	51-65	53-63	83	78-88	80-86
9	5-13	6-12	34	27-41	30-38	59	52-66	55-63	84	79-89	81-87
10	6-14	7-13	35	28-42	31-39	60	53-67	56-64	85	80-90	82-88
11	7-15	8-14	36	29-43	32-40	61	54-68	57-65	86	81-91	83-89
12	7-17	9-15	37	30-44	33-41	62	55-69	58-66	87	82-92	84-90
13	8-18	10-16	38	31-45	34-42	63	56-70	59-67	88	83-93	85-91
14	9-19	11-17	39	32-46	35-43	64	57-71	60-68	89	85-93	86-92
15	10-20	12-18	40	33-47	36-44	65	58-72	61-69	90	86-94	87-93
16	11-21	13-19	41	34-48	37-45	66	59-73	62-70	91	87-95	88-94
17	12-22	14-20	42	35-49	37-47	67	60-74	63-71	92	88-96	89-95
18	13-23	14-22	43	36-50	38-48	68	62-74	64-72	93	89-97	91-95
19	14-24	15-23	44	37-51	39-49	69	63-75	65-73	94	90-98	92-96
20	14-26	16-24	45	38-52	40-50	70	64-76	66-74	95	91-98	93-97
21	15-27	17-25	46	39-53	41-51	71	65-77	67-75	96	93-99	94-98
22	16-28	18-26	47	40-54	42-52	72	66-78	68-76	97	94-100	95-99
23	17-29	19-27	48	41-55	43-53	73	67-79	69-77	98	95-100	96-100
24	18-30	20-28	49	42-56	44-54	74	68-80	70-78	99	96-100	97-100
25	19-31	21-29	50	43-57	45-55	75	69-81	71-79	100	97-100	98-100

Values for frequencies 0-9% and 91-100% are "exact" binomials, and were calculated according to Steel and Torrie (1960).

Appendix D

Examples of Plot Forms Used for Frequency Sampling

1: **Form for collecting data in four blocks.**

2: **BLM form for collecting data using 10 transects.**

3: **BLM form for collecting data in nested quadrats.**

4: **BLM form for collecting data on a quadrat by quadrat basis.**

5: **Form for collecting frequency data with dry-weight-rank and comparative yield data. Usually use one form per transect or block.**

PLANT FREQUENCY DATA FORM

Plot No.______________ Number of Plots________________ Size of Plot____________

Ranch or Allotment____ Sampling Design

Pasture____

Legal Description of Location____

General Description____

____

Utilization or other information____

____

Observers

HITS	Tran. 1		Tran. 2		Tran. 3		Tran. 4		Total	%
Bare Ground										
Gravel (¼"-3")										
Rock (3")										
Litter										
Live Vegetation (basal)										
FREQUENCY <u>Tree and Shrub Species</u>										
<u>Perennial Grass Species</u>										
<u>Perennial Forb Species</u>										
<u>Annual Species</u>										

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PAGE _____ OF _____

TREND STUDY DATA
QUADRAT FREQUENCY METHOD

STUDY NUMBER	DATE	EXAMINER

ALLOTMENT NAME & NUMBER	PASTURE

COVER CATEGORY	TR 1	TR 2	TR 3	TR 4	TR 5	TR 6	TR 7	TR 8	TR 9	TR 10	TOTALS	COV %
BARE GROUND												
PERSIST LITTER												
NON-PER LITTER												
ROCK (≥1/2 INCH)												
LIVE VEG (BASAL)												
COVER TOTALS												100%

PLANT SPECIES	FR	FREQUENCY	TOTALS	FREQ %

NOTES (USE OTHER SIDE OR ANOTHER PAGE)

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TREND STUDY DATA
NESTED FREQUENCY METHOD - TEN TRANSECTS

PAGE ____ OF ____

FRAME SIZES 1 | 2 / 4 | 3	STUDY NUMBER	DATE	EXAMINER	ALLOTMENT NAME & NUMBER	PASTURE

PLANT SPECIES	TRANS 1	TRANS 2	TRANS 3	TRANS 4	TRANS 5	TRANS 6	TRANS 7	TRANS 8	TRANS 9	TRANS 10

NOTES (USE OTHER SIDE OR ANOTHER PAGE)

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STUDY METHOD- ______

TREND STUDY DATA

PAGE ---- OF ----

STUDY NUMBER	DATE	EXAMINER	ALLOTMENT NAME & NUMBER	PASTURE

PLANT SPECIES | SAMPLE NUMBER (0 10 20 30 40 50 60 70 80 90 100) | TOTAL

NOTES (USE OTHER SIDE OR ANOTHER PAGE)

LOCATION	TRANSECT	OBSERVER	DATE

SPECIES	FREQUENCY		DRY-WEIGHT-RANK				
	TALLY	% FREQ	TALLY			WTD.	% COMP.
			1	2	3		
			SUMS--				

COMPARATIVE YIELD				
RANK	TALLY	TOTAL x RANK	CLIP RANK	CLIP WT.
0				
.5				
1				
1.5				
2				
2.5				
3				
3.5				
4				
4.5				
5				
	SUMS-			
	MEANS--			
	YIELD =			

NOTES

Appendix E

Equations for Estimating Comparative Yield

RATIO ESTIMATE OF YIELD

$$\frac{\bar{X}_e}{\hat{Y}_e} = \frac{\bar{X}_h}{\bar{Y}_h} \qquad \text{OR} \qquad \hat{Y}_e = \frac{\bar{X}_e \bar{Y}_h}{\bar{X}_h}$$

REGRESSION ESTIMATE OF YIELD

$$\hat{Y}_e = \bar{Y}_h + b(\bar{X}_e - \bar{X}_h)$$

Confidence Interval (C.I.) Calculations

$$\text{C.I.} = t_p \sqrt{s^2_{\hat{y}_e}}$$

where:

$$s^2_{\hat{y}_e} = s^2_{y.x} \left\{ \frac{1}{n} + \frac{(\bar{X}_e - \bar{X}_h)^2}{\Sigma X_h^2 - \frac{(\Sigma X_h)^2}{n}} \right\} + \frac{b^2 \, s^2_{\bar{x}_e}}{m}$$

$$s^2_{y.x} = \frac{\left[\Sigma Y_h^2 - \frac{(\Sigma Y_h)^2}{n}\right] - b^2 \left[\Sigma X_h^2 - \frac{(\Sigma X_h)^2}{n}\right]}{n - 2}$$

$$b = \frac{\Sigma X_h Y_h - \frac{\Sigma X_h \Sigma Y_h}{n}}{\Sigma X_h^2 - \frac{(\Sigma X_h)^2}{n}}$$

$$s^2_{\bar{x}_e} = \frac{\Sigma X_e^2 - \frac{(\Sigma X_e)^2}{m}}{m-1}$$

- $\hat{Y}_e$ = estimated average weight/quadrat for sample
- b = slope of regression of ranks on weight for harvested quadrats
- X_e = individual ranks of main sample quadrats
- X_h = individual ranks of harvested quadrats
- Y_h = individual weights of harvested quadrats
- m = number of main sample quadrats
- n = number of harvested quadrats
- t_p = Student's t value at probability level p for m-1 degrees of freedom (two tailed)

NOTE : X_e's and X_h's (and therefore m and n) may or may not be mutually exclusive depending on the sampling procedure used. They are exclusive in the examples shown here.

EXAMPLE FROM FIGURES 2 and 3:

$\bar{X}_e = 2.52$ $\qquad \Sigma Y_h = 228.0$ $\qquad N = 25$

$\bar{X}_h = 3.0$ $\qquad \Sigma X_e^2 = 189.0$ $\qquad n = 5$

$\bar{Y}_h = 45.6$ $\qquad \Sigma X_h^2 = 55.0$ $\qquad t_p = 2.064$

$\Sigma X_e = 63.0$ $\qquad \Sigma Y_h^2 = 13,678$ $\qquad p = .05$

$\Sigma X_h = 15.0$ $\qquad \Sigma X_h Y_h = 865$

Ratio Estimate:

$$\hat{Y}_e = \frac{(2.52)(45.6 \text{ g/quadrat})}{3.0} = 38.3 \text{ g/quadrat}$$

$$38.3 \text{ g/quadrat} \left(\frac{62500 \text{ quadrats/ha}^*}{1000 \text{ g/kg}} \right) = 2394 \text{ kg/ha}$$

Regression Estimate:

$$\hat{Y}_e = 45.6 \text{ g/quadrat} + 18.1(2.52 - 3.0) = 36.9 \text{ g/quadrat}$$

$$36.9 \text{ g/quadrat} \left(\frac{62500 \text{ quadrats/ha}^*}{1000 \text{ g/kg}} \right) = 2307 \text{ kg/ha}$$

$$S^2_{Xe} = \frac{189 - \frac{(63)^2}{25}}{24} = 1.26$$

$$b = \frac{865 - \frac{(15)(228)}{5}}{55 - \frac{(15)^2}{5}} = 18.1$$

$$S^2_{Y.X} = \frac{\left[13,678 - \frac{(228)^2}{5}\right] - (18.1)^2 \left[55 - \frac{(15)^2}{5}\right]}{3} = 1.7$$

$$S^2_{\hat{Y}e} = 1.7 \left\{ \frac{1}{5} + \frac{(2.52 - 3.0)^2}{55 - \frac{(15)^2}{5}} \right\} + \frac{(18.1)^2 (1.26)}{25} = 16.89$$

$$\text{C.I.} = 2.064 \sqrt{16.89} = \pm 8.4827/\text{quadrat}$$

$$8.4827 \text{ g/quadrat} \left(\frac{62500 \text{ quadrats/ha}^*}{1000 \text{ g/kg}} \right) = 530.2 \text{ kg/ha}$$

Yield = 2307 ± 530 kg/ha

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*for 40cm x 40cm quadrat

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