QUADRAT FREQUENCY SAMPLING IN A
SEMI-DESERT GRASSLAND

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ABSTRACT

Frequency sampling on six semi-desert range sites was studied with the following objectives: (1) to determine the minimal representative sample area, (2) to compare systematic quadrat placement to subsampling with transects, and (3) to determine relative efficiency of linear versus rectangular plots.

Species presence was recorded in 11 plot sizes ranging from .25 m^2 to 900 m^2. Plot size needed to record 50% of total species in the stand was used as the criterion for a representative sample. A plot of 10 x 10 m met this criterion.

Species frequency was recorded in .16 m^2 quadrats in a 20 x 20 grid (400 quadrats) spaced at 1.25 m intervals. Occurrence of species in quadrats was found, in most cases, to be independently distributed, thus permitting statistical treatment of systematic data. Grouping quadrats into 20 transects and analyzing components of variance showed that, for most species, use of transects gave no increase in precision compared to grid placement.

Using 250 quadrats, sampling efficiency of rectangular plots (10 x 25 quadrat grid) was compared to linear plots with quadrats placed end-to-end spaced 1.75 m apart. Based on six plots of each shape the number required to sample at a given level of precision was found to be 9-10 plots in both cases.

CHAPTER 1

INTRODUCTION

Effective management decisions are based on a thorough knowledge of the environment. If in studying the vegetation component, the researcher were to locate and measure all plant populations, he could make exact statements about species coverage, yield, density, or other attributes. However, it is impractical to observe or count every individual in the plant community. Instead one studies bits (samples) of the vegetation and assumes the averages (estimates) obtained are close to the population parameters.

Sampling grasslands often presents special problems because it is difficult to estimate some population parameters. Plant density is difficult to obtain, since recognition of an individual is not always possible. Estimating coverage is slow and tedious, yield tends to fluctuate with seasonal climatic changes. However, plant frequency is a particularly suitable attribute for range studies, since estimates are quantitative, easy to obtain, objective, and remain relatively stable from season to season.

This study was part of an overall investigation of range site classification using species frequency, however development of appropriate sampling techniques seemed of sufficient interest to warrant this separate report. Problems considered in the study are adequacy of the sample, methods for locating quadrats, and efficiency of plot shapes. Frequency, as defined for the study, is the percentage of quadrats occupied by a particular species in repeated placements throughout the stand. It is important to define the size of the quadrat, since the estimate of mean frequency is a function of quadrat size. Obviously, if the size of the quadrat is increased, there is a greater chance of species occupancy. An appropriate quadrat size samples the most commonly occurring species at 86% frequency (Curtis and McIntosh 1950). The size of quadrat used in my study was previously tested for species frequency across a range of semi-desert grasslands by E. L. Smith, Jr. and P. R. Ogden (1978).

The study also considers the adequacy of the sample in representing species composition. If a sample covers so small an area that few species are recorded, then true community structure is not represented. The concept of 'Minimal Area' is used to estimate the area on each site that contains a representative percentage of the total species diversity.

In addition, the study compares two methods of locating quadrats within a sample plot. The first method involves placing quadrats at a regularly spaced interval, producing a systematic grid. The second method is more tedious and involves placing quadrats in transects, then randomly locating each transect in the plot. This adds an element of randomization to the study which is necessary for statistical analysis. The lengthy procedure is considered necessary because recording species presence in quadrats involves less time than randomizing individual locations. Consequently, quadrats are located within randomly placed transects.

Lastly, the study considers the efficiency of multiple sample plots in characterizing a vegetation unit. If each plot in a study contains significantly different species frequencies, the design is inefficient, because many plots will be required to sample at a predetermined level of precision. However, plots that cross patches of high and low density vegetation can be expected to contain similar amounts of species. The objective of this part of the study is to compare the efficiency of long, narrow plots to rectangular plots for characterizing a stand.

The results of the study will assist investigators in rapidly obtaining objective, quantitative frequency data to be used in comparing and classifying range sites on the basis of species abundance, composition, and condition.

CHAPTER 2

LITERATURE REVIEW

Frequency

Frequency is an attribute of the vegetation that is useful in describing plant communities. The method depends on the presence or absence of species in a given number of repeatedly placed small sample quadrats within the community (Raunkiaer 1934). The sampling unit is a square of defined area adjusted to the size and spacing of individual plants. Plots are distributed either at random or in some regular manner within the community. The result is a quantitative assessment of abundance as expressed by the frequency percentage; the percentage of plots in which each species has been found.

The frequency percentage is easy and quick to determine, since it is just the chance of finding the species within a particular size of sample area in any one trial. The number of samples in which the species occurs, expressed as a proportion or percentage of the total is an estimate of the chance of occurrence. The method is objective because one only identifies the species and records its presence when found within a quadrat (Greig-Smith 1964). Also, frequency data can be used to judge range condition, correlate vegetation to environmental factors, and determine the natural grouping of species in a community (Hyder et al. 1966, Goodall 1953).

However, the frequency percentage only has meaning in relation to the particular size and shape of the sample quadrat. An increase in size of the quadrat will necessarily result in an increase in the chance of a species occurring in any particular sample. A more important drawback in the method is in the interpretation of the results. Frequency confounds the two parameters of density and dispersion of individuals. As an example, a species with a large number of individuals may show low frequency values simply because the individuals are concentrated in patches, whereas a species with the same number of individuals spread out evenly over the sample area may show 100% frequency. Therefore, frequency gives a certain indication of uniformity of distribution rather than of density. Of course, a species with a few individuals can never show high frequency values, even if they are uniformly distributed, unless the quadrat size is very large (Kershaw 1974).

Several attempts have been made to establish an exact relationship between frequency, density, and dispersion of individuals (Blackman 1942; Arberdeen 1958). Difficulty arose from the lack of randomness of individuals in natural populations. However, the loss of information from integrating frequency, density, and dispersion is counterbalanced by the great gain in speed and ease of description of vegetation (Greig-Smith 1964).

The adequacy of a frequency sample is usually determined independently of the species composition in the community, and is only a function of the number of quadrats studied (Smartt 1978). However, Grunow (1967) pointed out that a criteria for determining sampling adequacy for systematically located sampling quadrats in South African pastures is to include an adequate percentage of the estimated total number of plant species in the community.

Minimal Area

A minimal sample area must be used to insure that an adequate number of species of the total diversity is included in the sample. The larger the sample area examined the greater will be the information obtained, whether about species present, their quantitative abundance, or their pattern. Likewise, below the minimal area the sample plot will not contain all the characteristic features of the community (Mueller-Dombois and Ellenberg 1974).

The species/area curve is most often used to determine the minimal area for sampling a community (Goodall 1952). The curve is obtained by plotting the number of species present from a series of samples of increasing size against the area sampled. The slope of the curve is at first steep but gradually decreases.

There has been much past interest in determining an objective criteria for defining minimal area from a species/area curve. Cain (1934) claimed that a 'break' in the species/area curve could be recognized, above which the curve is nearly horizontal. This break indicated the minimal area. Later, he realized that determination by inspection of the position of the break depended on the relative ratio of the ordinate (Y) to the abscissa (X) (Cain 1938). A contraction of Y in proportion to X resulted in a curve flattening at a faster rate, thus an apparent decrease in minimal area.

Also, minimal area was suggested to be the point along the species/area curve at which an increase of 10% of the largest area sampled yielded only 10% more species of the total number recorded (Cain 1943). However, it can be shown mathematically that the 10% point continues to shift to the right as the area sampled increases (Rice and Kelting 1955).

Archibald (1949) suggested minimal area to be an area characteristic of the community that contains on the average of 50% of all the species present. This concept has been criticized as being dependent on the largest area sampled (Greig-Smith 1964). However, minimal area by this method usually lies to the right of the leveling off point on the curve (Mueller-Dombois and Ellenberg 1974). Thus, the effect of the curve shape becomes insignificant.

Sample Quadrat Placement

The method of quadrat placement within a sample plot must take into account the problem, the variables, and the purpose for data collecting. When the goal of the survey is estimation of population parameters or statistical inference, then random sampling designs are needed. Such sampling designs give every individual of the population an equal chance to occur in the sample and permit the application of statistical theory to estimate the variation about the mean value. Simple random sampling suffers from several weaknesses including tedious field tasks, potentially high sampling variance, and notorious underrepresentation of some parts of the suvey area (Sampford 1962).

Ashby (1948) found that truly random dispersal in plant populations is rarely, if ever, found in nature. Instead plant populations depart more or less from randomness, tending to be clumped. Thus, a grid of regularly spaced quadrats across the vegetation tends to give a better coverage of the range of variation and a more accurate mean than in random placement. Unfortunately systematic sampling provides no estimate of the precision of the mean value, since statistical theory cannot be applied to a survey where each individual in the population does not have an equal chance of being included in the sample.

However, for repeated systematic samples of quadrats in Netherland grasslands the precision of frequency estimates was equivalent to that of random sampling (Nielen and Dirven 1950). Also, for both semi-open African grasslands and an 'artificial' population, the variance of the mean obtained from systematic points was similar to random points provided the spacing between points exceeded the size of individuals or clumps of individuals (Tidmarsh and Havunga 1955). Consequently, frequency data from a systematic sample can be treated as if obtained from the same number of random quadrats, provided the spacing of quadrats does not coincide with any repetitive pattern in the population.

Hyder et al. (1963) have taken a different approach to frequency sampling. They have developed a subsampling strategy that allocates quadrats into transects. The proportion of quadrats allocated to each transect is allowed to vary according to the cost of sampling and/or the variability of the plant population in each community. The transects are randomly located in the plot and their variance is used to estimate the variance of the mean frequency percentage. A preliminary study is required, before actual community sampling, to estimate the optimal allocation of quadrats to transects that minimizes the variance for a fixed cost.

The subsampling method was tested in seventeen different plant communities in Central Nevada (Wilkie 1966). Results showed that each community had to be sampled with a different allocation of quadrats to transects.

Plot Shape

Traditionally the square plot has been used in ecological research, but some advantage may be obtained by the use of rectangular plots (Greig-Smith 1964). The advantage of the rectangular plot is the variance may be less for rectangular strips than for square plots. This is a result of a high chance of a rectangle crossing a high density patch and an adjacent low density patch simultaneously; thus, leveling out the variance over the whole area (Kershaw 1974).

The long axis of a rectangular plot should always cut across any observed countour, soil, or vegetation band (Bormann 1953). This is particularly important when obtaining quantitative parameters on the lesser species occurring sporadically throughout dominant vegetation.

CHAPTER 3

METHODS

The investigation consisted of three field studies. The first study investigated minimal areas of species composition for several stands on two study areas. The results of the survey were used to estimate sampling adequacy and plot size for Study 2, a study on the placement of frequency quadrats in a sample plot. The final study compared efficiency of two plot shapes, using the quadrat placement recommended from Study 2. Specific procedures for each study are discussed individually under appropriate study headings.

Study Areas

The two study areas were located in the desert grassland of southeastern Arizona. Weaver and Clements (1938) referred to the desert grassland type as part of the larger shortgrass plains region of the Central United States. However, many authors (Nichol 1952; Jaeger 1957; Lowe 1964) characterize the area as a distinctive semi-desert grassland type, transitional between higher elevation ever-green woodlands and lower desert scrub.

Open grasslands occur at midelevations in the zone. These pure grasslands are characterized by a perplexing number of short- and mid-bunchgrasses. Common members are blue grama (Bouteloua gracilis), black grama (B. eriopoda), sideoats grama (B. curtipendula), slender grama (B. filiformis), hairy grama (B. hirsuta), Arizona cottontop (Digitaria californica), and several species of three-awn (Aristida sp.). Such stands have deep soils with few rocks, shrubs, or cacti.

Grass/shrub mixtures occur at higher and lower elevational limits than open grasslands. Such grass/shrub sites, occurring on rocky soils, support a reduced diversity of grasses owing to the competition from shrub lifeforms. Mesquite (Prosopis juliflora) is the dominant shrub at low elevations. Subordinate species are several cacti, including prickly pears and chollas (Opuntia sp.), ocotillo (Fouquieria splendens), and catclaw acacia (Acacia greggii). Oaks (Quercus emoryii and Q. arizonica) dominate the landscape at upper elevational limits. Subordinate species are beargrass (Nolina microcarpa) and velvetpod mimosa (Mimosa dysocarpa).

One study area was located in the Empire Valley to represent an open grassland aspect of the semi-desert grassland. The study area is approximately 3.5 miles north of Sonoita, Arizona in sections 11 and 14, T20S, R16E, of the Gila and Salt River Base Meridian. Three sites were located at the study area to investigate topographical influence on vegetation sampling. Specific characteristics of the sites are listed in Table 1.

The second study area was located on the Santa Rita Experimental Range (U.S. Forest Service) in sections 11 and 12, T19S, R14E, and in sections 8, 9, and 18, T19S, R15E, of the Gila and Salt River Base Meridian. Three sites were located at the study area to

Table 1. Comparison of Elevation, Slope and Aspect of Topography, Vegetation Structure, and Soil Classification for the Study Sites

Study Area	Site	Elevation	Topography	Vegetation structure	Soil
Empire Valley	1	5040 ft.	Moderate slope (5-15%) South facing	Open grassland	White House gravelly loam Ustollic Haplargid Fine, mixed, thermic
Empire Valley	2	4460 ft.	Level (0-3%) Floodplain	Open grassland	Pima silty loam Antropic Torrifluvent, Fine, silty, mixed, thermic
Empire Valley	3	5060 ft.	Moderate slope (15-20%) North facing	Open grassland	White House gravelly loam Ustollic Haplargid Fine, mixed, thermic
Santa Rita	4	4300 ft.	Level (0-5%) West facing	Mesquite trees Low density	Comoro sandy loam, Typic Torrifluvent Coarse-loamy, mixed, thermic
Santa Rita	5	4040 ft.	Level (0-5%) West facing	Mesquite shrubs high density	White House gravelly loam Ustollic Haplargid Fine, mixed, thermic
Santa Rita	6	3960 ft.	Level (0-5%) West facing	Mesquite trees low density Mesquite shrubs moderate density	Pinaleno gravelly loam Typic Haplargid loamy-skeletal, mixed, thermic

investigate the influence of mesquite size and density on vegetation sampling. Specific characteristics of the sites are listed in Table 1.

CHAPTER 4

STUDY 1

Introduction

Minimal area is the smallest area that adequately represents species composition and structure of a plant community. The estimate is dependent on species diversity and dispersion of individuals. A sample, for any attribute of the population, must cover the minimal area to be considered typical of the community under study.

The objective of this study was to determine and compare minimal area for several sites in the semi-desert grassland.

Methods

Minimal area of a stand was determined by recording all species that occurred in increasingly larger plots of defined area, and plotting species/area curves. The study was conducted on Sites 1, 2, 4, 5, and 6.

On each site a stand was located in an area topographically uniform and homogeneous in terms of vegetation structure. Plots .25 m^2, .5 m^2, 1 m^2, 2 m^2, 4 m^2, 8 m^2, 16 m^2, 32 m^2, 64 m^2, and 225 m^2 were randomly located by co-ordinates on two 30 m baselines. All annual and perennial species rooted within each plot were identified and recorded separately by plot. In addition, any species occurring within the area created by the baselines but not in a plot was noted. Only species presence/absence was recorded.

The data were used to generate species/area curves for each site (Figures 1 and 2). Minimal area was objectively determined on each curve as the area corresponding to 50% of the total number of species encountered on the stand area (900 m^2).

Results and Discussion

Estimated minimal areas were 15-110 m^2 for the five study sites (Table 2). These values are slightly below the 50-100 m^2 given in Mueller-Dombois and Ellenberg (1974) for minimal area of dry grasslands. However, their estimates are averages from several sources.

Minimal area curves showed no evidence of leveling-off on Sites 2, 4, and 5 (Figures 1 and 2), indicating that species were continuing to be added to the community. As a result, estimated species diversity in 900 m^2 stands might be lower than actual community diversity.

Minimal areas were highest on the most diverse sites in each of the study areas. This is expected since the addition of species in a community requires that a larger area be searched to produce a representative sample of community composition.

In the open grassland, minimal area was highest on Site 2, since the vegetation was strongly dominated by Bouteloua gracilis and Lycurus phleoides which often occurred in large patches composed

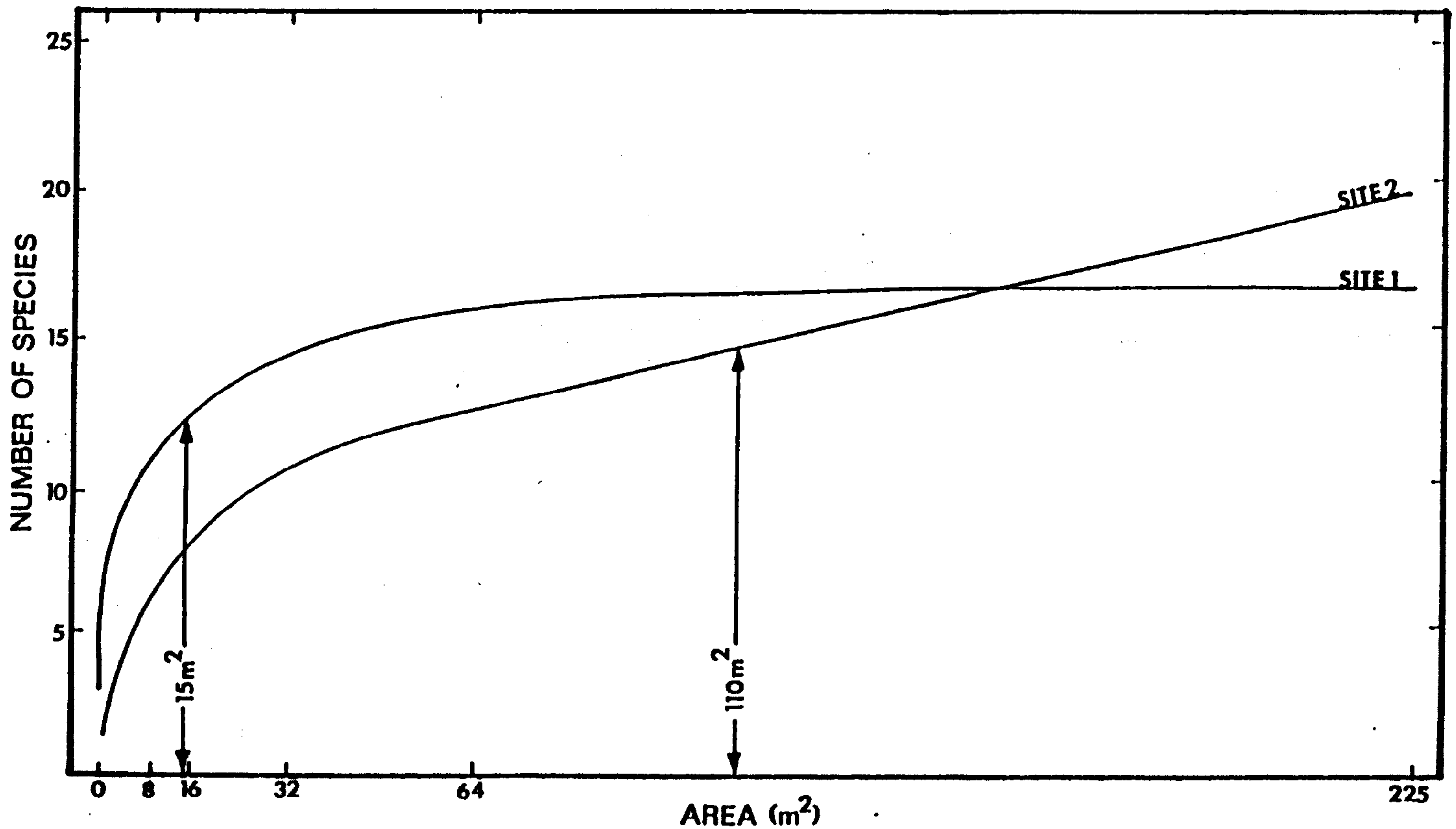

Figure 1. Relationship between Number of Species Encountered and Area Sampled for Sites 1 and 2 in Open Grassland.

Arrows indicate area needed to record 50% of total species in stands, respectively.

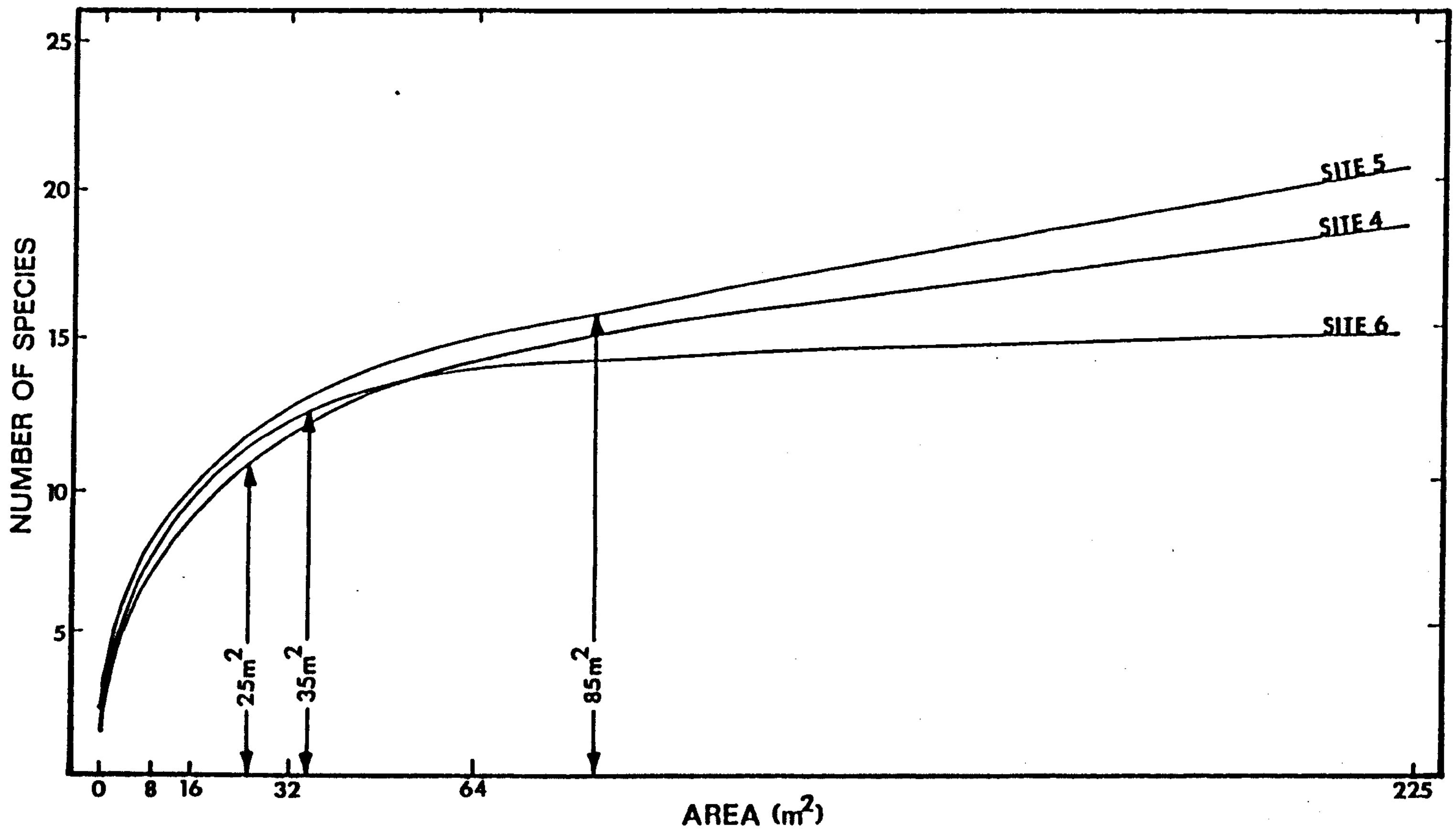

Figure 2. Relationship between Number of Species Encountered and Area Sampled for Sites 4, 5, and 6 in Mixed Grass/Shrub Community.

Arrows indicate area needed to record 50% of total species in stands, respectively.

Table 2. Species Diversity in Stand and Estimated Minimal Area as Shown in Figures 1 and 2 for Each Study Site

Study Area	Site	Species Diversity in Stand (900 m^2)	Estimated Minimal Area
Open Grassland	1	26	15 m^2
Open Grassland	2	30	110 m^2
Mixed Grass/Shrub	4	22	25 m^2
Mixed Grass/Shrub	5	32	85 m^2
Mixed Grass/Shrub	6	26	35 m^2

almost entirely of these species. Thus, a relatively large plot was required to encounter a representative sample of other species. On Site 1, Hilaria belangeri was the most abundant species, but grew more intermixed with other species. The result was a small area required for a representative sample of species composition.

The higher diversity on the floodplain of Site 2 in relation to the south facing slope of Site 1 can be attributed to topographic position. Whittaker and Niering (1965) noted that in semi-desert vegetation diversity increases along the gradient toward more xeric communities, but ravine communities are usually richer than submesic slopes.

Minimal area increased with increasing soil diversity in the three mixed grass/shrub sites. The Comoro soil of Site 4 (Table 1) is uniform across the surface and has little change in texture and structure at depth, producing large homogeneous 'patches.' Individuals of minor species became established in close proximity on each 'patch,' consequently a small area was required to record a percentage of the total composition. In contrast, the White House soil of Site 5 (Table 1) is gravelly and has horizons which vary in thickness and texture. The resulting numerous microsites forced individuals of minor species to be more widely dispersed. A representative number of species only occurred together in large plots. Site 6 was intermediate in soil development and minimal area.

Soil diversity can also account for differences in numbers of species (Oliveira 1979). The White House soil has many different microsites for establishment of invading species. For the uniform Comoro soil, there are few diverse habitats for invading species to colonize.

Conclusions

Minimal area depends on characteristics of the vegetation and environment on each site. However, it is difficult, if not impossible, to determine minimal area from a visual appraisal. This is evident on Sites 1 and 2 which were separated by only a few hundred meters, yet, minimal areas differed by 95 m^2. Consequently, it is recommended that at least a 10 x 10 m plot be used in any vegetation survey in the semi-desert grassland.

I incorporated minimal area into a frequency study (Study 2), by requiring the sum total of area covered by quadrats to equal an average minimal area of 62 m^2. The purpose of this was to test if minimal area can be used to set sampling adequacy. Results are discussed in Study 2.

CHAPTER 5

STUDY 2

Introduction

The objective of this study was to compare two methods of locating quadrats within a sample plot. The first method consisted of a single sample of regularly placed quadrats. The data fit a binomial distribution since species presence or absence in a set of independent quadrats is recorded. In the second method, quadrats are located in randomly placed transects within the plot. In order to calculate an estimate of precision it is necessary to randomize transects within the sample. This study was used as a preliminary survey to determine optimum allocation of quadrats to transects.

The purpose was to determine if the use of transects provides any additional information beyond the mere presence or absence of species in quadrats. If variance due to the use of transects is insignificant, there is no benefit from their use. Thus, the estimate of precision of the mean frequency percentage can be based on a sample of independently placed quadrats.

Methods

The study consisted of one sample plot on each of the six sites. On each site, a 26 x 26 m plot was randomly located with the aid of coordinates drawn on 1:24,000 aerial photographs. Plots were permanently marked with a brightly painted rebar stake at each corner.

Size of the plot was arbitrarily determined to be approximately ten times the 62 m^2 minimal area. The purpose of this size was to allow the sum of the area within four hundred, 40 x 40 cm quadrats to equal the minimal area, yet sample a small proportion of total plot area.

Each plot was sampled for species presence or absence with a quadrat placed at the corners of a 1.25 m square grid. Field procedure involved placing the quadrat on the ground, and recording presence/absence of each species separately on a data sheet. A transect consisted of 20 quadrats placed at 1.25 m intervals along a North/South compass line. Data for each quadrat were recorded individually. There were 20 transects located 1.25 m apart.

The results were used to estimate species frequency from the percentage of occupancy of 400 uniformly spaced quadrats. Also, the results were used as a preliminary subsample survey to estimate cost and variance components for quadrats and transects. This was accomplished by treating each line of 20 quadrats as a transect and calculating frequency from the percentage of 20 quadrats that were occupied.

The presence or absence of a species was based on rooted frequency. A species was counted as present if more than half the stem at ground level, or more than half the area of bunchgrasses, was within the quadrat. In addition, cover frequency was recorded for mesquite if any branch crossed a vertical plane above the quadrat.

Analysis of Data

The first step in analysis was to determine independence of species occurrence in quadrats, since binomial probability requires each event in a sample to be independent of all others. The test of independence consisted of comparing an observed number of pairs of occupied quadrats with the number expected if species occurrence is independent. A pair occurs when two occupied quadrats adjoin each other within a row, column, or diagonal in the grid. Equations to determine the mean and variance of the distribution of the number of pairs are provided by Krishna-Iyer (1949, 1952). The null hypothesis of the test is the observed number of pairs does not significantly differ from the expected number of pairs.

If species occurrence in quadrats is independent, frequency data fit a binomial distribution. However, this does not preclude the use of normal theory statistics. The central limit theorem allows the use of a normal approximation to the binomial, except for very high and low frequency percentages. Assuming the quadrats are randomly located the variance of the mean frequency percentage by the normal approximation is estimated by:

$$\hat{V}_{\bar{p}(i)} = \frac{p_i \, q_i}{n - 1}$$

where, p_i is the percentage of occupied quadrats, q_i is the complement $(100 - p_i)$, and n is the sample size.

Subsampling is the efficient allocation of secondaries (quadrats) to primaries (transects) based on cost and variance components (Cochran 1977). A component of variance model (Table 3) is used to summarize the analysis of variance of subsample frequency data (Snedecor 1956). The parameter σ_q is the variance due to random effects of quadrats, and is estimated from the sample by S_q^2. The parameter σ_t is the variance due to random effects of transects, and is estimated by S_t^2.

When estimating frequency from a subsample the variance of the mean frequency percentage is given by:

$$\hat{V}_{\bar{p}(2)} = \frac{\Sigma(p_i - \bar{p})^2}{n(n - 1)}$$

A given variance can result from different allocation of quadrats to transects, however, the optimum allocation gives specified variance components for the lowest cost or minimized variance for a specified cost. The preliminary study was used to determine optimal number of quadrats per transect (k_{opt}) at fixed costs, as given by,

$$k_{opt} = \sqrt{\frac{\sigma_q \; c_t}{\sigma_t \; c_q}}$$

where, variance components are estimated, c_t is the time to locate one transect, and c_q is the time to record one quadrat.

Table 3. Analysis of Variance of a Population Component of Variance Model

Source of Variation	Degrees of freedom	Mean square	Parameters estimated
Transects	$n - 1$	$\frac{k(\Sigma p_i - \bar{p})^2}{n - 1}$	$\sigma_q^2 + k\sigma_t^2$
Quadrats/transects	$n(k - 1)$	$\frac{k(\Sigma p_i\, q_i)}{n(k - 1)}$	σ_q^2

k = number of quadrats in a transect

p_i = percentage of quadrats in ith transect containing species

q_i = $(100 - p_i)$

$\bar{p}$ = average frequency percentage in sample

n = number of transects

In theory, use of the normal approximation to the binomial and the subsampling model require random selection of sampling units, whereas systematic sampling was conducted. Based on the work of Nielen and Dirven (1950) and Tidmarsh and Havunga (1955), the author assumes the estimates under systematic sampling are the same as would have resulted from random sampling.

Results and Discussion

Independence of Quadrats

Open Grassland. The difference of observed from expected numbers of pairs was not significant for the majority of species on Sites 1 and 2, indicating independence of species occurrence in quadrats (Tables 4 and 5). Significant differences in *Bouteloua gracilis*, *Lycurus phleoides*, and *Bouteloua hirsuta* in Plot 2 can be explained by the position of the plot on the site. The plot, by chance, was located near a xeric gradient in the floodplain. The three species occurred more frequently in the mesic side of the plot. Thus, their occurrence in quadrats was dependent on a moisture gradient.

The majority of species on Site 3 had a significant difference in observed from expected numbers of pairs (Table 6). The plot was on a moderate north facing slope, and species might have been distributed along moisture contours. This resulted in a lack of independence in quadrats. The nature of the vegetation in this plot is considered, again, later in the study.

Table 4. Plot 1: Comparison of the Observed Number of Pairs of Occupied Quadrats with the Expected Number of Pairs for 400 Quadrats. -- Species shown are those with more than 5 occupied quadrats.

Species	Quadrats Occupied	Number: Expected Pairs	Number: Observed Pairs
Hilaria belangeri	276	705	624 **
Aristida sp.	229	485	416 **
Bouteloua hirsuta	203	381	362
Lycurus phleoides	148	202	213
Bouteloua chondrosioides	53	26	27
Heteropogon contortus	38	13	62 **
Andropogon barbinodis	38	13	17
Eragrostis intermedia	38	13	15
Leptoloma cognatum	21	4	5
Viguiera annua	137	173	177
Aster tanacetifolius	80	59	85 **
Desmanthus cooleyi	70	45	52
Evolvulus sericeus	56	29	34
Nama hispidum	36	12	17
Solanum elaeagnifolium	36	12	21 *
Mimosa dysocarpa	23	5	6
Commelina dianthifolia	18	3	5

* Significantly different from expected number of pairs at 0.01 probability level

** Significantly different from expected number of pairs at 0.001 probability level

Table 5. Plot 2: Comparison of the Observed Number of Pairs of Occupied Quadrats with the Expected Number of Pairs for 400 Quadrats. -- Species shown are those with more than 5 occupied quadrats.

Species	Quadrats Occupied	Number: Expected Pairs	Number: Observed Pairs
Bouteloua gracilis	304	855	741 **
Lycurus phleoides	301	838	721 **
Aristida sp.	262	635	597 *
Bouteloua hirsuta	124	142	210 **
Carex sp.	87	69	91 *
Leptoloma cognatum	62	35	41
Eragrostis intermedia	53	26	24
Bouteloua chondrosioides	33	10	15
Bouteloua curtipendula	28	7	22 **
Viguiera annua	46	19	27
Commelina dianthifolia	45	18	23
Eriogonum wrightii	44	18	21
Desmanthus cooleyi	25	6	9
Haplopappus gracilis	25	6	9
Evolvulus sericeus	15	2	3
Croton corymbulosus	14	2	9 **

* Significantly different from expected number of pairs at 0.01 probability level

** Significantly different from expected number of pairs at 0.001 probability level

Table 6. Plot 3: Comparison of the Observed Number of Pairs of Occupied Quadrats with the Expected Number of Pairs for 400 Quadrats. -- Species shown are those with more than 5 occupied quadrats.

Species	Quadrats Occupied	Number: Expected Pairs	Number: Observed Pairs
Bouteloua hirsuta	184	313	400 **
Aristida sp.	175	283	297
Andropogon cirratus	164	248	315 **
Hilaria belangeri	139	178	257 **
Eragrostis intermedia	133	163	228 **
Bouteloua curtipendula	84	65	84 *
Leptoloma cognatum	63	36	64 **
Lycurus phleoides	50	23	38 **
Carex sp.	36	12	15
Bouteloua chondrosioides	33	10	24 **
Andropogon barbinodis	27	6	21 **
Viguiera annua	178	292	335 **
Desmanthus cooleyi	77	54	106 **
Commelina dianthifolia	72	47	59
Evolvulus sericeus	42	16	19
Nama hispidum	24	5	4
Haplopappus gracilis	17	2	8 **
Baccharis thesioides	10	1	0
Mimosa dysocarpa	9	1	1

* Significantly different from expected number of pairs at 0.01 probability level

** Significantly different from expected number of pairs at 0.001 probability level

Mixed Grass/Shrub. The difference of observed from expected numbers of pairs was significant for the majority of species in each of the mixed grass/shrub plots (Tables 7, 8 and 9). These results were not expected, since there were no observed environmental gradients that might have influenced species distribution. Consequently it was hypothesized that mesquite trees and shrubs were influencing distributions through competition or protection. Mesquite requires abundant water for growth and might competitively exclude species through soil moisture depletion. Also, mesquite might protect species from such hazards as grazing, resulting in a positive association.

The hypothesis of significant association between mesquite and the occurrence of species was tested in a 2 x 2 contingency table. The direction of association was determined by Cole's coefficient (Cole 1949).

The results show that only one species, Bouteloua rothrockii, which did not occur independently in quadrats was not influenced by mesquite (Table 10). Otherwise, the majority of species in Table 10 are either clumped with mesquite or occur as clumps away from mesquite. It is assumed that, in both cases, the clumps occur independently in the plot, because mesquite individuals are independent.

Adequacy of Sample

Open Grassland. A total of 25 species were recorded in the survey on Sites 1 and 2. These values are 96% and 83%, respectively,

Table 7. Plot 4: Comparison of the Observed Number of Pairs of Occupied Quadrats with the Expected Number of Pairs for 400 Quadrats. -- Species shown are those with 3 or more occupied quadrats.

	Number		
Species	Quadrats Occupied	Expected Pairs	Observed Pairs
Bouteloua filiformis	181	302	364 **
Aristida sp.	154	219	239
Aristida adscensionis	125	144	212 **
Panicum sp.	89	73	130 **
Bouteloua aristidoides	75	52	75 **
Bouteloua curtipendula	44	18	27
Digitaria californica	38	13	61 **
Boerhaavia coccinea	49	22	50 **
Prosopis juliflora	3	0	0

* Significantly different from expected number of pairs at 0.01 probability level

** Significantly different from expected number of pairs at 0.0001 probability level

Table 8. Plot 5: Comparison of the Observed Number of Pairs of Occupied Quadrats with the Expected Number of Pairs for 400 Quadrats. -- Species shown are those with more than 5 occupied quadrats.

Species	Number: Quadrats Occupied	Number: Expected Pairs	Number: Observed Pairs
Eragrostis lehmanniana	359	1193	957 **
Bouteloua curtipendula	53	26	49 **
Setaria macrostachya	41	15	27 **
Bouteloua rothrockii	25	6	17 **
Bouteloua chondrosioides	23	5	9
Digitaria californica	23	5	6
Bouteloua filiformis	19	3	7
Calliandra eriophylla	69	44	63 **
Solanum elaeagnifolium	46	19	42 **
Evolvulus sericeus	36	12	15
Portulaca oleracea	25	6	3
Prosopis juliflora	24	5	6
Haplopappus tenuisectus	21	4	3
Carlowrightia arizonica	15	2	13 **

* Significantly different from expected number of pairs at 0.01 probability level

** Significantly different from expected number of pairs at 0.001 probability level

Table 9. Plot 6: Comparison of the Observed Number of Pairs of Occupied Quadrats with the Expected Number of Pairs for 400 Quadrats. -- Species shown are those with more than 5 occupied quadrats.

Species	Quadrats Occupied	Number Expected Pairs	Observed Pairs
Eragrostis lehmanniana	311	895	780 **
Bouteloua eriopoda	174	280	311 *
Setaria macrostachya	50	23	78 **
Digitaria californica	46	19	40 **
Evolvulus sericeus	48	21	42 **
Haplopappus tenuisectus	35	11	14
Prosopis juliflora	12	1	2

* Significantly different from expected number of pairs at 0.01 probability level

** Significantly different from expected number of pairs at 0.001 probability level

Table 10. Significance and Direction of Association with Mesquite for Species in Mixed Grass/Shrub that Did Not Occur Independently in Quadrats

	Species	Chi-square	Cole's Coeffi-cient
Plot 4	Bouteloua filiformis	52.94 **	- 76%
	Aristida adscensionis	50.68 **	- 88%
	Panicum sp.	34.57 **	- 92%
	Bouteloua aristidoides	**	-100%
	Digitaria californica	65.40 **	+ 75%
	Boerhaavia coccinea	5.82 **	- 54%
Plot 5	Eragrostis lehmanniana	15.29 **	- 36%
	Bouteloua curtipendula	22.16 **	+ 37%
	Setaria macrostachya	47.00 **	+ 63%
	Bouteloua rothrockii	0.24	+ 6%
	Calliandra eriophylla	3.30 *	- 32%
	Solanum elaeagnifolium	3.68 *	+ 16%
	Carlowrightia arizonica	26.98 **	+ 82%
Plot 6	Eragrostis lehmanniana	40.70 **	- 26%
	Bouteloua eriopoda	27.95 **	- 70%
	Setaria macrostachya	204.71 **	+ 81%
	Digitaria californica	31.06 **	+ 33%
	Evolvulus sericeus	5.35 **	- 73%

* Significant at 0.05 probability level

** Significant at 0.01 probability level

of the estimated species diversity from Study 1, and well above the 50% of species diversity that was the criteria for minimal area. As a result, the samples adequately represent species composition of the community.

Mixed Grass/Shrub. A total of 19, 30, and 22 species were recorded in frequency quadrats on Sites 4, 5, and 6, respectively. These values are over 75% of the estimated species diversity for the sites. Thus, the sampling intensity of this study proved to be adequate in representing community composition.

Subsampling

The preliminary subsample results were analyzed for transects oriented North/South and East/West in the sample plot. This was made possible by data collection of species presence/absence separately for each quadrat, and later 'forming' transects oriented in different directions. The purpose was to investigate how transect placement could influence conclusions.

The null hypothesis that the transect component of variance was equal to zero was tested by an F-ratio (Snedecor 1956).

Open Grasslands. The transect component of variance was insignificant for the majority of species in Plots 1 and 2 (Tables 11 and 12). This indicates the variance of the mean frequency percentage is primarily due to quadrat variation, and the use of transects supplies little additional information. A negative value, calculated

Table 11. Plot 1: Variance Components, Estimated k_{opt}, and Sample Size (N) to Sample within 10% of a Mean Frequency of 50% with 95% Confidence, as Sampled with 400 Quadrats Allocated 20 per Transect in North/South and East/West Orientations

Species	North/South				East/West			
	s_q^2	s_t^2	k_{opt}	N	s_q^2	s_t^2	k_{opt}	N
Hilaria belangeri	2097.4	49.3	17	8	2013.2	137.8 **	10	12
Aristida sp.	2343.4	115.6	11	10	2472.4	- 19.7	--	--
Bouteloua hirsuta	2411.8	96.6 *	13	10	2432.9	76.4	14	9
Lycurus phleoides	2278.9	60.8	16	8	2292.1	47.0	18	8
Bouteloua chondrosioides	1167.1	- 15.1	--	--	1153.9	- 1.7	--	--
Heteropogon contortus	805.3	59.5	9	12	694.7	175.2 **	5	26
Andropogon barbinodis	823.2	- 1.9	--	--	842.1	20.8	16	8
Eragrostis intermedia	873.7	- 12.4	--	--	834.2	29.1 *	14	9
Leptoloma cognatum	496.1	2.8	34	6	485.5	13.8	15	9
Viguiera annua	2188.1	72.9 *	14	9	2180.3	81.2 *	13	9
Aster tanacetifolius	1531.6	76.0 **	11	10	1557.9	48.4 *	14	9
Desmanthus cooleyi	1450.0	- 2.8	--	--	1384.2	66.3 **	12	10
Evolvulus sericeus	1226.3	- 20.3	--	--	1197.4	10.1	28	6
Nama hispidum	781.6	41.4 **	11	11	831.6	- 11.0	--	--
Solanum elaeagnifolium	821.0	0.0	--	--	731.6	93.9 **	7	18
Mimosa dysocarpa	548.7	- 5.6	--	--	525.0	19.2	13	9
Commelina dianthifolia	431.6	- 0.8	--	--	421.0	10.3	16	9

* Significant at 0.05 probability level

** Significant at 0.01 probability level

Table 12. Plot 2: Variance Components, Estimated k_{opt}, and Sample Size (N) to Sample within 10% of a Mean Frequency of 50% with 95% Confidence, as Sampled with 400 Quadrats Allocated 20 per Transect in North/South and East/West Orientations

	North/South				East/West			
Species	S_q^2	S_t^2	k_{opt}	N	S_q^2	S_t^2	k_{opt}	N
<u>Bouteloua</u> <u>gracilis</u>	1826.3	2.4	70	6	1684.2	151.6	8	14
<u>Lycurus</u> <u>phleoides</u>	1701.3	174.1 **	8	15	1838.2	30.4	20	7
<u>Aristida</u> sp.	2268.4	- 3.2	--	--	2228.9	38.3 **	20	7
<u>Bouteloua</u> <u>hirsuta</u>	2093.4	110.1 **	11	11	1863.2	295.3 **	6	20
<u>Carex</u> sp.	1635.5	74.2 *	12	10	1725.0	- 19.7	--	--
<u>Leptoloma</u> <u>cognatum</u>	1271.0	44.1 *	14	9	1307.9	5.4	40	6
<u>Eragrostis</u> <u>intermedia</u>	1172.4	- 21.0	--	--	1132.9	20.4	19	8
<u>Bouteloua</u> <u>chondrosioides</u>	730.3	30.0 *	13	10	759.2	- 0.4	--	--
<u>Bouteloua</u> <u>curtipendula</u>	626.3	27.6 *	12	10	644.7	8.3	22	7
<u>Viguiera</u> <u>annua</u>	1026.3	- 6.3	--	--	992.1	29.6	15	8
<u>Commelina</u> <u>dianthifolia</u>	990.8	10.6	25	7	988.2	13.4	22	7
<u>Eriogonum</u> <u>wrightii</u>	986.8	- 5.6	--	--	981.6	- 0.1	--	--
<u>Desmanthus</u> <u>cooleyi</u>	588.2	- 0.8	--	--	577.6	10.3	19	8
<u>Haplopappus</u> <u>gracilis</u>	585.5	2.0	44	6	593.4	- 6.3	--	--
<u>Evolvulus</u> <u>sericeus</u>	361.8	0.0	--	--	359.2	2.8	29	5
<u>Croton</u> <u>corymbulosus</u>	334.2	4.6	22	6	331.6	7.4	17	7

* Significant at 0.05 probability level

** Significant at 0.01 probability level

for some species, is difficult to analyze but can be taken as an indication of a zero component and its contribution ignored (Searle 1971).

Optimal transect lengths (k_{opt}) in Plots 1 and 2 averaged 15-22 quadrats per transect (Tables 11 and 12). The values are close to the 20 quadrats per transect of the preliminary survey. The estimated number of transects to sample within 10% of a mean frequency percentage of 50% with 95% confidence is given in the last column of Tables 11 and 12,

$$\text{where, } N = \frac{t^2\ S^2}{(e.c.i.)^2}$$

and, $\underline{t}$ is the tabular $\underline{t}$ value, $\underline{S}^2$ is the variance of frequency percentages for subsamples, and e.c.i. is the expected-confidence-half-interval. Values for sample size averaged 8 to 13 transects per sample. The results indicate the preliminary survey consisted of optimal transect lengths, but twice the estimated number of transects.

The results from Plot 3 show that the orientation of transects can influence conclusions (Table 13). Transects oriented East/West, along slope contours, had significant components for a majority of species. However, components were not significant when transects were oriented North/South, across contours. The preferred orientation of transects when sampling slopes is across contours (Bormann 1953).

There was some question of the independence of species occurrence in quadrats on Site 3. However, the majority of species can be

Table 13. Plot 3: =Variance Components, Estimated k_{opt}, and Sample Size (N) to Sample within 10% of a Mean Frequency of 50% with 95% Confidence, as Sampled with 400 Quadrats Allocated 20 per Transect in North/South and East/West Orientations

	North/South				East/West			
Species	s_q^2	s_t^2	k_{opt}	N	s_q^2	s_t^2	k_{opt}	N
Bouteloua hirsuta	2494.7	- 4.7	--	--	1697.4	832.5 **	4	40
Aristida sp.	2482.9	- 16.6	--	--	2298.7	186.1 **	9	13
Andropogon cirratus	2339.5	89.9 *	13	9	1771.0	686.7 **	4	35
Hilaria belangeri	2246.0	28.4	23	7	1761.8	536.8 **	5	30
Eragrostis intermedia	2225.0	0.0	--	--	1938.2	301.2 **	6	20
Bouteloua curtipendula	1607.9	58.0 *	13	9	1544.7	124.3 **	9	13
Leptoloma cognatum	1206.6	129.9 **	8	16	1338.2	- 8.3	--	--
Lycurus phleoides	1086.8	10.1	26	7	1023.7	76.4 **	9	13
Carex sp.	802.6	19.3	16	8	813.2	8.3	25	7
Bouteloua chondrosioides	751.3	7.9	25	7	732.9	27.2 *	13	10
Andropogon barbinodis	598.7	33.9 **	11	11	606.6	25.6 *	12	10
Viguiera annua	2415.8	63.2	16	8	2015.8	483.2 **	5	26
Desmanthus cooleyi	1546.0	12.9	28	6	1311.8	258.8 **	6	23
Commelina dianthifolia	1457.9	22.9	20	7	1376.3	108.6 **	9	13
Evolvulus sericeus	915.8	27.6	15	9	942.1	0.0	--	--
Nama hispidum	568.4	- 3.2	--	--	557.9	7.9	22	7
Haplopappus gracilis	401.3	7.0	19	8	398.7	9.7	16	9
Baccharis thesioides	226.3	- 2.1	--	--	239.5	5.1	17	10
Mimosa dysocarpa	219.7	0.8	42	7	219.7	0.8	42	7

* Significant at 0.05 probability level
** Significant at 0.01 probability level

taken as independently distributed across contours, since transect components are insignificant.

Mixed Grass/Shrub. Transect components of variance were not significant for the majority of species in Plots 5 and 6 (Tables 14 and 15). As in the open grassland, subsampling was an inefficient means of estimating variance, because the effect of transects supplied no additional information beyond the variation of quadrats.

Optimal transect lengths in Plots 5 and 6 averaged 11 to 22 quadrats per transect, and sample size averaged 11 to 14 transects per sample. These estimates are slightly below those of Hyder et al. (1965) which were 10 transects of 25 quadrats for sampling semi-arid vegetation.

The majority of species in Plot 4 had significant components for both orientations of transects (Table 16). Thus, the variation in species frequency in placement of independent quadrats underestimates the variation in species distribution.

The significance of transects in Plot 4 can be attributed to the large patches of vegetation created by mesquite trees or soil differences. Transects are expected to be significant since some will be located within a patch while other transects might miss completely. In repeated sampling the estimate of the mean frequency percentage will vary due to location of transects and quadrats within transects.

Table 14. Plot 5: Variance Components, Estimated k_{opt}, and Sample Size (N) to Sample within 10% of a Mean Frequency of 50% with 95% Confidence, as Sampled with 400 Quadrats Allocated 20 per Transect in North/South and East/West Orientations

	North/South				East/West			
Species	s_q^2	s_t^2	k_{opt}	N	s_q^2	s_t^2	k_{opt}	N
Eragrostis lehmanniana	917.1	5.4	33	6	911.8	10.9	23	7
Bouteloua curtipendula	1093.4	61.8 **	11	11	1038.2	119.8 **	8	17
Setaria macrostachya	930.3	- 8.4	--	--	909.2	13.7	21	7
Bouteloua rothrockii	577.6	10.3	19	8	572.4	15.8	15	9
Bouteloua chondrosioides	527.6	16.4	14	8	548.7	- 5.6	--	--
Digitaria californica	543.4	- 0.1	--	--	548.7	- 5.6	--	--
Bouteloua filiformis	448.7	5.1	24	6	448.7	5.1	24	6
Calliandra eriophylla	1427.6	3.6	51	6	1343.4	92.0 **	10	12
Solanum elaeagnifolium	981.6	40.6	12	9	1007.9	13.0	22	7
Evolvulus sericeus	802.6	19.3	16	8	821.0	0.0	--	--
Portulaca oleracea	585.5	2.0	44	6	596.0	- 9.1	--	--
Prosopis juliflora	557.9	7.9	21	7	573.7	- 8.7	--	--
Haplopappus tenuisectus	381.8	18.5 **	12	9	496.0	2.8	34	6
Carlowrightia arizonica	343.4	19.3 **	11	10	348.7	13.8 *	13	9

* Significant at 0.05 probability level

** Significant at 0.01 probability level

Table 15. Plot 6: Variance Components, Estimated k_{opt}, and Sample Size (N) to Sample within 10% of a Mean Frequency of 50% with 95% Confidence, as Sampled with 400 Quadrats Allocated 20 per Transect in North/South and East/West Orientations

	North/South				East/West			
Species	s_q^2	s_t^2	k_{opt}	N	s_q^2	s_t^2	k_{opt}	N
Eragrostis lehmanniana	1632.9	106.4 **	10	12	1743.4	- 9.6	--	--
Bouteloua eriopoda	2139.5	340.6 **	6	20	2457.9	6.3	50	6
Setaria macrostachya	978.9	123.4 **	7	18	1031.6	68.2 **	10	12
Digitaria californica	997.4	24.1	16	8	1018.4	2.0	57	6
Evolvulus sericeus	1036.8	22.9	17	8	976.3	86.4	9	14
Haplopappus tenuisectus	803.9	- 3.6	--	--	811.8	- 12.0	--	--
Prosopis juliflora	297.4	- 5.9	--	--	297.4	- 5.9	--	--

* Significant at 0.05 probability level

** Significant at 0.01 probability level

Table 16. Plot 4: Variance Components, Estimated k_{opt}, and Sample Size (N) to Sample within 10% of a Mean Frequency of 50% with 95% Confidence, as Sampled with 400 Quadrats Allocated 20 per Transect in North/South and East/West Orientations

	North/South				East/West			
Species	S_q^2	S_t^2	k_{opt}	N	S_q^2	S_t^2	k_{opt}	N
Bouteloua filiformis	1698.7	824.2 **	4	41	2459.2	25.6	25	7
Aristida sp.	2326.3	49.7	17	8	2273.7	105.0 *	12	10
Aristida adscensionis	1869.7	298.3 **	6	20	2038.2	121.4 **	10	12
Panicum sp.	1640.8	98.2 **	10	11	1635.5	103.7 **	10	12
Bouteloua aristidoides	1430.3	101.8 **	10	12	1461.8	68.7 **	12	10
Bouteloua curtipendula	984.2	- 2.9	--	--	978.9	2.6	49	6
Digitaria californica	826.3	37.4 *	12	10	721.0	147.9 **	6	22
Boerhaavia coccinea	1040.8	38.7 *	13	9	1040.8	38.7 *	13	9

* Significant at 0.05 probability level

** Significant at 0.01 probability level

Conclusions

Subsampling was less efficient than systematic sampling for estimating the mean frequency percentage, because the variation in repeated placements of transects did not supply significant information about population variance. The precision of the mean is due only to the random placements of independent quadrats.

In addition, the subsampling method is difficult to apply to multispecies stands, since each species requires a different allocation of quadrats to transects. The two dominants *Bouteloua gracilis* and *Lycurus phleoides* in the North/South orientation of Plot 2, differ in allocation from 70 to 8 quadrats per transect, respectively.

Also, the method provides different estimates of variance with a change in transect direction. The dominants *Eragrostis lehmanniana* and *Bouteloua eriopoda* in Plot 6 have highly significant components for North/South transects, but components are insignificant in the East/West orientation.

The uniform placement of quadrats is an acceptable method for frequency sampling semi-desert grasslands, provided the spacing of quadrats exceeds the size of clumps of individuals. This is important on sites with low densities of large mesquite trees, where patches can be large. If quadrats are placed close together, species occurrence is not independent of placement, and variances will be underestimated.

The results of the preliminary subsample indicate an optimal allocation of 10 transect of 20 quadrats. However, since transect components are insignificant, 200 independent and regularly spaced quadrats are recommended to adequately sample.

CHAPTER 6

STUDY 3

Introduction

The objective of efficient sampling is to reduce variation between plots, thus fewer plots are required to characterize a vegetation unit. This is accomplished by including high and low densities in plant distribution within each plot. As a result, plots appear similar, and between plot variation is reduced. This study was initiated to compare the efficiency of rectangular and linear plots, each containing 250 quadrats, in sampling a mixed grass/shrub site.

Methods

On Site 5, six random points were located with the aid of 1:24,000 aerial photographs. A 20 x 45 m rectangular plot was established at each point, with the long direction along a North/South compass line. Plots were sampled with frequency quadrats similarly to Study 2, except a rectangular grid of 10 x 25 quadrats was used.

In addition, each point became the starting location for a line of 250 quadrats, spaced at a regular interval of 1.75 m. Sampling proceeded along a randomly oriented compass line until reaching a boundary of the site, whereupon the line turned 90° left or right depending on the outcome of a coin toss. The process continued until all quadrats were recorded.

The null hypothesis that linear and rectangular plots had equal variances was tested by an F-ratio (Snedecor 1956). The estimated number of plots to sample within 10% of a mean frequency percentage of 50% with 95% confidence was determined for N:

$$\text{where,} \quad N = \frac{t^2\ S^2}{(\text{e.c.i.})^2}$$

and, *t* is the tabulated *t* value for 95% confidence, $\underline{S}^2$ is the estimated variance of the frequency between plots, and e.c.i. is the expected-confidence-half-interval.

Results and Discussion

There was no significant difference in sampling efficiency between linear and rectangular plots for the majority of species encountered (Table 17). It was expected that linear plots would be significantly more efficient, since each plot would cross patches in the vegetation while rectangular plots would tend to lie wholly in one small section of the floristic pattern.

The unexpected results might be due to chance placements of the six rectangular plots in high density patches of *Bouteloua rothrockii*. This would explain the difference in dominants between the plots, since *Bouteloua rothrockii* occurred most frequently in rectangular plots while *Eragrostis lehmanniana* was dominant in linear plots.

The results also might be due to the influence of *Eragrostis lehmanniana* in disrupting plant distributions. *Eragrostis lehmanniana* is an aggressive colonizer that establishes itself on areas where

Table 17. Comparison of Species Frequencies, Number of Plots (N) Required to Sample within 10% of a Mean Frequency of 50% with 95% Confidence, and Ratio of Variances (F) for Rectangular and Linear Plots.-- Species shown are those with greater than 1% frequency.

		Rectangular		Linear	
Species	F	%F	N	%F	N
<u>Bouteloua rothrockii</u>	2.23	46.8	8.1	30.2	21.4
<u>Eragrostis lehmanniana</u>	1.35	36.0	17.3	49.1	21.5
<u>Digitaria californica</u>	6.55 *	12.3	11.3	8.9	2.2
<u>Bouteloua filiformis</u>	1.01	11.1	19.6	11.9	18.3
<u>Aristida</u> sp.	1.61	9.5	4.7	6.2	4.8
<u>Setaria macrostachya</u>	2.11	4.6	4.8	3.7	2.9
<u>Bouteloua chondrosioides</u>	2.85	4.3	11.4	4.4	4.0
<u>Calliandra eriophylla</u>	1.30	22.3	14.1	21.9	10.8
<u>Aster tanacetifolius</u>	1.21	20.3	17.0	15.0	17.8
<u>Sida</u> sp.	2.02	10.8	16.6	10.9	8.2
<u>Zinnia pumila</u>	1.50	6.4	12.0	5.5	8.0
<u>Solanum elaeagnifolium</u>	1.50	4.2	1.8	2.5	2.3
<u>Krameria parvifolia</u>	21.88 **	3.3	7.0	4.6	0.2
<u>Prosopis juliflora</u>	4.54	1.1	0.4	1.1	1.6

* Significant at 0.05 probability level

** Significant at 0.01 probability level

there is little competition, however it can quickly invade existing stands, and replace most of the natives (Cable 1971). This could create excessive 'patchiness' in plant distribution, to the point that linear or rectangular plots sample with equal efficiency.

An average of 9 to 10 plots are necessary to sample the vegetation at the predescribed level of precision. This average is comparable to the 10 to 12 plots that Hyder et al. (1965) estimated for sampling a blue grama range.

Conclusions

Either rectangular or linear plots can be used to sample semidesert vegetation, since there is no difference in efficiency. However, linear plots may have a practical advantage in that the investigator observes more of the surrounding vegetation on the site than when confined to the locality of a rectangular plot.

CHAPTER 7

SUMMARY

The objective of this thesis was to consider various problems when using frequency quadrats to sample range sites. Investigations involved estimating the representative area of several sites, comparing methods for locating quadrats in a sample stand, and comparing the efficiencies of two plot shapes. Results indicate:

1) Quadrat frequency sampling is an acceptable method for obtaining objective, quantitative data for comparing range sites with respect to species composition, abundance, and condition. Field sampling is relatively rapid compared to estimating density, yield, or cover.

2) It is important that the size of quadrat has been adjusted to the particular size and spacing of individuals under study. The quadrat used in this study had been previously tested across a range of similar plant communities.

3) The smallest area that adequately represents the species composition and structure of the entire site varies with species diversity and dispersion of individuals. Since, it is impossible to determine minimal area by visual inspection, a sample plot should be at least 10 x 10 m, which corresponds to the largest estimated value.

4) The proposal by Hyder et al. (1963) that quadrats be placed in randomly located transects is an inefficient means of plot sampling, since the transect component supplies no additional information to estimated variance. A single sample of quadrats can be systematically placed over a plot, provided the spacing between each quadrat exceeds the size of individuals or clumps of individuals. This can be a problem in communities with uniform soil and large mesquite trees where large patches of vegetation are created. If quadrats are too close together, the occurrence of species in a quadrat is not independent of all others, and the assumptions of the binomal distribution are violated.

5) The use of 400 quadrats provided a sample that adequately represented the species composition of the community. However, sample size does not need to be this large since an estimated 200-250 quadrats will sample a site at an acceptable level of precision.

6) There was no difference in statistical efficiency between rectangular plots and linear plots. However, linear plots are recommended for practical reasons, since the investigator is able to observe more of the surrounding vegetation than when confined to one locality.

APPENDIX A

SPECIES AND PERCENT FREQUENCY BY PLOT

Table A-1. Species and Percent Frequency for Plot 1

	Species	Percent Frequency
Grasses	Hilaria belangeri	69.00
	Aristida sp.	57.25
	Bouteloua hirsuta	50.75
	Lycurus phleoides	37.00
	Bouteloua chondrosioides	13.25
	Heteropogon contortus	9.50
	Andropogon barbinodis	9.50
	Eragrostis intermedia	9.50
	Leptoloma cognatum	5.25
	Bouteloua curtipendula	1.25
	Carex sp.	1.00
	Bouteloua gracilis	0.25
	Andropogon cirratus	0 *
Forbs and Shrubs	Viguiera annua	34.25
	Aster tanacetifolius	20.00
	Desmanthus cooleyi	17.50
	Evolvulus sericeus	14.00
	Nama hispidum	9.00
	Solanum elaeagnifolium	9.00
	Mimosa dysocarpa	5.25
	Commelina dianthifolia	4.50
	Sida procumbens	1.25
	Haplopappus gracilis	1.25
	Baccharis thesioides	0.75
	Mammillaria sp.	0.25
	Brayulinea densa	0 *

* Observed in the stand, but did not occur in a quadrat

Table A-2. Species and Percent Frequency for Plot 2.

	Species	Percent Frequency
Grasses	Bouteloua gracilis	76.00
	Lycurus phleoides	75.25
	Aristida sp.	65.50
	Bouteloua hirsuta	31.00
	Carex sp.	21.75
	Leptoloma cognatum	15.50
	Eragrostis intermedia	13.25
	Bouteloua chondrosioides	8.25
	Bouteloua curtipendula	7.00
	Andropogon barbinodis	1.00
	Andropogon cirratus	0.25
	Eragrostis lehmanniana	0 *
Forbs and Shrubs	Viguiera annua	11.50
	Commelina dianthifolia	11.25
	Eriogonum wrightii	11.00
	Desmanthus cooleyi	6.25
	Haplopappus gracilis	6.25
	Evolvulus sericeus	3.75
	Croton corymbulosus	3.50
	Brayulinea densa	1.25
	Sida procumbens	1.00
	Calliandra eriophylla	0.50
	Mimosa dysocarpa	0.50
	Opuntia engelmannii	0.25
	Nama hispidum	0.25
	Portulaca oleracea	0.25
	Aster tanacetifolius	0 *
	Baccharis thesioides	0 *
	Mammillaria sp.	0 *
	Opuntia spinosior	0 *

* Observed in the stand, but did not occur in a quadrat

Table A-3. Species and Percent Frequency for Plot 3

	Species	Percent Frequency
Grasses	*Bouteloua hirsuta*	46.00
	Aristida sp.	43.75
	Andropogon cirratus	41.00
	Hilaria belangeri	34.75
	Eragrostis intermedia	33.25
	Bouteloua curtipendula	21.00
	Leptoloma cognatum	15.75
	Lycurus phleoides	12.50
	Carex sp.	9.00
	Bouteloua chondrosioides	8.25
	Andropogon barbinodis	6.75
	Heteropogon contortus	0.75
Forbs and Shrubs	*Viguiera annua*	44.50
	Desmanthus cooleyi	19.25
	Commelina dianthifolia	18.00
	Evolvulus sericeus	10.50
	Nama hispidum	6.00
	Haplopappus gracilis	4.25
	Baccharis thesioides	2.50
	Mimosa dysocarpa	2.25
	Sida procumbens	1.25
	Aster tanacetifolius	1.00
	Portulaca oleracea	0.25
	Mammillaria sp.	0.25

Table A-4. Species and Percent Frequency for Plot 4.

	Species	Percent Frequency	
Grasses	Bouteloua filiformis	45.25	
	Aristida sp.	38.50	
	Aristida adscensionis	31.25	
	Panicum sp.	22.25	
	Bouteloua aristidoides	18.75	
	Bouteloua curtipendula	11.00	
	Digitaria californica	9.50	
	Setaria macrostachya	0	*
	Heteropogon contortus	0	*
	Bouteloua eriopoda	0	*
	Eragrostis lehmanniana	0	*
	Leptochloa dubia	0	*
	Andropogon barbinodis	0	*
Forbs and Shrubs	Boerhaavia coccinea	12.25	
	Prosopis juliflora	0.75	
	Allonia incarnata	0.50	
	Eriogonum wrightii	0.50	
	Sida procumbens	0.50	
	Brayulinea densa	0.25	
	Carlowrightia arizonica	0.25	
	Evolvulus sericeus	0	*
	Haplopappus tenuisectus	0	*

* Observed in the stand, but did not occur in a quadrat

Table A-5. Species and Percent Frequency for Plot 5

	Species	Percent Frequency
Grasses	*Eragrostis lehmanniana*	89.75
	Bouteloua curtipendula	13.25
	Setaria macrostachya	10.25
	Bouteloua rothrockii	6.25
	Bouteloua chondrosioides	5.75
	Digitaria californica	5.75
	Bouteloua filiformis	4.75
	Aristida sp.	1.25
	Bouteloua eriopoda	1.25
	Leptoloma cognatum	1.25
	Muhlenbergia porteri	1.00
	Hilaria belangeri	0.75
	Panicum sp.	0.75
	Andropogon barbinodis	0.50
	Bouteloua hirsuta	0.50
	Eragrostis intermedia	0 *
	Leptochloa dubia	0 *
Forbs and Shrubs	*Calliandra eriophylla*	17.25
	Solanum elaeagnifolium	11.50
	Evolvulus sericeus	9.00
	Portulaca oleracea	6.25
	Prosopis juliflora	6.00
	Haplopappus tenuisectus	5.25
	Carlowrightia arizonica	3.75
	Aster tanacetifolius	1.25
	Krameria pervifolia	1.25
	Opuntia engelmannii	0.75
	Sida procumbens	0.75
	Mimosa dysocarpa	0.50
	Ambrosia aptera	0 *
	Ditaxis neomexicana	0 *
	Desmanthus cooleyi	0 *

* Observed in the stand, but did not occur in a quadrat

Table A-6. Species and Percent Frequency for Plot 6

	Species	Percent Frequency	
	Eragrostis lehmanniana	77.75	
	Bouteloua eriopoda	43.50	
	Setaria macrostachya	12.50	
	Digitaria californica	11.50	
	Eragrostis intermedia	1.00	
	Andropogon barbinodis	0.25	
Grasses	Aristida sp.	0.25	
	Bouteloua filiformis	0.25	
	Panicum sp.	0.25	
	Leptochloa dubia	0	*
	Bouteloua rothrockii	0	*
	Bouteloua curtipendula	0	*
	Leptoloma cognatum	0	*
	Evolvulus sericeus	12.00	
	Haplopappus tenuisectus	8.75	
	Prosopis juliflora	3.00	
	Agave schottii	1.25	
	Sida procumbens	1.25	
Forbs and Shrubs	Carlowrightia arizonica	0.75	
	Ditaxis neomexicana	0.75	
	Solanum elaeagnifolium	0.75	
	Zinnia pumila	0.75	
	Ferocactus wislizen	0.50	
	Opuntia engelmannii	0	*
	Krameria parvifolia	0	*
	Opuntia spinosior	0	*

* Observed in the stand, but did not occur in a quadrat

APPENDIX B

EXPECTED-CONFIDENCE-HALF INTERVALS (E.C.I.) FOR

JUDGING THE PRECISION OF FREQUENCY DATA[a]

Frequency Percentage (p)	Added Increment of p									
	0	1	2	3	4	5	6	7	8	9
0	0.0	2.0	2.8	3.4	3.9	4.4	4.7	5.1	5.4	5.7
10	6.0	6.3	6.5	6.7	6.9	7.1	7.3	7.5	7.7	7.8
20	8.0	8.1	8.3	8.4	8.5	8.7	8.8	8.9	9.0	9.1
30	9.2	9.2	9.3	9.4	9.5	9.5	9.6	9.7	9.7	9.8
40	9.8	9.8	9.9	9.9	9.9	9.9	10.0	10.0	10.0	10.0
50	10.0	10.0	10.0	10.0	10.0	9.9	9.9	9.9	9.9	9.8
60	9.8	9.8	9.7	9.7	9.6	9.5	9.5	9.4	9.3	9.2
70	9.2	9.1	9.0	8.9	8.8	8.7	8.5	8.4	8.3	8.1
80	8.0	7.8	7.7	7.5	7.3	7.1	6.9	6.7	6.5	6.3
90	6.0	5.7	5.4	5.1	4.7	4.4	3.9	3.4	2.8	2.0
100	0.0									

[a]As derived from E.C.I. = $\pm \sqrt{pq/n-1}$ where n-1 = 100 to give an E.C.I. of 10% at a frequency of 50%

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