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Quadrat and sample sizes for frequency sampling mountain meadow vegetation

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QUADRAT AND SAMPLE SIZES FOR FREQUENCY SAMPLING MOUNTAIN MEADOW VEGETATION[1]

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ABSTRACT.—Proper quadrat and sample sizes for sampling species frequency vary among vegetation types. This study found 10 × 10-cm quadrats most appropriate for frequency sampling dry mountain meadows when using a single quadrat size. If large, broad-leaved forbs are of special interest, 25 × 25-cm, 25 × 50-cm, or 50 × 50-cm quadrats may be useful. One hundred 10 × 10-cm quadrats adequately sampled most common species at alpha = 0.20 ± 10% frequency. In contrast, more than five hundred 0.29-m^2 circular plots usually were needed to sample individual species yield at alpha = 0.20 ± 20% of the mean.

Monitoring rangeland vegetation with quadrat frequency data recently has received interest from several authors (Hironaka 1985, West 1985, Mosley et al. 1986, 1987, Smith et al. 1986, 1987, Whysong and Brady 1987, Whysong and Miller 1987). Quadrat frequency sampling measures the presence or absence of a species in a given number of repeatedly placed small sample quadrats. Frequency is a desirable attribute for rangeland monitoring because it is stable, objectively measured, and simple to obtain (Brown 1954, Hyder et al. 1966). An important distinction separating frequency from other common vegetation attributes, such as yield, cover, and density, is that these other attributes are not influenced greatly by the plot size used to measure them. Frequency is affected by quadrat size, as well as plant size, plant distribution, and plant density (Kershaw and Looney 1985). Therefore, any interpretation of frequency estimates is of value only in relation to quadrat size. Some authors have criticized frequency sampling for its dependence on quadrat size (e.g., Weaver and Clements 1938), but this argument has no more credibility than saying that measurements from a ruler are valueless because they depend on the ruler (Curtis and McIntosh 1950).

Since frequency values depend on quadrat size, determining the proper-sized quadrat is important. Yet techniques for doing so are not entirely objective. A single quadrat size will sample some species more precisely than others because of their dissimilar plant sizes, distributions, and densities. However, several species within a plant community are usually of interest; thus, most sampling strategies strive to sample properly a maximum number of species while retaining precision for the most common species (Hyder et al. 1963). Curtis and McIntosh (1950) developed an accepted standard for determining proper quadrat size, concluding that an appropriately sized quadrat samples the most prevalent species at 63–86% frequency. Smith (1982) considered 20% a reasonable lower limit for measuring less abundant species. Plot sizes supplying extremely high or low frequencies are inappropriate since these values are too close to the extremes (0% and 100%) for setting reliable confidence limits. Consequently, as frequencies approach these extremes, their associated confidence interval decreases (Snedecor and Cochran 1980).

In addition to proper quadrat size, the proper number of quadrats (sampling intensity) is also important when sampling frequency. One approach for determining the proper number of quadrats employs species-area curves (Cain 1943, Oosting 1956). These species-area curves are derived by plotting the number of species sampled against an increasing number of small quadrats. The slope of the curve is initially steep but gradually flattens. The minimum number of quadrats needed can be found by locating that point where the curve begins to flatten. A problem with using species-area curves to determine

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frequency sampling intensity is that they do not reflect sample variation or the number of occurrences of a species. This is an important limitation for the statistical analysis of frequency data. A species is counted as sampled even if it is present only once; yet, as mentioned earlier, extremely low frequencies are statistically unacceptable. Species-area curves may be used to determine sample size for vegetation description, but they are inadequate when the aim is to monitor changes in species abundance. This latter goal requires a more rigorous method. Unfortunately, completely objective guidelines do not exist and sampling intensity decisions are resultantly always subjective. Nevertheless, they should be based on good judgment (Mueller-Dombois and Ellenberg 1974). Required sampling intensity for frequency sampling depends on two factors.

First, frequency values obtained by a particular quadrat size will affect proper sampling intensity because frequencies are proportional data exhibiting a binomial distribution. Frequency data are skewed around low and high values but appear normally distributed about intermediate values. To compensate for the skewness, a larger sample size is needed for species or quadrat sizes supplying extremely high or low frequencies (Hyder et al. 1963). This binomial distribution of frequency values reemphasizes the need for proper quadrat sizes to provide intermediate frequencies.

Second, the number of quadrats needed also depends upon the level of precision desired. Because it is impractical to examine every individual within a plant community, vegetation must be sampled and inferences made about the population. Adequate sampling intensity is important if confidence is desired in sample estimates. And since each observation costs time and money, inevitably a compromise must be reached between precision and practicality, usually making it possible to evaluate only the more abundant species with reasonable accuracy (Mueller-Dombois and Ellenberg 1974). The dilemma of determining proper sampling intensity may be summarized best by Rice and Kelting (1955). They explain that in actual practice ecologists sample as many quadrats as their field experience indicates or their time and funds allow.

The purpose of this research was to provide guidelines for frequency sampling procedures in mountain meadows. Two related papers have explored potential uses of frequency data from mountain meadows of central Idaho (Mosley et al. 1986, 1987). This paper details the research that determined appropriate quadrat and sample sizes used in the two previously reported studies. For comparison, this study also examined an appropriate sample size for yield sampling mountain meadow vegetation.

METHODS

This study was conducted within dry mountain meadows of central Idaho located on the Boise, Payette, and Sawtooth National Forests. During the summers of 1982 and 1983 vegetation on study sites 1–12 was sampled for frequency and yield, while study sites 13–18 were sampled for frequency alone (Table 1). To sample variability within dry mountain meadows, we selected six sites from each of three range condition classes—good, fair, and poor. Condition was determined from U.S. Forest Service range analysis and trend study records. Botanical nomenclature followed Hitchcock and Cronquist (1973). Frequency sampling procedures followed those reported by Mosley et al. (1986), and yield sampling procedures followed Mosley et al. (1987). Rooted frequency of occurrence for individual species was recorded within 100 nested frequency quadrats per site, with 20 quadrats spaced along each of five transects. Frequency quadrats had several smaller quadrat sizes contained (nested) within one frame. Quadrat sizes were 5 × 5 cm, 10 × 10 cm, 25 × 25 cm, 25 × 50 cm, and 50 × 50 cm. Herbaceous yield was sampled by species within thirty 0.29-m^2 circular plots per site, allocated 10 plots along each of three transects.

Frequency data from all 18 study sites were analyzed to assess appropriateness of the different quadrat sizes for each study site. A proper-sized quadrat was the smallest quadrat that sampled a site's single most prevalent species at 63–86% (Curtis and McIntosh 1950). A lower limit of 20% was used to evaluate the ability of a quadrat size to measure less abundant species (Smith 1982).

TABLE 1. Study sites examined to estimate appropriate quadrat and sample sizes for frequency sampling mountain meadow vegetation.

Site no.	Site name	Elevation (m)	Ranger district	National forest
1	Ayers Meadow	1,950	Lowman	Boise
2	Bearskin Meadow	2,015	Lowman	Boise
3	Big Meadow	2,045	Lowman	Boise
4	Bruce Meadow	1,950	Lowman	Boise
5	Cache Creek	2,045	Lowman	Boise
6	Corduroy Meadow (a)	1,985	Lowman	Boise
7	Corduroy Meadow (b)	1,985	Lowman	Boise
8	Dead Cow Meadow	2,045	Lowman	Boise
9	Little East Fork	2,015	Lowman	Boise
10	Poker Meadow	1,985	Lowman	Boise
11	Pole Creek	1,985	Lowman	Boise
12	Stanfield Meadow	2,045	Lowman	Boise
13	Pen Basin	2,045	Cascade	Boise
14	Tyndall Meadow	2,135	Cascade	Boise
15	Hartley Meadow	2,135	McCall	Payette
16	Sater Meadow	1,920	McCall	Payette
17	Elk Meadow	2,045	Stanley	Sawtooth
18	Stanley Creek	1,985	Stanley	Sawtooth

Frequency data were also analyzed to assess sampling intensity on sites 1–12 (Table 1). Since proper sample size for frequency sampling is partially determined by quadrat size, proper sampling intensity was determined using the quadrat size deemed most appropriate in the first part of the study. To calculate an appropriate sample size for a particular species on a site, an estimate of the population variance, σ^2, was needed. This was supplied by the sample variance, s^2, and was calculated

$$s^2 = \frac{\Sigma p_i^2 - \frac{(\Sigma p_i)^2}{n}}{n(n-1)}$$

where $p_1, p_2, \ldots p_n$ were frequency percentages of a species by transect, and n was the number of transects sampled (Hyder et al. 1963). Estimated number of transects required, N, was calculated by

$$N = \frac{t^2 n s^2}{(\text{e.c.i.})^2}$$

where t was the tabular value, n was the number of transects already sampled, and *e.c.i.* was the expected-confidence-half interval (Hyder et al. 1963). Two different precision levels were evaluated, alpha = 0.10 ± 10% frequency and alpha = 0.20 ± 10% frequency. Since sample variances are correlated with frequency percentages, a complete set of e.c.i. values was needed to estimate the number of transects required for each species on each site. Values for e.c.i. standardized to within 10% of a mean frequency of 50% were taken from Hyder et al. (1963).

For comparison, yield data were analyzed to estimate adequate sampling intensity. Sample variance, s^2, was calculated

$$s^2 = \frac{\Sigma y_i^2 - \frac{(\Sigma y_i)^2}{n}}{n(n-1)}$$

where $y_1, y_2, \ldots y_n$ were dry weights (kg/ha) of species by transect, and n was the number of transects sampled. Estimated transects needed, N, was calculated

$$N = \frac{t^2 n s^2}{b^2}$$

where t was the tabular value, n was the number of transects already sampled, and b was the bound on error. The precision level evaluated was alpha = 0.20 ± 20% of the mean.

RESULTS AND DISCUSSION

Quadrat Size

Hyder et al. (1963) determined a 23 × 23-cm quadrat was most appropriate for frequency sampling sagebrush-bunchgrass vegetation of eastern Oregon. On blue grama (*Bouteloua gracilis*) rangeland in Colorado, a 5 × 5-cm quadrat nested within a 41 × 41-cm quadrat was recommended (Hyder et al.

TABLE 2. Site comparison of smallest quadrat size that sampled the most prevalent species at 63–86% frequency.

Study site	Range condition class	Most prevalent species	Proper quadrat size (cm)
Cache Creek	Good	*Deschampsia cespitosa*	5 × 5
Elk Meadow	Good	*Carex* spp.	10 × 10
Hartley Meadow	Good	*Deschampsia cespitosa*	10 × 10
Poker Meadow	Good	*Deschampsia cespitosa*	25 × 25
Sater Meadow	Good	*Trifolium longipes*	10 × 10
Stanfield Meadow	Good	*Danthonia intermedia*	25 × 50
Bearskin Meadow	Fair	*Carex* spp.	25 × 25
Corduroy Meadow (a)	Fair	*Deschampsia cespitosa*	10 × 10
Dead Cow Meadow	Fair	*Trifolium longipes*	10 × 10
Pen Basin	Fair	*Danthonia intermedia*	50 × 50
Pole Creek	Fair	*Trifolium longipes*	10 × 10
Stanley Creek	Fair	*Deschampsia cespitosa*	25 × 25
Ayers Meadow	Poor	Annual forbs	50 × 50
Big Meadow	Poor	*Achillea millefolium*	10 × 10
Bruce Meadow	Poor	*Achillea millefolium*	10 × 10
Corduroy Meadow (b)	Poor	*Trifolium longipes*	10 × 10
Little East Fork	Poor	*Danthonia intermedia*	10 × 10
Tyndall Meadow	Poor	*Danthonia intermedia*	25 × 25

1965). In this study, proper quadrat size varied from 5 × 5 cm to 50 × 50 cm (Table 2). However, the 10 × 10-cm quadrat was the proper size if only one quadrat size was to be used on 10 of 18 sites, far more often than any other single quadrat size. Of the 10 sites where 10 × 10 cm was most appropriate, 3 sites were in good range condition, 3 in fair condition, and 4 in poor condition. Apparently, proper quadrat size does not vary with condition class.

Proper quadrat size did vary with apparent vegetation density. Visually the Ayers Meadow and Pen Basin sites had the lowest total plant cover with wider spaces between individual plants. These two sites were best sampled by the 50 × 50-cm quadrat. Conversely, vegetation at Cache Creek was the most dense and was best sampled by the smallest quadrat evaluated, 5 × 5 cm. Ayers Meadow and Pen Basin were the driest sites sampled, whereas Cache Creek was the moistest site studied.

It is noteworthy that the most prevalent species was always a graminoid or small forb. Large, broad-leaved forbs did not reach high frequencies until most graminoids and small forbs had exceeded the 86% limit. Table 3 compares the optimal quadrat size for several common species. For many of the larger or more widely spaced forbs, including *Aster* spp., *Agoseris glauca*, and *Antennaria corymbosa*, larger plot sizes such as 25 × 25 cm, 25 × 50 cm, and 50 × 50 cm appear more appropriate. Therefore, a nested quadrat containing 10 × 10-cm, 25 × 25-cm, 25 × 50-cm, and 50 × 50-cm quadrats appears most efficient for sampling a variety of mountain meadow species for frequency (Table 4). Note that usually less than 50% of all species encountered on a site were sampled within 20–86% frequency (Table 4).

Sample Size

Appropriate sampling intensity depends upon the objectives of a study. Extremely time-consuming, intensive vegetation sampling may be justified in research studies or in other studies in which a rare or highly variable species is of special concern. But most land management activities are more constrained by limited amounts of time and money and must often be satisfied with sampling at lower precision levels.

In this study as many as 196 transects of ten 0.29-m^2 circular plots each were needed to sample individual species yield, even at a conservative precision level (Table 5). This sample size is not practical considering the time and effort required to sample yield by species. Only one of the most common species, *Deschampsia cespitosa*, was adequately sampled with fewer than 100 quadrats. Since most land management personnel usually sample 30 or

TABLE 3. Quadrat size comparison of the number of sites where specific common species were sampled within a range of 20–86% frequency.

Species	No. of sites species encountered	Number of sites where species adequately sampled, Quadrat size (cm): 5 × 5	10 × 10	25 × 25	25 × 50	50 × 50	Optimal quadrat size (cm)
GRAMINOIDS							
Carex spp.	18	11	13	11	11	10	10 × 10
Danthonia intermedia	17	6	11	10	10	7	10 × 10
Deschampsia cespitosa	13	7	9	7	5	5	10 × 10
Festuca idahoensis	8	1	3	5	4	4	25 × 25
Muhlenbergia filiformis	10	1	1	1	3	3	25 × 50
Stipa occidentalis	10	0	0	5	7	8	50 × 50
FORBS							
Achillea millefolium	13	6	9	8	6	6	10 × 10
Agoseris glauca	13	0	3	4	5	5	25 × 50
Antennaria corymbosa	17	0	2	6	7	8	50 × 50
Aster spp.	18	3	9	13	13	13	25 × 25
Cirsium vulgare	7	0	1	3	4	3	25 × 50
Gentiana calycosa	9	0	1	4	5	5	25 × 50
Senecio integerrimus	13	0	2	3	3	3	25 × 25
Trifolium longipes	14	7	7	4	4	4	5 × 5
Wyethia helianthoides	8	0	0	0	1	1	25 × 50

TABLE 4. Single quadrat size and nested quadrat group comparison of the number of species sampled within a range of 20–86% frequency.

Site no.	Total no. of species encountered	Number of species adequately sampled, Quadrat size (cm): 5 × 5	10 × 10	25 × 25	25 × 50	50 × 50	10 × 10, 25 × 25	10 × 10, 25 × 25, 25 × 50	10 × 10, 25 × 25, 25 × 50, 50 × 50
1	27	2	4	6	7	8	6	7	8
2	20	3	6	9	7	7	10	10	10
3	19	4	6	7	6	7	9	9	10
4	27	4	5	7	12	13	9	15	16
5	20	2	1	1	3	5	2	4	6
6	22	2	8	9	8	8	10	10	11
7	24	4	9	9	9	7	11	12	12
8	19	3	6	10	10	8	11	12	12
9	27	4	7	7	7	8	10	10	11
10	23	3	4	5	7	8	8	11	12
11	30	3	6	12	13	13	13	16	16
12	18	1	7	8	9	9	8	9	10
13	21	2	4	9	10	12	9	10	12
14	21	2	4	7	7	8	8	9	10
15	9	1	1	1	3	4	2	4	5
16	18	2	5	4	5	5	6	8	8
17	13	3	3	5	4	4	5	5	5
18	23	1	8	12	13	11	12	14	14
Mean	21.2	2.6	5.2	7.1	7.8	8.0	8.3	9.7	10.4
S.E.	1.2	0.2	0.5	0.7	0.7	0.6	0.7	0.8	0.8

TABLE 5. Site comparison of the number of transects needed to sample yield of 15 common species at alpha = 0.20 ± 20% of the mean, as sampled with 0.29-m^2 circular plots allocated 10 per transect.

	Sites												
Species	1	2	3	4	5	6	7	8	9	10	11	12	Mean
GRAMINOIDS													
Carex spp.	24	8	43	37	3	122	7	30	9	13	2	9	26
Danthonia intermedia	263	3	52	35	*	267	16	3	5	68	23	21	69
Deschampsia cespitosa	*	*	*	*	2	3	*	4	12	2	13	4	6
Festuca idahoensis	261	8	14	8	*	*	39	*	269	*	*	*	100
Muhlenbergia filiformis	*	*	*	*	11	*	261	*	271	*	73	77	139
Stipa occidentalis	8	75	33	60	*	*	*	*	*	*	*	*	44
FORBS													
Achillea millefolium	15	9	6	4	*	*	11	76	8	*	18	*	19
Agoseris glauca	*	117	267	209	*	*	10	*	2	89	*	*	116
Antennaria corymbosa	119	51	83	*	267	265	261	26	31	6	267	*	138
Aster spp.	9	117	206	14	148	3	62	3	3	18	31	42	55
Cirsium vulgare	*	*	248	135	*	*	*	15	267	*	265	*	186
Gentiana calycosa	*	*	*	*	*	12	*	*	42	11	111	68	49
Senecio integerrimus	267	135	*	31	20	49	39	*	*	2	7	22	64
Trifolium longipes	120	267	89	5	267	*	21	15	10	65	7	*	87
Wyethia helianthoides	267	267	*	169	*	*	*	*	*	267	10	*	196

* = species not encountered.

fewer quadrats per site, our results emphasize that individual species yield estimates collected by land management personnel usually have very wide confidence limits. Many transects are needed per site because of the great variability in species yield. Conversely, a site's total herbaceous yield required only 2.7 ± 0.9 transects of ten 0.29-m^2 circular plots each to sample at alpha = 0.20 ± 20% of the mean. Mueggler (1976) found that similar sample sizes were needed for total yield in most mountain grassland and sagebrush-grass habitat types of western Montana.

The number of transects required to sample species frequency with 10 × 10-cm quadrats was more reasonable than sample size needed for species yield, varying from 6 to 19 transects at the 90% confidence level (Table 6). However, 5 transects of 20 quadrats each are probably the maximum practical for land managers frequency sampling mountain meadow vegetation. Each transect requires up to 30 minutes for two individuals to complete; additional plots or transects would be time prohibitive. Table 7 lists the number of frequency transects needed to sample with less precision. Most common species were sampled adequately with 5 transects at the 80% confidence level. Thus, a compromise must be reached between precision and practicality. Five transects may not meet the preferred precision level, but this sampling intensity probably provides acceptable results.

It is important to note that only 11 of the 15 most prevalent species and probably very few of the less common species were adequately sampled at alpha = 0.20 ± 10% frequency. This emphasizes that variance-based statistical tests are poorly suited to analyzing species frequency. Perhaps other statistical tests such as chi-square are better suited to analyzing frequency data. Unfortunately, we know of no way to independently calculate an adequate sample size for chi-square analysis.

CONCLUSION

Dense meadow vegetation was sampled best by small quadrats; more widely spaced vegetation required larger quadrats. However, a 10 × 10-cm quadrat is recommended as most appropriate for frequency sampling dry mountain meadows when using a single quadrat size. If large, broad-leaved forbs are of special interest, larger quadrats, such as 25 × 25 cm, 25 × 50 cm, or 50 × 50 cm, may prove valuable. A 10 × 10-cm quadrat appears to be the smallest quadrat necessary, and a 50 × 50-cm quadrat appears to be the largest size needed. If several species with greatly varying plant sizes, distributions, and densities need to be measured, more than one quadrat size may be required (Smith et al. 1987).

TABLE 6. Site comparison of the number of transects needed to sample 15 common species within 10% of a mean frequency of 50% with 90% confidence, as sampled with 10 × 10-cm quadrats allocated 20 per transect.

	Number of transects required Sites												
Species	1	2	3	4	5	6	7	8	9	10	11	12	Mean
GRAMINOIDS													
Carex spp.	32	29	26	7	4	13	12	22	1	5	10	1	14
Danthonia intermedia	7	10	9	12	6	5	2	17	7	15	12	2	9
Deschampsia cespitosa	*	*	*	*	5	11	*	4	9	9	12	9	8
Festuca idahoensis	3	4	4	15	*	*	4	*	*	*	*	*	6
Muhlenbergia filiformis	*	*	*	*	28	6	*	*	3	*	3	3	9
Stipa occidentalis	6	14	11	9	*	*	*	6	*	*	*	*	10
FORBS													
Achillea millefolium	4	6	7	5	*	*	9	70	10	*	5	*	15
Agoseris glauca	*	*	6	7	*	*	11	*	4	*	*	*	7
Antennaria corymbosa	8	16	5	*	*	12	*	9	8	6	7	6	9
Aster spp.	13	51	34	7	13	7	2	6	11	11	5	12	15
Cirsium vulgare	*	*	36	6	*	*	*	3	6	*	6	*	12
Gentiana calycosa	*	*	*	*	6	8	*	*	13	3	6	8	8
Senecio integerrimus	6	6	*	6	19	3	2	*	*	6	7	*	7
Trifolium longipes	5	38	9	3	18	*	9	12	73	13	8	*	19
Wyethia helianthoides	*	5	*	6	*	8	*	*	*	6	6	*	7

* species not encountered

TABLE 7. Site comparison of the number of transects needed to sample 15 common species within 10% of a mean frequency of 50% with 80% confidence, as sampled with 10 × 10-cm quadrats allocated 20 per transect.

	Number of transects required Sites												
Species	1	2	3	4	5	6	7	8	9	10	11	12	Mean
GRAMINOIDS													
Carex spp.	17	15	14	4	3	7	7	12	1	3	5	1	8
Danthonia intermedia	3	5	5	7	3	3	1	9	4	8	6	1	5
Deschampsia cespitosa	*	*	*	*	3	6	*	2	5	5	6	5	5
Festuca idahoensis	2	2	2	8	*	*	2	*	*	*	*	*	4
Muhlenbergia filiformis	*	*	*	*	15	3	*	*	2	*	2	2	5
Stipa occidentalis	3	7	6	5	*	*	*	3	*	*	*	*	5
FORBS													
Achillea millefolium	2	3	4	3	*	*	5	8	5	*	3	*	5
Agoseris glauca	*	*	3	4	*	*	6	*	2	*	*	*	4
Antennaria corymbosa	5	8	3	*	*	6	*	5	5	3	4	3	5
Aster spp.	7	27	18	4	7	4	2	3	6	6	3	6	8
Cirsium vulgare	*	*	19	3	*	*	*	2	3	*	3	*	6
Gentiana calycosa	*	*	*	*	3	4	*	*	7	2	3	5	4
Senecio integerrimus	3	3	*	3	10	2	1	*	*	3	4	*	4
Trifolium longipes	3	20	5	2	10	*	5	6	38	7	4	*	10
Wyethia helianthoides	*	3	*	3	*	5	*	*	*	3	4	*	4

* species not encountered

Species frequency in mountain meadows was adequately sampled at a practical sampling intensity of one hundred 10 × 10-cm quadrats. In contrast, precise estimates of individual species yield required sample sizes beyond practical levels for land management personnel. Total herbaceous yield of mountain meadows was adequately sampled with a practical sample size of thirty 0.29-m^2 circular plots.

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