EVALUATION OF THE IMPROVEMENT IN SENSITIVITY OF NESTED FREQUENCY PLOTS TO VEGETATIONAL CHANGE BY SUMMATION[1]

Stuart D. Smith[2,3], Stephen C. Bunting[2], and M. Hironaka[2]

Abstract.—At four sites in Idaho, frequency was measured separately with three different-sized plots (10 x 25, 15 x 33.5, and 20 x 50 cm) arranged in a nested configuration. These individual frequency values were added together to create a summed "frequency." This summed value was compared to the original frequency values generated by each individual plot size in respect to its ability to detect range trend. The summation procedure consistently detected smaller changes in frequency than any individual plot size. In addition, the summed values detected a significant change in more species at each site. Summing the frequency values usually detected changes at a lower alpha level than did any single plot (0.10 vs. 0.20).

Range trend has historically been defined as either apparent or measured. Apparent trend is a subjective rating reached with only one observation of the land. Various site and vegetational indicators of trend are observed and judged against published standards. This approach has been described by many authors, including Pickford and Reid (1942), Costello and Turner (1944), and Ellison and Croft (1944). Measured trend is an objective record of successive condition ratings. Two or more successive observations of condition must be made over an interval of time to determine measured trend.

Before sampling for measured trend begins, the vegetational attribute with which condition (and thus measured trend) is measured must be determined. Cover, production, density, and frequency are the most common attributes considered. For management purposes, the selected attribute should exhibit the following characteristics: (1) precision, (2) ease in sampling, and (3) sensitivity to successional change. Fluctuations in any of the attributes due to between-year and between-season weather variations and current grazing use reduce the precision and sensitivity of the resulting measurements. Cover (both foliar and basal) and yield reflect these variations and, therefore, are too transient for determining trend. Density is the attribute least affected by weather variation, especially with perennial vegetation. However, as Strickler and Stearns (1963) point out, measuring density can become tedious or imprecise if the plants are small and numerous or if they reproduce vegetatively. Considering the alternatives, frequency becomes a logical choice. A search of the available literature shows various authors, including Blackman (1942), Hyder et al. (1963), and Greig-Smith (1964) alluding to the advantages of frequency for determining vegetational change. As a function of density, frequency is relatively stable over time. This stability, coupled with objective measurements, provides a high degree of precision. Brown (1954) adds that frequency is measured easily and rapidly. In addition, use of frequency as a method of monitoring range trend is becoming more prevalent (U.S. Department of Agriculture, Forest Service 1981, Despain 1982). Results presented by Smith et al. (1986) show frequency to be a sensitive measure of successional change.

Frequency, however, does have certain limitations that must be accounted for to maximize its usefulness. These limitations have been listed by Kershaw (1973) as four variables that determine frequency results: (1) plot size, (2) plant size, (3) plant distribution, and (4) plant density. A change in any one of these variables will change the resulting frequency value (Brown 1954), thus obscuring determination of the variable(s) responsible for change. It is impossible to control plant

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[2]Department of Range Resources, University of Idaho, Moscow, Idaho 83843.
[3]Present address: Applications Branch, EROS Data Center, Sioux Falls, South Dakota 57198.

size, distribution, or density when sampling vegetation. Plot size, therefore, is the only variable that can be altered to give desired frequency values. Appropriate frequency values for vegetation monitoring are usually considered to be in the 63 to 86% range for the most prevalent species. At these levels, plot sizes will be one and two times, respectively, the mean area of the individuals of that species in a randomly distributed population (Curtis and McIntosh 1950).

The ideal frequency sampling scheme to account for variations in plant size, distribution, and density would include a different-sized plot for each species (Despain 1982), since a given plot size will sample certain species more adequately than others (Hyder et al. 1963). Many investigators have avoided this complexity by standardizing the plot size used on a variety of vegetation types (Shimwell 1971, Tueller et al. 1972). However, the inherent variability in plant size, distribution, and density often makes it difficult for only one plot size to adequately sample various areas.

The use of a single plot size is further constrained by Raunkiaer's Law of Frequency (Raunkiaer 1934), which states that there are more species with few individuals than with many (Shimwell 1971). This skewed distribution of frequencies can present problems in frequency sampling for range trend, since it is more difficult to detect change over time in species with low frequencies (Smith et al. 1986). Although most "key" management species monitored for range trend are not rare, there are often cases when interest is directed toward both numerous and scarce species occupying the same site. Increasing species frequency by enlarging a single plot size could improve the likelihood of detecting range trend in species having lower frequencies. However, this is not practical, since enlarging plot size would simultaneously increase frequency for all species present. If the frequency of any species reached 100%, it would become impossible to make comparisons because future increases in density of that species would still yield values of 100% frequency. Therefore, enlarging plot size could potentially narrow the range of frequency values of various species and thus reduce the total number of species having frequency values useful for determining range trend. A preferable alternative would somehow widen the range of frequencies and at the same time improve the sensitivity to change for those species with lower frequency readings.

One alternative solution might be to select one plot size, among several, best suited for a particular site. This is employed in the nested frequency plot method where three or four variously sized plots are located (nested) within each other in a single configuration. Frequencies recorded for each of the plot sizes are compared. Data from only the plot size giving the most sensitive detection of change over a period of time are used to determine range trend for a site. Although use of frequency plots has the potential to improve sensitivity for detection of trend, procedures commonly employed with the nested technique may not use data as efficiently, since data from only one of the several plot sizes are ever utilized for any given species.

This study investigated the summation of frequencies from three different nested plot sizes in an effort to increase sensitivity and efficiency for detection of trend of any individual plot size alone. For example, in 100 nested configurations each consisting of three plot sizes, a total occurrence of 300 would be possible for any given species. It is proposed that such a summation would have three advantages: (1) Compared to any single plot size, it would widen the range of possible occurrence values for any species by increasing the maximum possible number of observations from 100 to 300 (assuming three nested plots are used). Differences that might not be significant at lower frequency levels may become significant when the range of occurrences is increased. (2) The smaller plot sizes in the nested design would provide inherently smaller frequency readings. Should such smaller values be added to the total, they would decrease the probability that the summed value would reach 300. This would improve the likelihood of detecting changes in already abundant species whose frequency increased over time. (3) It should increase the number of species showing significant changes in frequency over time, adding credibility to the estimation of range trend.

METHODS

Field Methods

During the summer of 1981, four sites located within 70 km of Salmon, Idaho, were studied. These sites were selected to test the procedures in a variety of vegetational types. Listed as habitat types (Hironaka et al. 1983, Steele et al. 1981), the sites are:

1. *Pinus ponderosa/Festuca idahoensis*. Located at an elevation of 1,500 m, this site exhibited a typical fire-maintained *P. ponderosa* stand structure (Morris and Mowat 1958). It combined an uneven-aged stand overstory with a grass-dominated understory.
2. *Artemisia tridentata* subsp. *vaseyana/Festuca idahoensis*. Several *Pseudotsuga menziesii* trees had invaded this site, although there was no indication of previous occupation by this species. The elevation was 1,975 m.
3. *Artemisia tridentata* subsp. *vaseyana/Festuca idahoensis*. This site had been burned three years prior to sampling. The elevation was 2,250 m.
4. *Artemisia tridentata* subsp. *vaseyana/Festuca idahoensis*. This site was located on an exposed, high-elevation (2,725 m) ridge. There was an abundance of small forbs and a lack of shrubs. The few *Artemisia* individuals present were small and stunted.

Vegetation data reported in this study consist of the herbaceous component only. Usage of scientific names in this report except for *Artemisia* follows that of Hitchcock and Cronquist (1973).

The sampling process consisted of three phases designed to simulate trend sampling over a period of years. In phase 1, frequency and cover baseline measurements were taken. Phase 2 consisted of randomly excluding known amounts of vegetation from further sampling, simulating a known compositional change over time. In phase 3, the plots sampled in phase 1 were resampled after the vegetation change had been created. Phases 2 and 3 were completed a total of three times, since three different levels of change were studied.

The frequency sampling unit consisted of a series of metal plot frames arranged concentrically in a nested configuration. Plot sizes were 10 x 25, 15 x 33.5, and 20 x 50 cm, representing areas of 250, 500, and 1,000 cm^2, respectively. The nested configuration allowed direct comparison of any different size, since a plant located in a particular plot would also be included in all larger plots.

At each site, ten 10-m transects were located within a uniform area. The transects were usually placed parallel to each other with a distance of 2 to 3 m between them. Along each transect, 40 of the nested configurations were uniformly spaced, for a total of 400 samples per site.

At each of the 400 nested configurations, frequency of occurrence for individual species rooted within each of the three frequency plots was recorded. These separate frequencies were also summed into one value for each species. In addition, 120 systematically located point measurements were made along each transect (1,200 points per site) to measure foliar cover. These frequency and cover measurements comprise phase 1. In phase 2, changes in density were created to simulate successional trend. To do this, randomly located sections of the transect, each 20 cm long, were established. Each section also extended perpendicularly from the transect to include all sizes of the sample plots. Any plant located within these "exclusion areas" was considered to have disappeared, thus simulating vegetation change over time. To achieve the desired levels of change (10, 20, and 30% reduction in vegetation), 5, 10, and 15 exclusion areas were located on each transect, approximating a 10, 20, and 30% reduction in ground surface area occupied by the exclusion areas. Varying amounts of change within a single sample plot were created by superimposing the randomly located exclusion areas over the uniformly spaced sample plots. It was possible for an exclusion area to fall directly on a sample plot removing all vegetation from that plot. An exclusion area could also fall between two sample plots and not affect either. However, neither of these possibilities occurred frequently. Instead, varying amounts of partial overlap occurred between the exclusion areas and the sample plots. Following each of the three levels of change, phase 3 resampled the original sample plots, minus the exclusion areas, for frequency and cover.

While this study considered "change" to be a reduction in species density, a reversal of the data could be used to illustrate the effects of species increases. With the same set of data, however, analysis of either a reduction or increase would still be possible. Since this study was testing for sensitivity to small levels of change, the amount of change induced was limited to a maximum of 30%.

The objective of this study was to compare changes in frequency levels detected by different plot sizes. Without a reference standard, it would be impossible to determine if the frequency changes detected by one plot size were more precise than any other plot size. Frequency itself could not be used as a reference for two reasons: (1) it is the value being tested, and (2) its results are highly related to plot size. For this reason, a vegetation measurement other than frequency had to be established as a reference. Density, yield, and cover were considered. For practical reasons, cover was the attribute chosen. It was found, however, that basal cover levels at the sites studied were too small to be useful. Foliar cover was thus chosen as the reference standard. It was determined that using the previously mentioned 1,200 points per site would give an accurate assessment of change. The sole purpose of the foliar cover data was to determine if a significant change had occurred as a result of the exclusion process. Normally, foliar cover is not used to determine trend; it is subject to yearly and seasonal fluctuations. However, it was used as a parameter in this study, since all sampling on a site was done within a few days' time.

Data Analysis

Sampling 400 plots is usually considered too time-consuming for most management requirements. Therefore, to test the procedure under likely operating conditions, the original 400 nested configurations were considered to be a population, from which a random sample of 200 was drawn for analysis. The 600 foliar cover points associated with these 200 samples were also used in the analysis. All results shown here are from the smaller (200 plot) sample size. Data from each of the four sites were analyzed independently; no attempt was made to combine information from different sites.

TABLE 1. Percent foliar cover before and after each exclusion level.

Exclusion level (%)	Site 1	Site 2	Site 3	Site 4
0	20	54	45	38
10	17	50	42	34
20	15**[1]	44**	37**	31*
30	13**	39**	32**	28**

[1] * significant at $\alpha = 0.20$
** significant at $\alpha = 0.10$

Significance determined by separate t-tests between the 0% removal level and each of the "exclusion" levels within a column.

Site 1 = *Pinus ponderosa/Festuca idahoensis* habitat type.
Site 2 = *Artemisia tridentata* subsp. *vaseyana/Festuca idahoensis* habitat type (unburned).
Site 3 = *Artemisia tridentata* subsp. *vaseyana/Festuca idahoensis* habitat type (burned).
Site 4 = *Artemisia tridentata* subsp. *vaseyana/Festuca idahoensis* habitat type (high-elevation ridgetop).

Foliar Cover

Considering foliar cover as a continuous variable, individual t-tests were used to compare differences between control (original) conditions and each of the three "exclusion" treatments. For these tests, each of the 10 transects within a site was considered one sample. Results were compared at alpha levels of 0.10 and 0.20.

Frequency

The observations per species from the three individual plot sizes were added together to create a summed frequency value for each nested configuration. The frequency data thus contained the number of occurrences of each species per plot size (including the summed value) at the control and each "exclusion" level. For the frequency analysis, each species–plot-size combination was considered a sample. Using frequency as a discrete, present-or-absent variable, a chi-square test with Yates' correction factor (Mueller-Dombois and Ellenberg 1974) was used to determine for each plot size (including the summed value) whether significant ($\alpha = 0.20$ or 0.10) changes in frequency had occurred between the control and any of the exclusion levels. This procedure allowed for comparison of the summation results with those for each individual plot size.

RESULTS AND DISCUSSION

Foliar Cover

Results of the individual t-tests, using the foliar cover data, showed that it was not possi-

TABLE 2. Results on selected species from the Chi-square analysis on frequency for the *Pinus ponderosa/Festuca idahoensis* habitat type. The first row for each plot size contains the initial frequency and the three subsequent frequencies resulting from the exclusion process. The second row is the percent change from the original frequency. This list includes only those species in which a change was detected. Summed values listed here were standardized to a 0–100 range after analysis.

Species	Initial cover (%)	Plot type (cm^2)	Exclusion level (%) 0	10	20	30
Festuca idahoensis	7.7	250	26	24	22	20
				8	15	23*
		500	45	42	39	36
				7	13	20**
		1000	62	57	53	48
				8	15*	23**
		Sum	44	41	38	34
				7	14**	23**
Antennaria microphylla	2.3	250	24	22	20	18
				8	17	25*
		500	36	34	30	28
				6	17	22*
		1000	52	50	45	42
				4	13	19**
		Sum	37	36	32	29
				3	14**	22**
Lupinus caudatus	1.0	250	5	4	4	4
				20	20	20
		500	10	10	8	8
				0	20	20
		1000	18	14	12	10
				22	33*	44**
		Sum	11	10	8	7
				9	27**	36**
Agropyron spicatum	0.3	250	4	4	3	3
				0	25	25
		500	8	8	7	6
				0	12	25
		1000	15	12	10	8
				20	33	47**
		Sum	9	8	7	6
				11	22*	33**
Poa sandbergii	0.2	250	10	9	7	6
				10	30	40
		500	14	14	12	10
				0	14	29
		1000	20	19	17	14
				5	15	30*
		Sum	15	14	12	10
				7	20	30**
Apocynum androsaemifolium	1.7	250	8	8	8	6
				0	0	25
		500	14	12	11	10
				14	21	29
		1000	20	18	16	15
				10	20	25
		Sum	14	12	11	10
				14	21	29**
Frasera albicaulis	1.0	250	6	6	6	4
				0	0	33
		500	8	8	8	6
				0	0	25
		1000	18	16	16	14

Table 2 continued.

Species	Initial cover (%)	Plot type (cm^2)	Exclusion level (%) 0	10	20	30
				11	11	22
		Sum	10	10	10	8
				0	0	20*
Arenaria congesta	0.7	250	7	6	6	6
				14	14	14
		500	14	13	12	12
				7	14	14
		1000	20	18	17	16
				10	15	20
		Sum	14	13	12	11
				7	14	21*
Collinsia parviflora	0	250	6	4	4	2
				33	33	67
		500	12	10	10	8
				17	17	33
		1000	15	14	14	12
				7	7	20
		Sum	11	20	9	8
				9	18	27*
Stipa occidentalis	0	250	3	2	2	1
				33	33	67
		500	6	5	4	2
				17	33	67
		1000	8	8	6	6
				0	25	25
		Sum	6	5	4	3
				17	33	50**
Tragopogon dubius	0	250	2	2	1	1
				0	50	50
		500	2	2	2	1
				0	0	50
		1000	6	6	4	3
				0	33	50
		Sum	3	3	2	2
				0	33	33**

* Significant at $\alpha = 0.20$.
** Significant at $\alpha = 0.10$.

ble to detect a significant difference ($\alpha = 0.20$) in foliar cover when only 10% of the ground surface area was excluded (Table 1). However, at the 20% "exclusion level," all sites showed significant ($\alpha = 0.10$ for sites 1, 2, and 3; $\alpha = 0.20$ for site 4) reductions in foliar cover. When 30% of the ground surface area was excluded, all four sites showed significant ($\alpha = 0.10$) reductions in foliar cover when compared to their respective controls. These data provide additional information indicating that a change had occurred. Once it was known that a statistical change in cover had occurred, frequency data were analyzed.

Frequency

Except as noted, space considerations allow the frequency results from only the *Pinus ponderosa/Festuca idahoensis* habitat type to be reported. The results from the three other sites were similar.

Results from the chi-square analysis on frequency data are shown in Tables 2 and 3. Since the summation procedure used data from three plot sizes, a total summed "frequency" of 300% was possible. The chi-square analysis tested for significant changes in species occurrence over a potential range from 0

TABLE 3. Total number of herbaceous species which are significantly different ($\alpha = 0.20$) from the initial sample period at three exclusion levels for the 20 × 50 cm and summation plots.

Habitat type	Plot type (cm^2)	Exclusion level (%)		
		10	20	30
Pinus ponderosa/Festuca idahoensis	1000	0	2	5
	Sum	0	4	11
Artemisia tridentata subsp. *vaseyana/Festuca idahoensis* (unburned)	1000	0	3	5
	Sum	2	5	8
Artemisia tridentata subsp. *vaseyana/Festuca idahoensis* (burned)	1000	0	2	5
	Sum	0	4	10
Artemisia tridentata subsp. *vaseyana/Festuca idahoensis* (high elevation)	1000	0	2	5
	Sum	2	6	8

to 300 for the summed data, and 0 to 100 for the individual plot sizes. For ease of interpretation, the summed values were standardized, after analysis, to a maximum of 100%, consistent with the individual plot levels.

It should be recognized that data gathered with nested plots are not truly independent; a species recorded in a smaller plot is also in all larger plots. Theoretically, this may introduce a degree of bias. Under actual testing, however, this bias may not be significant. Hironaka (1985) demonstrated that separate, randomly placed frequency plot data were highly correlated ($R^2 = .998$) with nested plot frequency data. This suggests that the bias due to nested quadrats may be small and outweighed by the advantage of increased sensitivity.

Table 2 shows the results for the summation technique for the *Pinus ponderosa/Festuca idahoensis* habitat type. The table shows, by species, the relationship between initial frequency and the smallest subsequent change in frequency that is statistically different from the control. These changes were created by the three (10, 20, and 30%) exclusion levels. The summation technique detected a smaller change in frequency than any individual plot size at any given initial frequency. The summation technique was also able to detect changes in frequency in six additional species when 30% of the ground surface area was excluded. The additional species frequently had coverage values less than 2%, a value so small that changes were not detected with any single plot size.

The summation technique proved useful in increasing the resolution of range trend frequency data in several additional ways. The technique often detected a change with greater confidence at a lower alpha level (0.10 versus 0.20) than any single plot size (Table 2). For example, with *Festuca idahoensis* in Table 2, both summation and single-plot methods detected a 15% change in frequency. Furthermore, the summation technique detected this change at a probability level of 0.10, whereas the single-plot difference was significant at the $\alpha = 0.20$ level only. The summation technique detected change at a lower initial frequency than any single plot size (Table 2). Using the summation process would be advantageous when attempting to detect change in species having lower frequency values. Compared to any individual plot size, the summation procedure detected significant changes in an average of four additional species per site (Table 3). Detecting change in a greater number of species at smaller amounts of change adds credibility and confidence to any judgment about range trend.

The use of summed frequencies can be an advantage also when the change is relatively large. For example, if a particular species of interest was becoming more numerous over time, the smaller plots included in the nested plot configuration would help prevent the resulting "frequency" value from truncating at 100 in subsequent measures. Even though one or more of the larger plots in the configuration might reach 100% frequency as the species became more numerous, it would be unlikely for one of the smaller plots to do so at the same time. When the frequencies of all the plot sizes are added together, the presence of the smaller plot's frequency will prevent the summed total from reaching 300% "frequency" (assuming three plot sizes are used).

If, instead, a single plot had been used to monitor the same species, it would be initially advantageous to use a plot size giving an initial frequency of 20 to 80%. However, if the species increased in density and the frequency at any succeeding sample reached 100%, subsequent increases in that species could not be detected. Since the influence of the smaller plot sizes on the summed total is inherent, the summation technique would eliminate the need to change plot size over time as a species experienced major changes in density. Therefore, using the sums of nested plots provides more sensitivity to vegetational change over a wider range of species abundance than any single plot.

Smith et al. (1986) noted that initial frequency and magnitude of ensuing changes are the main factors controlling the sensitivity of frequency plots to vegetational change. This also held true when the change being sampled used the sums of nested plots. As initial frequency and/or percentage change increased, so did the ability of the nested frequency plots to detect that change. Detection of small percentage changes required a large initial frequency. It was rare to detect a 10% change if the initial frequency was less than 60%, but a 30% change was often detected when the initial frequency was less than 15%.

Conclusion

Frequency data are highly correlated with plot size. Although frequency data gathered with a single plot size are easiest to analyze, no one plot size can adequately sample a wide variety of plant species at the same time. This study examined the possibility of summing data from three different plot sizes, arranged in a nested configuration, in an effort to further improve the sensitivity and efficiency of frequency as a method for detection of trend.

For the four sites studied, summation of frequencies provided greatest sensitivity to vegetational change. Such changes in summation values were shown to be significant at lower alpha levels than for any single plot within the nested configuration. These results were consistent over a wide range of frequencies. In addition, summation was superior for detecting changes in species having low initial frequencies and foliar coverages. Finally, the summation technique detected significant changes in more species than did any single plot size.

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