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Differences in Stubble Height Estimates Resulting from Systematic and Random Sample Designs

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ABSTRACT

Sampling design influences the accuracy and confidence that an investigator can place on the information derived from a data set. This study was undertaken to quantify the influence of systematic and random sample designs on the estimation of stubble height. Variance estimates, data set range, adequate sample size, and relative variation were greater with the systematic sampling design, and mean estimates were lower when compared with estimates derived from a random sampling design.

Introduction

The Society for Range Management Rangeland Assessment and Monitoring Committee (2018) described a history of sampling, procedural, and personal errors that have impacted the measurement of utilization by land management agencies. These sampling errors include false indications of data precision and confidence.

The objective of sampling is to obtain unbiased estimates of a population attribute and determine the level of confidence that can be placed on that estimate (Schumacher and Chapman, 1948). Sampling methodologies used in this effort rely on sample randomization to ensure an unbiased estimate. Randomization requires sampling to be conducted so that each potential sample has an equal opportunity of selection and that the resulting sample set achieves interspersion throughout the population (Snedecor and Cochran, 1967; Coulloudon et al., 1999). In simplest terms, random numbers are used to establish plot locations until an adequate number of samples are recorded to represent nonrandom (patterned) populations (Steel and Torrie, 1980).

Species within a plant community are commonly distributed in a nonrandom pattern that reflects a patchwork of high and low density across a landscape (Greig-Smith, 1964). These patterns reflect interspecific and intraspecific interactions among plant populations, as well as nonrandom patterns of environmental conditions in which the vegetation is growing (Harper, 1977; Silvertown and Doust, 1993). To address this nonrandom pattern, randomness needs to be incorporated into a vegetation sampling design so that statistical analysis can be performed, valid estimates of the error can be calculated, and objective conclusions can be drawn (Steel and Torrie, 1980; Coulloudon et al., 1999).

Formal monitoring programs require use of scientific methods to obtain measurements that can be repeated and report a confidence of 90% or 95% by whomever takes the measurements. The important point is that all of the scientific sampling techniques available are based on being able to estimate the probability that a measured attribute represents the entire population of interest. If some type of random selection in the sampling process is not incorporated into the study design, the probability cannot be determined and no statistical inferences can be made (Elzinga et al., 1998).

Some monitoring techniques rely on systematic sampling with instructions that randomization is achieved if a single random number is chosen and then applied as the distance between all plot locations along a line within the key area. A key area is a single plant community or ecological site that has uniform species composition and other characteristics and is anticipated to respond similarly to management (Coulloudon et al., 1999). In reality this means the first sample is random, but all samples that follow are systematic. Nonrandom systematic sampling occurs when every k^{th} individual in the population is included in the sample set (Steel and Torrie, 1980). Most sampling formulas were designed for randomly collected sample sets. Computing sampling errors from nonrandom sample sets results in higher or lower error estimates that reflect nonrandom population patterns (Freese, 1989).

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The objective of this study was to assess the impact of systematic and random data sets collected from grazed riparian and upland ecological sites for stubble height assessments and forage utilization.

Study Locations

The study areas were in eastern Oregon in the Snake River and Blue Mountain Ecological Provinces of eastern Oregon (Anderson et al., 1998). The annual average precipitation of the Blue Mountain Province is 57 cm and of the Snake River Province is 28 cm. Approximately 28 – 32% of the annual precipitation falls between April and July during the active growing season, and over half occurs between November and March. The elevation of the study areas ranges from 1 230 to 1 500 m.

Each province encompasses numerous ecological sites and in practice can be described in terms of vegetation differences caused by local geology, geomorphology, and climate. The sites are located on the Wallowa Whitman National Forest in Baker County Oregon and are part of a cool forest composed of Ponderosa pine (*Pinus ponderosa* Dougl.), Douglas fir (*Pseudotsuga menziesii* [Mirbel] Franco.), larch (*Larix occidentalis* Nutt.), and some grand fir (*Abies grandis* [Dougl.] Forbes) with an understory of pinegrass (*Calamagrostis rubescens* Buckl.), elk sedge (*Carex geyeri* Boott), as well as shade-tolerant grass and forb species. The livestock grazing that occurs within study area allotments is managed to protect natural resources for wildlife and listed endangered fish species. The upland communities that were surveyed in this study were composed of pinegrass, elk sedge, mountain brome (*Bromus carinatus* H. & A.), and Columbia needlegrass (*Stipa columbiana* Macoun) within the cool forest described earlier.

The riparian populations surveyed in this study occur as narrow interrupted ribbons along geologically constrained tributary streams described by Rosgen (1996) as having a gradient near 2%, channel widths of 1 – 4 m, and channel substrates consisting of cobbles, gravels, and smaller fragmented materials. Riparian populations within the mountainous regions of Eastern Oregon often form a narrow interface that is several feet wide between aquatic and terrestrial ecosystems (Kovalchik and Chitwood, 1990). Riparian communities in this study are moist and dry phase moist meadows composed of small-fruited bulrush (*Scirpus microcarpus* Presl.), Nebraska sedge (*Carex nebrascensis* Dewey), Baltic rush (*Juncus balticus* Willd.), swordleaf rush (*Juncus ensifolius* Wikst.), Mannagrass (*Glyceria striata* [Lam.] Hitchc.), and thin bentgrass (*Agrostis diegoensis* Vasey).

Materials And Methods

Data sets from 4 target populations (riparian and upland) in *each of* 3 different grazing allotments *(12 target populations in total)* were collected for assessment. Random samples were located on permanent key riparian and upland areas. Ecological sites that are identified by their species composition and other characteristics are anticipated to respond similarly to management. Each sampling event was conducted using a random method of sample selection (using a random number generator for pacing) to place 0.1-m^2 plots within the plant population for observation (Bonham, 1989). The mean vegetation (leaf) height of forage species (stubble height length) was measured to the nearest 1.2 cm (≥ 5 plants) and averaged within each plot across the key area.

The systematic sampling technique relied on the toe of the boot to establish each sample point where a radius of unspecified length was used to identify the nearest forage species regardless of size. A random starting point for each systematic data set was established, and a set number of paces were used to locate each sample point (Coulloudon et al., 1999). The stubble height length of the forage plant was measured to the nearest 1.2 cm using a ruler and recorded for each point.

Data analyses were performed to separate differences in data set attributes. Differences between data set variances were determined using Hartley's test for variance equality (Dowdy and Wearden, 1983). The adequacy of each data set to achieve an estimate within 10% of the population mean with a confidence of 95% was assessed using Stein's two-stage sample adequacy formula (Steel and Torrie, 1980). Student's *t*-test comparisons were used to determine the significance ($P < 0.05$) of estimated mean differences (Snedecor and Cochran, 1967). All Student's *t*-test comparisons used the unbiased variance estimate from the random data set. Design efficiency and relative deviation about the mean were assessed using the coefficient of variation (Snedecor and Cochran, 1967; Freese, 1989).

Results

Variance Comparison

When sampling errors are calculated from nonrandom sample sets, the investigator inappropriately applies formulas designed for random data analysis. As a result, error estimates from systematic designs will typically be biased (Freese, 1989). Table 1 contains variance comparisons between random and systematic data sets collected from the same target population. The systematic variance calculations consistently yielded variance estimates that were different (larger) than random data set estimates. Because the data sets are collected from the same population, these differences suggest that systematic variance estimates are influenced by population patterns. A portion of this difference would also be associated with the interspersion achieved by the random sampling designs, which collected information from areas of the population that were unsampled by the systematic design. Furthermore, the use of a point over a quadrat area emphasizes the range of individual plant sizes over an average measurement of plants used to represent the quadrat. All these factors contributed to an expanded data set range for the systematic data sets. The systematic design yielded data set ranges that were 25%–100% greater when compared with the random data set.

An assessment of the relative variation (coefficient of variation) for random and systematic data sets is presented in Table 1. Those calculations show that the random data sets contain only 30 – 50% of the variation observed in the systematic data sets and suggest that the systematic design is prone to greater variation than the random sample design.

Sample Adequacy

Calculation of the adequacy of each sample data set is shown in Table 2. The sample sets collected using the random sample design all exceeded the sampling goal of being within 10% of the true mean with 95% confidence. In most cases, sample adequacy was reached in the random data sets with fewer than 20 samples. By contrast, none of the systematic data sets achieved sample adequacy given an initial sample size of 30 – 52 samples. In most cases, the systematic data sets were estimated to require > 100 samples to achieve a similar level of sample ad-

Table 1
Variance and data set range differences between random and systematic data sets.

Allotment	*F* value	Significance	Range S/R %	Relative variation R/S %
1	1.58	< 0.10	128	35
	1.80	< 0.05	133	48
	2.1	< 0.01	140	44
	1.44	Ns	133	44
2	4.87	< 0.01	200	33
	2.25	< 0.05	142	53
	2.25	< 0.05	133	46
	3.6	< 0.05	166	31
3	2.95	< 0.05	142	50
	2.24	< 0.05	125	50
	3.68	< 0.01	150	36
	2.64	< 0.01	180	35

Ns indicates nonsignificant.

Table 2
Sample size attributes from random and systematic data sets.

Allotment	Sample size	Random required samples	Systematic required samples	Percent random/systematic
1	40	11	92	12
	40	25	101	25
	40	18	83	22
	40	23	121	19
2	40	8	63	13
	30	27	91	30
	40	23	104	22
	30	13	128	10
3	30	15	92	23
	40	22	92	24
	52	17	128	13
	40	27	197	14

equacy. Overall, the random design achieved sample adequacy with < 19% of the samples required to achieve the same level of accuracy and confidence using the systematic design.

Mean Comparison

Table 3 shows a comparison of the mean stubble height differences observed between random and systematic data sets. Mean stubble heights from random data sets were consistently greater than means derived from the systematic data sets. These differences ranged from 2.0 to 13.0 cm and averaged 5.0 cm greater for the random data sets. This difference would obviously impact determinations of noncompliance and subsequent restrictions on grazing during the following growing season. Student's *t*-test comparisons using the unbiased variance estimate showed that the lower systematic stubble height estimate was consistently different from the random estimate and underestimated the stubble height.

Discussion

Evans and Love (1957) introduced the use of the step point methodology as a means of estimating species composition and total ground cover. The method has its origin in point quadrat sampling (Levy and Madden, 1933) and yields a binomial data set based on presence and absence. The step point method was described as a series of systematic transects covering the target population with the recommendation that 300 – 500 points would be required to adequately represent the variability in vegetation commonly found in natural plant communities.

Application of the step point method for the measurement of stubble height was described by Coulloudon et al. (1999), who suggested that systematic sampling was a common utilization and residue measurement technique analogous to simple random sampling when the population being sampled is randomly dispersed. Random dispersion of plants in communities is exceedingly rare. In addition, in actual field practice over the years, the step point technique has had sampling intensity reduced from multiple systematic transects to one or a few transects using an unidentified plot radius where a single plant is measured for leaf length. Today, the single transect can consist of 30 or fewer plant measurements to determine grazing compliance.

There are many sampling methods for monitoring plant utilization, but randomization must be present in the method if confidence in the estimate is to be determined. Random plot locations provide an unbiased means of accounting for plants that are grazed at varying levels of use and those that are not grazed if they are conducted to achieve interspersion that ensures enough samples are measured in a dispersed fashion throughout the population.

Investigators should not assume that nature has provided a random plant population to allow standard error calculations of data sets collected systematically (Schumacher and Chapman, 1948). Systematic sampling designs need to be modified to yield a set of randomly located transects (systematic) so that transect summaries can be used to calculate an unbiased error estimate (Steel and Torrie, 1980; Bonham, 1989). Quadrat size also needs to be considered in the design of sampling methodology because it influences population estimates by impacting the precision of sample estimates (Coulloudon et al., 1999). In general, increases in sample size and plot size are necessary to address increased vegetation variability (Bonham, 1989). Finally, the practice of placing sampling units, whether quadrats or points, along a single transect or even a few transects should be avoided because it results in poor interspersion and makes it unlikely that the sample set represents the target population (Coulloudon et al., 1999).

Table 3
Mean[1] stubble height differences from riparian and upland sites in 3 grazing allotments.

Allotment	Random height (cm)	Systematic height (cm)	*t* value	Significance	Difference (cm)
1	23	10	17.96	< 0.01	13
	13	8	8.37	< 0.01	5
	13	8	10.2	< 0.01	5
	15	8	11.67	< 0.01	7
2	18	13	11.67	< 0.01	5
	20	15	24.97	< 0.01	5
	15	10	8.5	< 0.01	5
	10	8	12.15	< 0.01	2
3	20	18	4.61	< 0.01	2
	25	20	7.43	< 0.01	5
	18	13	11.0	< 0.01	5
	13	8	10.69	< 0.01	5

[1] Mean values and differences are rounded to the nearest significant digit.

Implications

Results reported in this study indicate that the step point methodology, as currently applied by land management agencies to measure stubble height, is unlikely to achieve the level of accuracy and confidence normally associated with evidence used to support a punitive action. In this study, variance comparisons showed random and systematic data sets to be dissimilar with the range of the systematic data set typically being larger. These two systematic data attributes result in expanded confidence intervals, a reduced ability to detect stubble height differences, and an inadequate sample size when compared with the random data sets. Finally, the tendency to underestimate mean stubble height using the systematic design means that compliance assessments are biased toward noncompliance and false precision.

The intent of monitoring utilization is to measure the forage plant population, considering plants that are grazed at varying levels of use and those that are not grazed. The monitoring technique should be capable of addressing type I and type II statistical errors to address the validity of compliance and noncompliance issues. The stratified random sample design used in this study achieved those objectives. When a proper sampling design is used to monitor the forage population at the beginning and end of a grazing period, as well as the end of the grazing season, a complete picture of utilization is achieved.

Conflicts of interest

All of the authors declare that they have no financial or personal relationships that could inappropriately influence their work.

Ethical statement

Subject informed consent

The presented study was approved by the Canton of Vaud ethics committee and all subjects were enrolled in the study after written informed consent.

Ethics in publishing

Each of the listed authors was involved in the conception, design, execution, interpretation, and/or manuscript preparation of the reported study. The authors also confirm that this is their original work. Furthermore, none of the authors declare any financial or personal relationships that could inappropriately influence this work.

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