Bias in Estimates of Herbage Utilization Derived from Plot Sampling

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Highlight

The ocular estimate by plot method may be biased by the lack of proper weighting procedures. The nature and magnitude of bias is related to sample size, the variability and distribution of yield, and correlation between herbage production and use by livestock. To form unbiased estimates of the population mean, individual estimates must be weighted by production.

Utilization is defined by the Range Term Glossary Committee (1964) as: "the proportion of current year's forage production that is consumed or destroyed by grazing animals." The units of measure may be height or weight, but for purposes of this discussion the units of measure are restricted to weight.

Expressed in mathematical terms, utilization is then defined as:

$$\overline{X} = U/P \qquad (1)$$

where $\overline{X}$ is the mean utilization of the population, U is the total weight of current growth removed by livestock, and P is the total weight of current production.[2] Normally, utilization is expressed as a percentage, or

$$\overline{X} = 100\,(U/P) \qquad (2)$$

The ocular estimate by plot method was described by Pechanec and Pickford (1937). According to the authors: "It differs from the general reconnaissance method in that each estimate is made on a plot of such limited area that the entire plot is clearly visible from one point, and percentage utilization is the average of estimates from a series of plots selected at random."

Thus, if n such plots are examined

$$\bar{x} = \frac{100}{n}\sum_{i=1}^{n}\frac{u_i}{p_i} \qquad (3)$$

Or

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (4)$$

Equations 3 and 4 constitute an incorrect averaging of percentages if $p_1 \neq p_2 \neq \ldots \neq p_n$. Proper procedure dictates that

$$\bar{x} = \frac{\sum_{i=1}^{n} u_i}{\sum_{i=1}^{n} p_i}\,100 \qquad (5)$$

Or, comparable results can be obtained by weighting x_i by the corresponding p_i, so that

$$\bar{x} = \frac{\sum_{i=1}^{n} p_i x_i}{\sum_{i=1}^{n} p_i} \qquad (6)$$

Factors Affecting the Bias

Equations (3) and (4) are unbiased if the p_i are equal—a condition in which the coefficient of variation is equal to zero, and the production on any given sample unit is equal to the population mean. Since a condition such as this is unknown in populations of natural vegetation, some observations will be over-weighted and some under-weighted by this procedure.

In a normally distributed population, a model for the p_i may be written as:

$$p_i = \overline{P} + e_i, \text{ for } i = 1, 2, \ldots, n \qquad (7)$$

where the e_i are normally distributed elements of chance with mean zero and variance p^2. Then equation (3) may be rewritten as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n}\frac{u_i}{\overline{P} + e_i} \qquad (8)$$

From equation (8) it is obvious that the value of e_i determines whether a sample unit is over-weighted or under-weighted. The hypothesis may be made that, since e_i are normally distributed and $\overline{E} = 0$, the errors tend to counterbalance and average zero. But rarely will $\bar{e}_i$ equal zero since sampling error is involved, therefore the estimate $\bar{x}$ will be somewhat biased.

The assumption of a normal distribution of the e_i is also open to question. Greig-Smith (1957) suggested that yield data usually show an "approximately" normal distribution. However, he recognized that small samples may result in distribution curves that are strongly skewed. The shape of the distribution curve may vary with the size of the sample unit.

Skewness to the left results in overweighting an excessive number of low-producing sample units, and tends to introduce a positive bias to the estimate of average utilization. Conversely, skewness to the right results in underweighting an excessive number of high-producing units and introduces negative bias in the estimate of average utilization.

A third source of bias exists when production and utilization are not independent. If utilization is positively correlated with production, the procedure of Pechanec and Pickford will tend to under-estimate average utilization. Conversely, if utilization is negatively correlated with production, percentage utilization will tend to be over-estimated. Cook (1959) found utilization of forage to be heavier on unfavorable sites than on favorable sites. He later found that utilization of some species was correlated with their abundance (Cook, 1962). The nature of the correlation, positive or negative, varied among species.

Application to an Example

Data from a study where both production and utilization of Idaho fescue (*Festuca idahoensis* Elmer) were measured exemplify the magnitude of bias introduced by the use of (3) as an estimator. The Burgess Experimental Pastures[3] are located in the Bighorn National Forest of north central Wyoming. The pastures consist of three experimental units subject to different livestock management practices. Each experimental unit was first divided into three primary strata corresponding to known intensities of past use by livestock. Then two substrata were selected to conform with soil parent material. Fifteen random sampling units, 2 × 2 ft, were selected from each of the substrata.

Sampling within substrata was analogous to simple random sampling. Consequently, the difference in estimates formed by equations (4) and (6) is a

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[2] Parameters are symbolized by capital letters; statistics by lowercase letters.

[3] A cooperative study by the Big Horn Permittees Association, the Wyoming Natural Resource Board, the Wyoming Agricultural Experiment Station, and the U.S. Forest Service.

Table 1. Unweighted estimates of percentage utilization ($\overline{X}$) of Idaho fescue and discrepancy (D) as unweighted minus weighted estimates on substrata within the Burgess Experimental Pastures, 1961–62.

Experimental unit	Year		Light[1] G[2]	Light[1] S	Moderate G	Moderate S	Heavy G	Heavy S
I, Moderate season-long grazing	1961	D	–0.9	—	0.4	–3.1	–1.8	–2.6
		$\overline{X}$	44	—	25	67	14	31
	1962	D	–0.8	—	0.9	2.7	–2.1	–0.8
		$\overline{X}$	27	—	13	41	6	26
II, Moderate rotation grazing	1961	D	–0.4	0.3	–5.1	–2.2	2.4	1.7
		$\overline{X}$	18	19	29	50	3	29
	1962	D	–0.6	0.7	–8.5	–10.1	–10.8	–2.0
		$\overline{X}$	13	17	13	28	34	34
III, Heavy rotation grazing	1961	D	–0.4	2.7	–2.4	0.9	–4.8	1.7
		$\overline{X}$	56	43	53	46	12	48
	1962	D	2.1	–0.7	–8.0	–10.5	–6.8	–5.3
		$\overline{X}$	65	57	38	43	31	54

Primary strata: Light, Moderate, Heavy.

[1] Light, moderate, and heavy refer to relative intensity of past use by livestock.
[2] G & S refer to the soil parent material of the substrata; granitic and sedimentary, respectively.

measure of the bias present in the estimate of mean utilization of the substrata. The bias was generally small and negative (Table 1). In 1961, the maximum observed bias was –5.1% (average = –0.8%). In 1962, the maximum was –10.8% (average = –3.6%).

If Pechanec and Pickford's method is applied to stratified random sampling, the population mean is estimated by:

$$\bar{x} = \frac{1}{N_h}\sum N_h\bar{x}_h \qquad (9)$$

where N_h is the total number of sample-sized units in the h-th stratum, and $\bar{x}_h$ is the sample mean for the h-th stratum. To estimate percent utilization in this manner ignores the possibility of varying production among strata—a situation analogous to the use of equation (4) in simple random sampling. To form unbiased estimates of the population mean, the strata means must be weighted by the product of area and productivity. Thus,

$$\bar{x} = \frac{1}{\sum N_h\bar{p}_h}\sum \bar{x}_h(\bar{p}_h N_h) \qquad (10)$$

where $\bar{x}_h$ is the mean utilization in the h-th stratum, $\bar{p}_h$ is the mean production in the h-th stratum, and N_h is the number of sample units in the frame for the h-th stratum.

A comparison of estimates by equations (9) and (10) forms a measure of the bias present in the primary strata and unit means. In 1961, the bias ranged from 3.5 to –10.4% (average = –2.7%) among the primary strata (Table 2). The estimate of average utilization on the experimental units was biased by 0.4 to –4.6% (average = –1.9%). In 1962, the bias ranged from 0.6 to –12.7% (average = –5.0%) among primary units and –2.8 to –7.8% (average = –4.7%) among the experimental units.

Table 2. Unweighted estimates of percentage utilization ($\overline{X}$) of Idaho fescue and discrepancy (D) as unweighted minus weighted estimates on primary strata and experimental units on the Burgess Experimental Pastures, 1961–62.

Experimental unit	Year		Primary strata (Intensity of past use) Light	Moderate	Heavy	Mean
I, Moderate season-long grazing	1961	D	–0.9	–6.1	–6.2	–4.6
		$\overline{X}$	44.0	26.9	19.5	25.4
	1962	D	–0.8	0.4	–6.4	–2.8
		$\overline{X}$	27.0	14.3	12.5	15.1
II, Moderate rotation grazing	1961	D	0.1	–2.4	–2.6	0.4
		$\overline{X}$	18.6	36.6	16.5	22.7
	1962	D	0.4	–9.9	–6.1	–3.6
		$\overline{X}$	15.3	18.4	34.0	23.7
III, Heavy rotation grazing	1961	D	3.5	1.1	–10.4	–1.5
		$\overline{X}$	45.8	47.6	24.0	40.8
	1962	D	0.6	–10.3	–12.7	–7.8
		$\overline{X}$	58.7	41.8	38.7	47.7

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A Permanent Plot for Measurement of Vegetation Change[1]

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Range and wildlife managers have been dissatisfied generally with techniques for marking permanent plots for future analysis. The authors, faced with the need to measure vegetation change in a low shrub-grassland complex in Wyoming's Red Desert, designed a sampling frame which can be installed rapidly at permanently marked sampling points. The device was used on key areas of pronghorn antelope winter ranges by employing a cluster sampling technique.

The intent of the design was to enable (1) rapid positioning of the sampling unit, (2) rapid location and placement of a permanent pivot stake, (3) rapid location and placement of a second reference stake, and (4) rapid and accurate relocation of the sampling frame at future dates.

Fig. 1 illustrates both the design and the positions of the permanent marker stakes. A length of steel rod (⅜ × 48 in.) was bent at one end to form a collar with an inside diameter of one inch. The collar was formed to fit tightly, but smoothly, around a piece of one inch pipe, 18 inches in length. These pieces of pipe were driven about one ft into the ground. The six inches protruding above the ground surface served as the pivot stake and receptacle for the collar of the sampling frame.

The sampling frame was also made of steel rod. For our purposes we chose a rectangular frame (1 × 2 ft). It was welded to the rod at the end opposite the collar.

The following procedure was used to locate permanently each sampling frame (side view, Fig. 1). First, a piece of one inch pipe was driven vertically into the ground, using care to prevent damage to the top of the pipe. Secondly, the collar was placed over the section of pipe protruding above the ground surface. Next, the sampling frame was positioned. Finally, a piece of concrete reinforcing rod (⅜ × 12 in.) was driven into the ground directly beneath the point where the "arm" of the sampling apparatus bisected the sampling frame. This rod served as the second reference stake to enable exact relocation of the frame.

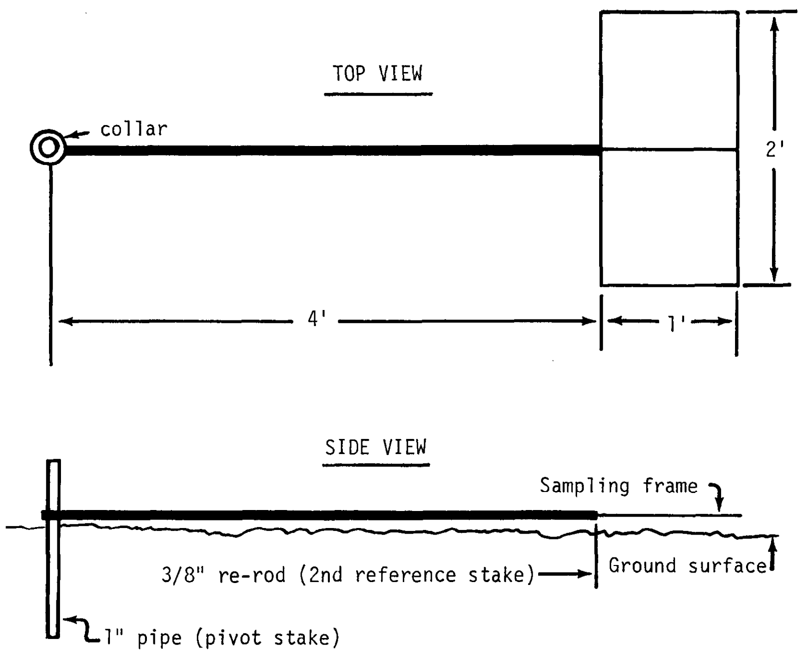

FIG. 1. Design of the sampling frame.

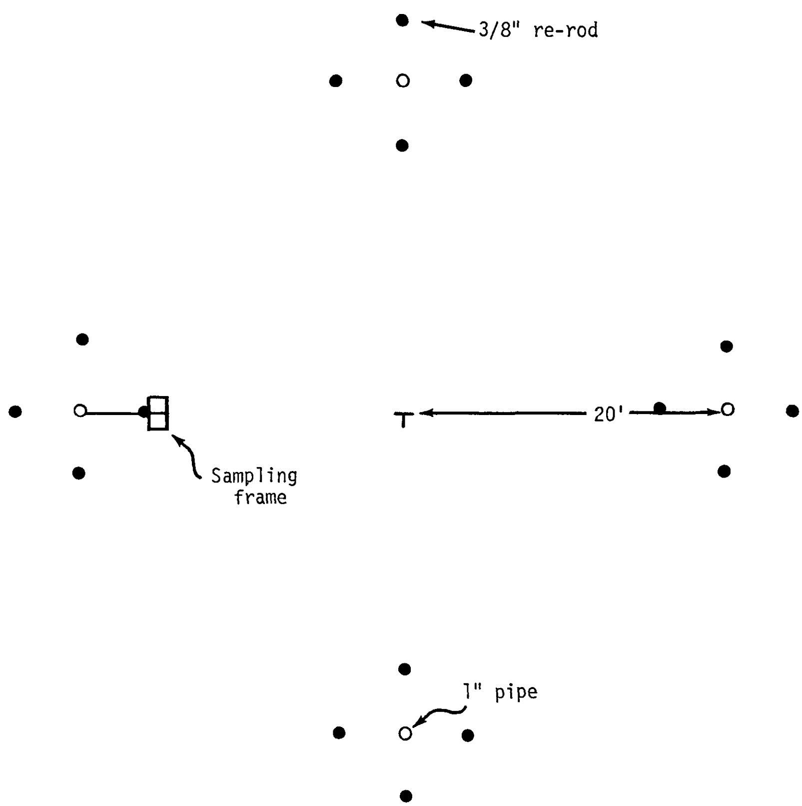

FIG. 2. The cluster sampling design.

[1]The technique reported herein was developed while the senior author was employed by the Technical Services Division of the Wyoming Game and Fish Department.

For the cluster design (Fig. 2), a six-ft steel fencepost was driven into the ground as a reference marker for the center of the cluster. Four 18-inch pieces of pipe were driven into the ground 20 ft from the marker post at 90° intervals around an imaginary circle. This provided for exclusion of measures within a circle with a radius of 15 ft (area = approx. 707 ft^2) around the fencepost. A larger area could be excluded, but this amount was deemed adequate for our purposes. Four reinforcing rods were then positioned at 90° intervals four ft distant from each pipe (the secondary reference stakes).

In this study, 30 clusters with a total of 120 plots and 480 subplots were used. However, the number of clusters, number and location of plots, and the number, location and size of the subplots should be suited to the attributes of the vegetation studied and the measurements desired. Likewise, the lengths of marker pipe and re-rod may have to be longer for stability in some soils. This method of plot location would be difficult to use in rocky soils or on steep slopes where soil movement is evident, but should be suitable for most other soil conditions. In areas with frost heaving, care should be taken to make the pipe and marker rod long enough to reach below the level of soil movement or into the upper portion of the parent material. Sheep and antelope did not disturb the marker stakes, although this might be a problem on cattle ranges. On ranges where vehicular traffic occurs, some means of marking the pipe locations may be necessary to avoid tire damage. Threading the top of the pipe and fitting with a cap may be desirable.

The technique has been completely satisfactory for the conditions encountered.