Indirect Estimation of Standing Crop[1]

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Highlight

Criteria such as density and cover are correlated with standing crop of alpine species. Use of these variates, however, in a double sampling design was less efficient than a single clipped sample of equal cost.

Standing crop, the quantity of vegetation present at a given time, is of particular value for the description and comparison of vegetations. With proper timing it will often give a good approximation of primary production. Direct measurement, however, requires the clipping and weighing of herbage from a series of sample units. This requirement is of major significance to the ecologist because it may impose two major limitations on the study:

1. The clipping and weighing of herbage is time-consuming and expensive. Consequently, the number of sample units on which standing crop can be directly measured may be inadequate for an accurate estimate.

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[1] *Portions of this paper were presented by the senior author to the Graduate School, University of Wyoming in partial fulfillment of the requirements for the Master of Science Degree.*

[2] *Central headquarters maintained at Fort Collins in cooperation with Colorado State University; research reported here was conducted in cooperation with the University of Wyoming at Laramie.*

2. The complete removal of herbage profoundly affects subsequent plant vigor and reproduction. Consequently, the use of permanent sample units is precluded in many ecological studies involving the repeated sampling of the same population. Where the primary interest is change in the population mean from one occasion to the next, the loss in efficiency may be too great.

The possibilities of eliminating the need for clipping and, instead, evaluating the standing crop indirectly from measurements of certain plant attributes have been reviewed by Reppert et al. (1963). Ground cover, foliage cover, plant height, and products of height and cover are among the attributes studied.

The study reported in this paper provides further information about indirect estimates of standing crop. The purpose of this study was to identify supplementary variates closely related to standing crop, to develop regression estimates from these variates, and to evaluate the efficiency of these estimators in double sampling.

Field Procedures

The study was conducted on the Medicine Bow Range in southern Wyoming during the summer of 1963. The vegetation on the area was representative of the upper limits of the subalpine sedge/hairgrass community and this transition to the alpine sedge/hairgrass community described by Johnson (1962). The following species were selected for study:

Alpine bluegrass (*Poa alpina* L.)
American bistort (*Polygonum bistortoides* Pursh)
Ebony sedge (*Carex ebenea* Rydb.)
Mat sedge (*Carex elynoides* Holm.)
Parry's clover (*Trifolium parryi* Gray)
Timberline bluegrass (*Poa rupicola* Nash)
Tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.)
Various-leaved cinquefoil (*Potentilla diversifolia* Lehm.)

Sample units were purposely selected to include a wide range in standing crop for each species. Thirty or more sample units were selected for each species, although in some instances observations were made on two or more species in a single unit. The sample units were one foot square.

The variates measured for each species were not always the same because of differences in life form and ease of measurement (e.g., individual plants were readily identifiable for some species but obscure for others). For the individual variate, the method and unit of measurement were consistent among species. The variates and the respective methods of measurement were as follows:

Standing crop was expressed as grams oven-dry weight per square foot. Herbage was clipped at ground level by species and oven-dried at 70 C. The oven-dry material was then weighed to the nearest 0.01 g.

Foliage cover, expressed in percent of area, was measured by the point method of Levy and Madden (1933). The observation on each sample unit consisted of 100 vertical pins in a systematic grid. On each pin, a single hit was recorded for each species encountered. The pins were constructed of 3/16-inch welding rod ground to a sharp point, and hits were recorded on the apex of the point.

Basal cover was also expressed in percent of area. The measurement technique differed from that for foliage cover in that basal cover hits were recorded only at ground level; that is, a maximum of one hit per pin.

Density was expressed in number of plants counted.

Average maximum leaf length in millimeters, was estimated by measuring on all plants, to a maximum of ten plants, the distance from the ground to the top of the longest basal leaf in an extended position.

Average maximum stem length, in millimeters, was measured identically to average maximum leaf length.

Number of stems.—All stems were counted.

Sum of the basal diameters.—This variable, in millimeters, was the sum of the basal diameters of all individuals in the sample unit. The basal diameter of an individual plant was estimated by measuring the major and minor diameters and taking an average of the two as the estimate. Dead centers were measured and subtracted from the total.

Number of pedicels. — This variable was expressed as the total number of pedicels within the sample unit.

Analysis of Data

Multiple correlation and regression techniques were used to analyze the data. As a preliminary step, scatter diagrams were prepared in which standing crop was plotted against each of the independent variables (Table 1). Inspection of the diagrams indicated a linear relationship, so the analysis was based on a linear model.

Table 1. Independent variables used in the regression analysis for each species.

	Alpine bluegrass	American bistort	Ebony sedge	Mat sedge	Parry's clover	Timberline bluegrass	Tufted hairgrass	Various-leaved cinquefoil
Foliage cover (X_1)	x	x	x	x	x	x	x	x
Basal cover (X_2)	x	x	x	x	x	x	x	x
Density (X_3)	x	x				x	x	
Leaf length (X_4)	x	x	x	x	x	x	x	x
Stem length (X_5)	x	x	x	x	x	x	x	x
Number of stems (X_6)	x	x	x	x	x	x	x	
Basal diameter (X_7)						x	x	
Number of pedicels (X_8)								x
$X_1 X_4$ (X_9)	x	x	x	x	x	x	x	x
$X_5 X_6$ (X_{10})	x	x	x	x	x	x	x	
$X_2 X_4$ (X_{11})	x		x	x		x	x	
$X_4 X_7$ (X_{12})						x	x	
$X_5 X_8$ (X_{13})								x

The data were analyzed on an IBM 1620 computer by means of a program for the stepwise regression system written and developed by James N. Boles, Associate Professor of Agricultural Economics at the University of California. All included variables had an F value with $p < 0.01$, and all excluded variables had an F value with $p > 0.05$.

Results and Discussion

Regression equations developed from the significant variables accounted for 89 to 96% of the variation in standing crop (Table 2). The influence of any one variate changed widely among the eight species, which is readily understood when the diversity of growth forms is considered. Four independent variables, however, or cross-products derived from them, were more consistently correlated with weight than any others: (1) foliage cover, (2) number of stems, (3) stem length, and (4) leaf length.

The predicting equations may change with annual climate, site, sampling, and measurement techniques. New predicting equations should be developed for each sampling problem.

The use of regression estimators to increase the precision or efficiency of a sample by making use of supplementary information is well known. Sampling techniques that make use of a single concomitant variable are well developed in literature (Cochran, 1953; Yates, 1953; Hansen et al., 1953). Beatty (1958) developed a multiple regression estimate of the population mean as well as the variance of this estimate. The population mean of the auxiliary variates will not be known, however, and the investigator must rely on double sampling techniques. Double sampling techniques for the development, with a single auxiliary variate, of a regression estimate and the variance of this estimate are described in many standard texts (e.g., Cochran, 1953; Yates, 1953; Hansen et al., 1953). The theory of double sampling with more than one auxiliary variate has not been developed.

The efficiency of double sampling is determined by two criteria: (1) a high correlation between standing crop and the related variable, and (2) a favorable ratio of the cost of clipping a plot to the cost of measuring the related variables. High correlations were found under the conditions of this study, but these high correlations must now be evaluated in terms of the cost ratios.

For a given value of P, the correlation coefficient parameter, the ratio of the cost per unit of clipping to the cost per unit of measuring the independent variable must exceed a critical value before an increase in precision is realized (Cochran, 1953).

Take Parry's clover as an example, since it involves only one variable and Cochran's formulae apply. Percent foliage cover was selected at the first step in the regression analysis as the independent variable which gave the greatest initial reduction in unexplained variance of standing crop. All other variables were subsequently deleted. The correlation coefficient for this relationship was 0.96. With a correlation of this magnitude, in an optimum double sampling design, the cost of clipping a plot must be greater than 1.8 times the cost of measuring foliage cover in order to gain any efficiency.

For each species, the observed cost ratio was far less than required for efficient use of double sampling techniques. Unless the cost of measuring the independent variables can be reduced, without loss of correlation, double sampling for standing crop on a single occasion would result in a loss of efficiency. Variance of the double samples would range from about two to four times that of a single clipped sample of equal cost.

The measurement of foliage and basal cover by the point method was by far the most costly of the independent variables. These two variables, plus those products involving them, were deleted and a second stepwise regression analysis was made. The correlations obtained in this analysis were much lower. Without cover measurements the prediction equations were not suitable for efficient double sampling.

As indicated in Cochran (p. 284), where the periodic change in standing crop is of major concern, the efficiency of double sampling may be improved since it permits the use of permanent plots. The gain in efficiency will depend upon high correlations between repeated measurements on permanent plots.

There is a further advantage of permanent plots that has not entered into the analysis so far. The cost of drawing and establishing a probability sample on rangeland is relatively large in comparison with the cost of plot monumentation. Where remeasurements will be made several times, the cost of monumentation is quickly amortized thru savings associated with not having to draw and establish a new probability sample

Table 2. Summary of stepwise regression analyses. Independent variables are listed in order of decreasing importance.

Species	Regression Equation	Coefficient of Multiple Determination
Alpine bluegrass	$Y = -0.03550 + 0.00748X_{11} + 0.00038X_{10} + 0.09795X_1$	0.89
American bistort	$Y = -0.27207 + 0.24290X_6 + 0.11542X_1$	0.91
Ebony sedge	$Y = -0.22332X_1 + 0.08444X_6$	0.94
Mat sedge	$Y = 2.37398 + 0.00428X_{11} + 0.03495X_6 - 0.03655X_4$	0.96
Parry's clover	$Y = 0.36450 + 0.12767X_1$	0.91
Timberline bluegrass	$Y = -0.65025 + 0.25336X_2 + 0.00039X_{12} + 0.00028X_{10} - 0.04387X_6$	0.90
Tufted hairgrass	$Y = -0.13370 + 0.00052X_9 + 0.00121X_{10} + 0.00019X_{12} - 0.30864X_6$	0.94
Various-leaved cinquefoil	$Y = 0.04304 + 0.27875X_1 + 0.05693X_8 - 0.00341X_9$	0.94

on each occasion; this saving would swing the comparison more favorably towards double sampling and the use of permanent sample units.

Summary and Conclusions

Standing crop of eight alpine species in Wyoming was measured by clipping square foot plots. Before harvest, characteristics such as density and foliage cover were measured.

Regression equations accounted for 89 to 96% of the variation in standing crop. The influence of any one characteristic changed widely among the eight species. Four variables, however, were more consistently correlated with standing crop than any others—foliage cover, number of stems, stem length, and leaf length.

Cost analyses showed that use of these correlated variables to estimate standing crop was inefficient. Variance of the double sampling estimate would range from two to four times that of a single clipped sample of equal cost.

Where periodic change in standing crop is of primary concern, the advantages of permanent sample units may outweigh the inefficiences of double sampling.

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