Estimating Overwinter Bitterbrush Utilization from Twig Diameter-Length-Weight Relations

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Highlight: Overwinter utilization of bitterbrush by big game can be estimated from measurement of the basal diameter and remaining length of a random sample of 100 twigs collected at the end of the browsing season. In this method, regression equations are used to predict unbrowsed twig length or weight. The range manager is thus able to obtain estimates of big game use at less expense, or to survey more area for the same cost than with more time-consuming methods.

Despite proposals for more efficient methods (Stickney 1966; Lyon 1970), many range and wildlife managers still base estimates of shrub and small tree utilization on twig measurements made before and after browsing. The primary disadvantages of the before and after method are the necessity to locate, tag, and measure twigs on a number of shrubs before browsing begins, and to relocate and remeasure the same twigs after browsing (Smith et al. 1963).

If a method could be developed that would eliminate the marking and measuring of twigs before browsing, the time saved would permit either a more economical evaluation of utilization or a more extensive coverage of important areas for the same amount of effort. Basile and Hutchings (1966) proposed such a method for bitterbrush (*Purshia tridentata* (Pursh) DC.). They suggested the use of a regression equation based on twig diameter to predict the prebrowsing twig length or weight. The relations between basal diameter, length, and weight of the annual twigs of bitterbrush used by Basile and Hutchings were determined from a study of two adjacent sites in Boise County, Ida., in 1961.

This paper describes additional research on diameter-length and diameter-weight relations of bitterbrush twigs, and on the use of these relationships to sample utilization. Data obtained by Basile and Hutchings in 1961 are included in some of our analyses.

Definition and Utilization

Degree of utilization is expressed as the percent removal of the total twig growth of the previous year, or as the mean percent

loss from individual twigs. It is the latter estimate of utilization that we are primarily trying to obtain by the use of regression equations.

For a single twig, the percent utilization (U) in terms of length is

$$U = 100[1 - (L_R/L_T)],$$

where L_T is total length and L_R is the remaining length after browsing. Basile and Hutchings' estimator of utilization ($\hat{U}$) is

$$\hat{U} = 100[1 - (L_R/\hat{L}_T)]$$

where $\hat{L}_T$ is the regression estimate of the total length. The statistic $\hat{U}$ is a biased estimator of U ; however, it is a useful estimator for our purpose. A similar estimator for utilization by weight can be constructed using estimated total weight and remaining weight.

Developing Equations

We desired to obtain information on the twig characteristics of bitterbrush from a reasonably wide variety of sites in southern Idaho and to include variation that might occur as a result of climatic variations from year to year.

In the autumn of 1964 we selected three sites in southwestern Idaho and four sites in southeastern Idaho. In addition, the two 1961 sites of Basile and Hutchings were resampled. In the autumns of 1965 and 1966, the nine sites were resampled, and samples were taken at five additional sites in southwestern Idaho and four additional sites in southeastern Idaho. Table 1 includes basic descriptive information for these 18 study areas and four areas sampled in field tests in 1969.

Annual twig growth was sampled during autumn (October–December) each year. At each site, 30 shrubs were selected at random. Because Basile and Hutchings (1966) found some significant differences in twig length-diameter and weight-diameter relations by canopy position, each shrub sampled was visually divided into upper and lower halves and north and south halves, thus quartering the canopy. Three unbranched twigs were then collected from each quarter. An effort was made to obtain a wide variety of twig lengths at each site. Twigs less than 1 inch in length were avoided if possible. Twigs were cut off at the base and immediately placed in plastic bags. Bags were sealed and identified by site, shrub number, and canopy quarter.

Length and diameter (1/2-inch above the basal end) of all twigs were measured within 24 hours after collection. Twig length was measured to the nearest 0.1 inch, and twig diameter measured to the nearest 0.001 inch with a dial gage. Mean diameter was calculated from two measurements taken at 90° from each other. To obtain oven-dry weight, twigs were dried at 70°C for 48 hours, and weighed to the nearest 0.01 gram.

All data were transferred from field forms to punch cards for automatic data processing.

Using the data obtained during 1964, 1965, and 1966, several different forms of regression models were developed to express the relationship of twig basal diameter to twig length and to twig oven-dry weight. The equations $\text{Length} = a + bD$ and $\text{Weight} = a + b(D^2)$ (where D equals mean twig diameter 1/2 inch above the base) were

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Table 1. Location and characteristics of study areas used to sample the annual twig growth of bitterbrush in southern Idaho.

Site designation	County	No. of years sampled	Soil parent material	Elevation (feet)	Exposure	Annual precipitation (inches)
Southwest Idaho:						
Basile & Hutchings	Boise	4	igneous	3,200	NE	16
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Cinch Creek	Boise	3	igneous	3,300	SW	18
Ola	Gem	3	volcanic	3,050	E	19
Peaceful Cove	Ada	3	lacustrine	3,400	S	15
Thomsen Ranch	Elmore	2	igneous	3,800	NW	12
Spring Valley	Boise	2	sedimentary	3,400	W	14
Timber Creek	Gem	2	sedimentary	3,500	W	19
Webb Creek	Gem	2	alluvial	2,900	S	19
Grasmere	Owyhee	2	volcanic	5,750	W	14
Southeast Idaho:						
Kinney Creek	Bannock	3	sedimentary	5,900	SW	13
St. Charles Canyon	Bear Lake	3	sedimentary	6,050	NW	10
Montpelier Canyon	Bear Lake	3	sedimentary	6,400	SE	14
North Juniper Mt.	Fremont	3	alluvial	5,700	E	14
Lower Knox Creek	Power	2	sedimentary	5,500	SE	14
Crystal	Power	2	lacustrine	5,200	NW	13
Mink Creek	Bannock	2	sedimentary	5,250	W	14
Skyline	Bannock	2	sedimentary	6,400	W	14
<i>1969-70 Test Sites</i>						
Highland Valley	Ada	1	igneous	4,000	W	12
Walker Creek	Bannock	1	sedimentary	5,500	S	13
Goodenough Creek	Bannock	1	sedimentary	6,400	SW	14
Black Pine	Cassia	1	sedimentary	6,200	SW	13

found to express the relationships adequately. Little additional precision was gained when the data were fitted to more complex models.

Regression coefficients for the models were computed for both length and weight of twigs from each of the 47 site-years of data (2 in 1961, 9 in 1964, and 18 in 1965 and 1966). In addition, data were pooled into three different categories: (1) "grand" equations, using data from all site-years; (2) "general" equations, using only data for 1965 and 1966; and (3) "regional" equations, using only 1965 and 1966 data but computing separate equations for southwestern Idaho and southeastern Idaho. The regional equations were derived because of considerable differences in climatic conditions between the two parts of the State.

Grand, general, and regional regression equations for both twig length and twig weight are shown in Table 2. Also shown are the number of site-years data used to derive each equation, and the multiple correlation coefficient (R^2) and standard error (Snedecor and Cochran 1968). The 47 individual site-year equations are not listed in Table 2; however, the range for R^2 and standard error is given.

Regression equations for predicting unbrowsed twig length or weight would be most useful if they could be applied equally well throughout a large geographical area. If the 47 site-year combinations of data can be considered random samples of a large population of

site-year conditions, then our best estimates for the prediction equations would be the grand equations. However, in the data collected in 1965 and 1966, all 18 sites sampled across southern Idaho were equally represented. In the presence of a site, or site-year effect, the data taken in 1965 and 1966 would yield equations which are unbiased estimates of the length and weight for the area sampled.

Individual site-year equations also were calculated and tested. However, such equations would not be as convenient for the range manager to use as would general equations.

To test for equality of regression coefficients between regional equations or among site-year equations, the analyses of variances were used. Extremely small differences in coefficients were found to be significant due to the large number of degrees of freedom we have in these experiments. Since small differences in estimated length or weight will result in even smaller differences in estimated utilization, we did not seek to identify the sources of significance in the analysis of variance. Instead, we attempted to evaluate our ability to estimate utilization through computer simulation.

Simulation of Utilization

We designed a computer program to simulate deer utilization of a population of twigs and to simulate our sampling of that population (site-year condition). We thus could model the effect of our sampling and estimation of utilization for a range of specified utilization patterns and a variety of site-year conditions. We simulated in a short time the type of testing that would take years to do in the field.

Three levels of utilization were simulated: 25%, 50%, and 75%. Sample size was varied in some test runs. When a site-year equation was used to estimate utilization with the data base from the same site-year condition, the simulation represented the best we could hope for in a field test. For each site-year condition 20 simulations of 100-twig samples were evaluated.

When individual site-year regression equations for length were used, the estimates of percent utilization were within ± 5 percentage points of the known (simulated) utilization level for 99% of the runs (Table 3). For example, if the known utilization

Table 2. Grand, general, and regional regression equations for twig length (L) and twig weight (W), and range of multiple correlation coefficients and standard errors for individual site-years.

Description	Site-years	Equations	R^2	Standard error
Length				
Grand	47	$L = -1.86 + 93.32D$	0.627	1.07
General	36	$L = -1.95 + 93.20D$	.651	1.03
Regional, SW	20	$L = -1.84 + 91.45D$	.623	1.10
Regional, SE	16	$L = -2.21 + 98.81D$	.565	.93
Site-years	1	(47 equations)	.367 to .850	.57 to 1.35
Weight				
Grand	47	$W = -.058 + 51.38(D^2)$	.836	.046
General	36	$W = -.066 + 50.94(D^2)$	.863	.041
Regional, SW	20	$W = -.071 + 52.33(D^2)$	.849	.049
Regional, SE	16	$W = -.044 + 43.05(D^2)$	.797	.027
Site-years	1	(47 equations)	.505 to .890	.015 to .088

Table 3. Number of samples yielding utilization estimates within $\pm 5\%$ of the simulated utilization, when individual site-year equations for twig length and weight were used.

Simulated percent utilization	Number of samples	Number within $\pm 5\%$	
		Length	Weight
25	235	234	207
50	470	467	413
75	235	235	216

was 50%, the estimated utilization must fall between 45% and 55% to be within ± 5 percentage points. Individual site-year equations for weight attained the same precision in 89% of the simulation runs.

The general equations were used with simulation runs for all site-year conditions. For utilization by length, the general equation estimated utilization within ± 5 percentage points of the known value in 88% of the runs (Table 4). For utilization by weight, only 64% of the runs were this precise.

Table 4. Number of samples yielding utilization estimates within $\pm 5\%$ of the simulated utilization, when the general equations for twig length and weight were used.

Simulated percent utilization	Number of samples	Number within $\pm 5\%$	
		Length	Weight
25	235	213	154
50	470	401	295
75	235	216	154

Tests of the general equations on samples from site-years not used in deriving the general equations (1961 and 1964 data) yielded utilization estimates within ± 5 percentage points in 79% of the runs for length and in 37% of the runs for weight.

Field Testing

In autumn, 1969, four previously unsampled bitterbrush stands (one in southwestern Idaho and three in southeastern Idaho) were selected for study (Table 1). At each site, 20 shrubs were randomly located and marked. Two branches on each shrub were similarly chosen and tagged. Ten twigs from the current year on each branch were measured for total length and marked with canary leg bands. In addition, 15 other twigs were clipped from each shrub and returned to the laboratory for diameter measurement.

To test the usefulness of the grand, general, and regional equations for providing an estimate of utilization by length, the actual utilization of all relocatable tagged twigs at each location was determined in the spring of 1970. These data are given in the following tabulation:

Site	Number of twigs sampled	Mean percent utilization
Highland Valley	393	35
Walker Creek	399	24
Goodenough Creek	398	28
Black Pine	400	21

The collection and measurement of the tagged twigs provided a pattern of use at each of the four sites. The same pattern of utilization was artificially applied to the 300 twigs that had been collected the previous autumn at each site. This was done by clipping off the required portion from each twig to correspond with the actual degree of use observed on the tagged twigs.

Table 5. Estimated mean utilization of individual twigs (length) obtained through the use of grand, general, and regional equations.

Site	Actual utilization (%)	Estimate using regression equation (%)		
		Grand equation	General equation	Regional equation
Highland Valley	35	32	31	31
Walker Creek	24	31	30	31
Goodenough Creek	28	35	33	34
Black Pine	21	24	23	25

From this sample of twigs the grand, general, and regional equations for twig weight were evaluated for their accuracy in providing utilization estimates by weight.

As shown in Table 5, the percent utilization by length was determinable within $\pm 6\%$ of the actual utilization at all four sites by the general equation, and within $\pm 7\%$ at all four sites by the grand and regional equations.

Percent utilization by weight was determinable within $\pm 5\%$ of the actual utilization by each of the three equations on three of the four sites (Table 6). On the Highland Valley site none of the equations gave an estimate of utilization closer than $\pm 8\%$.

Table 6. Estimated mean utilization of individual twigs (weight) obtained through the use of grand, general, and regional equations.

Site	Actual utilization (%)	Estimate using regression equation (%)		
		Grand equation	General equation	Regional equation
Highland Valley	28	20	18	18
Walker Creek	17	17	15	13
Goodenough Creek	24	23	20	19
Black Pine	17	17	15	13

Standard errors and the sample means were determined for sample sizes of 10, 20, 30, 40, or 100 twigs at each simulated utilization level (25, 50, and 75%). As the sample size increased, the standard error of the mean decreased. However, there was only a slight improvement when the sample size was increased from 30 to 100 twigs. It is doubtful if there could be much increase in precision if sample size were increased beyond 100 twigs.

Discussion

Of the 940 samples tested by using the general equation for twig length in the simulated browsing phase of this study, 95% of the estimates of utilization were within ± 6 percentage points of the true mean. Eighty-eight percent of the estimates were within $\pm 5\%$.

The level of precision considered acceptable for utilization estimates will probably vary among range managers. There will be times when an experienced range manager or game biologist can accurately judge that a bitterbrush stand has been slightly browsed, or heavily browsed (75% or more), by careful observations. Mere observation becomes considerably more unreliable when the level of utilization is between 25 and 75%. In such cases it may be more desirable to arrive at an estimate that is within ± 5 percentage points of the true utilization than one that is within ± 10 percentage points.

In the test of the equations by simulated utilization, 20 samples were taken from each of 47 site-year's data. Figures 1 and 2 show the number of site-years in which estimates of utilization were within 5, 6, or 7 percentage points of the simulated utilization in either 90 or 80% of the samples tested. These figures are based on the use of the general equations for twig length and weight.

Fig. 1. Number of site-years in which the estimates of utilization were within x percentage points of the simulated utilization in 90% of the samples tested (general equations for twig length and twig weight). Total number of site-years = 47.

The grand equation for twig length, from all data, was not evaluated in our full-scale test using simulated browsing. However, in a limited, preliminary test using 10 samples from each of 13 different site-years, this equation enabled estimates within $\pm 5\%$ in 9 or more samples from 8 of the 13 site-years. Estimates within $\pm 6\%$ were obtained in at least 9 out of 10 samples in 11 of the 13 site-years. For these same 13 site-years, the general equation was slightly less accurate than the grand equation.

For estimating twig utilization by weight, the grand equation was not quite as good a predictor as the general equation when used on data from the same 13 site-years.

A more reliable estimate of utilization, by length, can usually be obtained if regression equations derived from each specific site are used. In the simulated browsing test, utilization estimates by length were within $\pm 5\%$ of the true mean in 90% or more of the samples from 46 of the 47 site-years tested.

Comparing the grand and general equations for length on the basis of the field test of 1969–70, on four sites, there was little difference between estimates based on the two equations, and all estimates were within $\pm 7\%$ of the true mean (Table 5). For utilization by weight, both equations were within $\pm 5\%$ of the true mean utilization on three sites, and gave estimates that were 8–10% low on the remaining site (Table 6).

The regional equations might have been expected to give estimates somewhat closer to the true values than the grand or general equations. However, in the field test they proved no better than the latter two for estimating utilization by length, and slightly less accurate for estimates by weight (Tables 5 and 6).

The results of the field test of utilization estimates by weight were surprising. Previous tests of the several regression equations, based on simulated utilization, indicated that such equations worked best in calculating utilization by length rather than by weight. However, as shown in Table 6, the equations for twig weight gave closer estimates of utilization for three of the four sites than did the equations for twig length.

Estimating Total Utilization

In discussing twig utilization we have been referring to the mean decrease in length or weight of individual twigs. Another

Fig. 2. Number of site-years in which the estimates of utilization were within x percentage points of the simulated utilization in 80% of the samples tested (general equations for twig length and twig weight). Total number of site-years = 47.

way to describe utilization of browse by animals is in terms of the ratio of the amount taken to the amount available. This is what is done when all the current year's twig growth is measured on selected branches of a number of shrubs, and these same twigs are remeasured at the end of the browsing period.

Two different procedures can be used to calculate an estimate of total utilization. In one, the regression equation would be solved only once to obtain either the average original twig length or the average original twig weight for all twigs in the sample. This would be done by using the average diameter (for length) or the average squared diameter (for weight) of all the twigs in the sample. Then the average residual twig length or weight would be used to calculate the estimate of utilization.

In the second procedure the regression equation would be used to predict the original length or weight of each twig in the sample (excluding the unbrowsed twigs, whose measurements are known). Then the sum of the predicted and known original lengths or weights and the sum of the residual lengths or weights are used to compute the estimate of utilization.

These two procedures were used with the data from the four sites in the 1969–70 field test. Using the first method with the grand, general, regional, and site-year equations for length, we found that in each case only two of the four estimates were within $\pm 5\%$ of the known total utilization. The other estimates ranged from 6 to 14% higher than the known value.

The grand, general, and regional weight equations greatly underestimated utilization, but the site-year equation yielded almost exact estimates. The latter result, however, was to be expected because the respective site-year equations were developed from the same 300-twig samples that were used to test each of the different weight equations.

The second method has only been used with the grand equation. For estimating utilization by length, it resulted in estimates within $\pm 1\%$ on two sites and within $\pm 6\%$ on the other two test sites. Estimates by weight were within $\pm 5\%$ on two sites and approximately 10% low on the other two sites.

Advantages and Disadvantages

The primary advantage offered by the use of regression equations to estimate the prebrowsing twig measurements is the

time saved by not having to locate and permanently tag a number of shrubs (and a sample of their twigs), which must then be remeasured following the browsing period. This saving in time is slightly offset if a sample of twigs is collected from which to develop the regression equation. However, it is likely that for a given region of similar terrain and climate an equation such as our "grand" equation can be developed and used repeatedly. A second advantage is that an estimate of utilization by weight can be obtained; the method involving pre- and post-browsing measurement of twigs yields only utilization by length.

One disadvantage of the method is the difficulty of accounting for the total use of some twigs. The omission of completely utilized twigs from the sample would result in a biased estimate of utilization. This only occurs to a significant extent on areas where browsing is very heavy, and average utilization is in the 75 to 90% range. On such areas, the calculation of the percent utilization would be slightly lower than the actual utilization, which would not be of any practical importance when utilization is that great.

Another source of bias is the estimator U itself, since the expected value of a ration ($U_R/\hat{U}_T$) is not equal to U_R divided by the expected value of $\hat{U}_T$. Through simulation we have found the amount of bias to be small when evaluating a sample of 100 or more twigs. So no adjustment was made for estimation of utilization.

Recommendations

We believe either the grand or general equations are suitable for use on most southern Idaho sites for estimating mean utilization of individual twigs by both length and weight. Despite the fact that the grand equations were derived from somewhat larger data bases than the general equations, there is no solid evidence that the grand equations are better predictors. Although using either of these existing equations will save the time required to derive a site-year equation, development of a site-year equation, development of a site-year equation should usually result in more accurate estimates of utilization.

For bitterbrush areas outside of southern Idaho we suggest the development and use of individual site-year equations for both length and weight, until such time as sufficient data are compiled to evaluate site or regional equations.

To develop a regression equation for predicting the unbrowsed twig length or weight, a representative sample of the current year's twig growth must be obtained from the chosen site. Use some method of random selection to locate shrubs from which to take the twig sample. Ten twigs from each of 20 shrubs, well distributed over the area, should suffice. Clip each twig cleanly at the base, avoiding any that are browsed or broken. Include twigs from different sides of the shrubs and from lower branches as well as upper branches. Obtain a range of twig lengths, from 1 inch to near the maximum length occurring on the selected shrubs.

Immediately place the clipped twigs in a suitable plastic bag to prevent desiccation. Sprinkling a small quantity of water inside the bag will provide a humid atmosphere.

Preferably, the diameter and length of the sample twigs should be measured the same day as collected. However, twigs can be stored overnight in a refrigerator in a sealed plastic bag without a significant effect on the measurement.

Measure the diameter to the nearest .001 inch, using a dial gage, at a point 1/2 inch above the basal end of the twig. Dial gages used in our study were manufactured by the L. S. Starrett

Company, Athol, Massachusetts. Model 1015B was modified to provide screw driver type contact points top and bottom, blade approximately 1/2 inch long, range 0-1/2 inch.¹ Take two measurements at right angles at the same point, and calculate the mean. If a bud occurs 1/2 inch from the base, take the measurement just above the bud.

If an equation for twig weight is desired, oven-dry the twigs at 70°C for 24 hours and weigh each twig to the nearest 0.01 gram.

Once the values of length, weight, and diameter have been determined for all twigs, the equations relating length and weight to diameter can be considered. The linear regression equations $\text{Length} = a + b(D)$ and $\text{Weight} = a + b(D^2)$ will probably be adequate. Calculations of the regression coefficients follow standard linear regression procedures (Snedecor and Cochran 1968). Consider the first equation, $\text{Length} = a + b(D)$. The coefficients a and b are calculated using the values of twig length (L) and twig diameter (d) measured in the sample just taken. First calculate the average length, $\bar{L}$, and the average diameter, $\bar{D}$, for all the twigs in the sample. For each twig the difference between the average length $\bar{L}$ and the length of that twig, L , is y . Similarly, for each twig the difference between the average diameter, $\bar{D}$, and the diameter of that twig, D , is x . The summation over all twigs of the product of x and y is the cross product term S_{xy} . The summation over all twigs in the square of x is the term S_{xx} . The regression coefficient b is the ratio of these two terms:

$$b = S_{xy}/S_{xx}.$$

The coefficient a is then the average length, $\bar{L}$, minus the product of b and $\bar{D}$:

$$a = \bar{L} - b(\bar{D}).$$

The coefficients for the weight equation can be calculated in a similar fashion. Note, however, that in these calculations the twig weight replaces twig length in the above procedure and twig diameter squared replaced twig diameter. The average diameter is replaced by the average of the squared twig diameters.

To obtain an estimate of the average utilization of bitterbrush twigs on a particular range site, decide on an objective way to designate approximately 20 shrubs that will be representative of the site. Then devise a way to randomly select five individual twigs of the current year from each shrub.

Collect the total number of twigs desired, keep them in a plastic bag, and return to the office to obtain the diameter and residual length or residual weight measurements. Twigs should be handled as described in the section on developing a regression equation.

In the office, record the mean twig diameter and residual length (or residual weight following oven drying) of each twig. Solve the regression equation to predict the original length or weight of each twig. Then calculate estimated utilization of each twig and the mean value. Unbrowsed twigs in the sample need not be measured, but should be listed as zero percent utilized, and included in the calculation of the mean value.

If an estimate of total utilization is preferred, the sum of the predicted original twig lengths or weights (including unbrowsed twigs, which in this case will have to be measured or weighed) and the sum of the residual twig lengths or weights may be used. This procedure is more likely to give satisfactory estimates for twig length than for twig weight.

¹Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

Literature Cited

Basile, Joseph V., and Selar S. Hutchings. 1966. Twig diameter-length-weight relations of bitterbrush. *J. Range Manage.* 19:34-38.

Lyon, L. Jack. 1970. Length- and weight-diameter of serviceberry twigs. *J. Wildl. Manage.* 34:456-460.

Smith, Dwight R., Pat O. Currie, Joseph V. Basile, and Neil C. Frischknecht. 1963. Measurement and evaluation of range use by livestock and game. U.S. Dep. Agr. Misc. Pub. 940. p. 93-102.

Snedecor, George W., and William G. Cochran. 1968. Statistical methods. 6th ed. Iowa State Univ. Press, Ames.

Stickney, Peter F. 1966. Browse utilization based on percentage of twig numbers browsed. *J. Wildl. Manage.* 30:204-206.