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Volume and Biomass For Curlleaf Cercocarpus in Nevada

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RESEARCH SUMMARY

Volume and biomass equations were developed for curlleaf cercocarpus (*Cercocarpus ledifolius* Nutt.) in the Egan and Schell Mountains near Ely, NV. Fifty-two trees were sampled to measure cubic foot volume. Diameter at root-collar (DRC) was used to develop a simple linear volume prediction equation for individual trees. Volume predictions can be converted to biomass by wood density factors reported from the study. A ratio equation was developed to predict volume and biomass for various utilization standards. A method was developed for obtaining bark volume and biomass.

The jackknife technique was used to assess the reliability of the equations. This technique allowed computation of confidence intervals for predictions from several equations used in a series. The 95 percent confidence intervals (expressed as a percentage of the predicted value) were generally less than 20 percent of predicted volume and biomass for curlleaf cercocarpus trees within 2-inch diameter classes.

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INTRODUCTION

The Resources Planning Act (RPA) of 1974 calls for assessment of all forest and rangelands, including shrubby woodlands. Curlleaf cercocarpus (*Cercocarpus ledifolius* Nutt., with the former common name of curlleaf mountain-mahogany), a woodland tree found mainly in Nevada and Utah, is included. In addition to its wood fiber value, it is an important browse plant for wildlife and has root nodules that fix nitrogen. This study sought to develop volume and biomass prediction equations for cercocarpus to provide foresters with tools needed to assess woodlands.

In anticipation of changing inventory and management needs for cercocarpus, I developed equations and methods to obtain the following:

1. Gross volume and biomass of wood and bark to a 1.5-inch minimum branch diameter (mbd[1]), with capability to vary mbd.
2. Gross volume and biomass of wood to a 1.25-inch mbd, with the capability to vary mbd.
3. Volume and biomass of bark to a 1.5-inch mbd.

Volume was expressed in cubic feet and biomass in pounds according to current USDA Forest Service Forest Survey standards.

PREVIOUS WORK

Numerous ecological studies have been conducted on cercocarpus, but few studies include methods to estimate wood volume or biomass. Whittaker and Niering (1975) evaluated biomass of hairy cercocarpus (*C. breviflorus*) in the Santa Catalina Mountains of Arizona. They developed a stem-wood volume equation from 15 trees (with average diameter 3.26 cm):

$$V = 76.03 + 0.2939D^2H$$

where:

V = volume of stem wood (cm^3)

D = basal diameter (cm) at 10 cm above ground line

H = total tree height (m).

[1]The mbd is measured inside the bark for wood only. In all other cases it is measured outside the bark.

R. O. Meeuwig (personal communications, 1980) did some preliminary work on biomass estimation of cercocarpus in the Sweetwater Mountains of Nevada. He identified crown diameter, the number of stems greater than 3 inches found at breast height, and basal diameter 6 inches above ground line as potential variables to predict biomass. Weaver (1977) developed several biomass equations for cercocarpus and other shrubs in Montana. He related crown area to total biomass in a single equation, applicable to sagebrush, cercocarpus, dogwood, ninebark, bitterbrush, sumac, buffaloberry, and huckleberry:

$$\log_{10}BM = -1.95 + 1.26 \log_{10}A$$

where:

BM = total aboveground biomass (kg)

A = 3.34 · MXR · MNR

MXR = maximum plant radius (cm)

MNR = minimum plant radius (cm).

Research has indicated that diameter, height, number of stems, and crown area should be considered as potential predictor variables of cercocarpus volume. For this study, these and several other variables were measured on trees.

DATA COLLECTION METHOD

Data were collected at three locations in the Egan Mountains and one location in the Schell Mountains near Ely, NV (fig. 1). Trees were selected arbitrarily by 2-inch diameter classes. Diameter measurement was made at the root-collar (DRC) at ground line. At each location, one or two trees in each diameter class were sampled, totaling 52 trees in diameter classes ranging from 2 to 22 inches. Tree heights ranged from 5 to 21 ft.

The following variables were measured for potential volume and biomass prediction:

1. DRC to nearest 0.1 inch
2. Diameter at breast height (d.b.h.) to nearest 0.1 inch
3. Total tree height to nearest foot
4. Crown diameter maximum and minimum to nearest foot
5. Number of stems at 20 percent of tree height
6. Number of stems greater than 3 inches in diameter at 4.5 ft

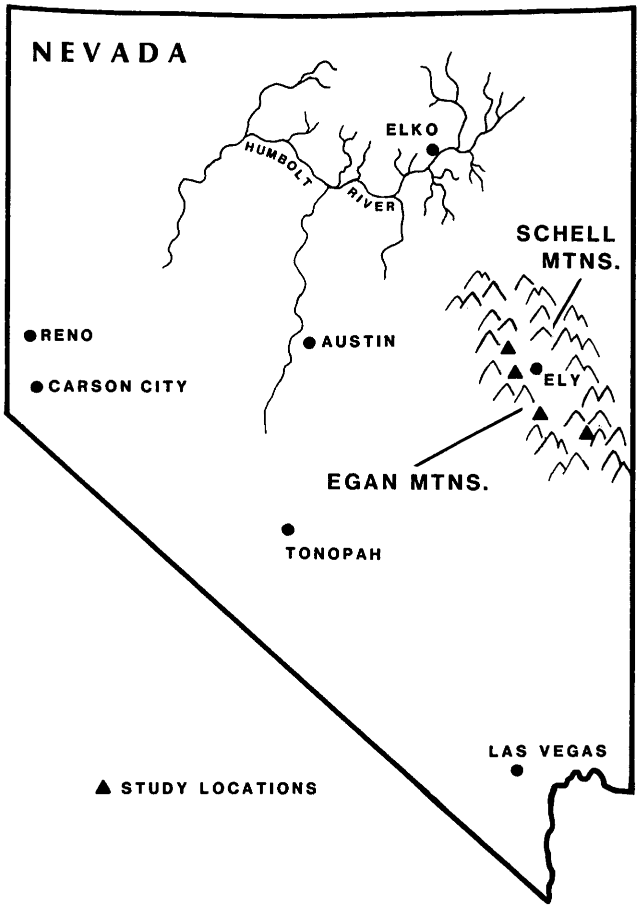

Figure 1.—Study locations were in the Schell and Egan Mountains.

If the tree stem forked at the the point of measurement, I computed an equivalent diameter (Meeuwig and Budy 1981):

$$\text{Equivalent diameter} = \sqrt{\sum_{i=1}^{n} D_i^2}$$

where:

D_i = DRC of the ith stem.

n = number of stems at measurement point (DRC or d.b.h.).

Stems smaller than 1.5 inches in diameter were not included in the DRC and d.b.h. measurements.

The trees were cut into segments from 1 to 5 ft long to measure diameter and length, depending on stem forks and taper of the segments. Although the intent was to keep segment taper less than 15 to 20 percent, average taper was 23 percent on the 1,122 segments measured.

I made outside bark diameter measurements (to the nearest 0.1 inch) at each segment's large end, midpoint, and small end. These were used to compute volume.

I recorded percent of internal defect for each segment and identified segments containing all dead wood. Limbs severed from the trees were also included as dead wood. These were fairly common, apparently due to a heavy wet snowfall the spring prior to sampling.

Three segments from each tree were subsampled for a cross-sectional disk 2 inches thick. These disks were from the top, midsection, and butt of each tree and were used to determine specific gravity and inside bark diameter for biomass computation.

DATA ANALYSIS AND RESULTS

I used the segment data to compute volume and biomass for the trees, developed methods to predict volume and biomass, and assessed the reliability of the prediction methods.

Computation Volume and Biomass

To develop prediction models, volume and biomass of the wood and bark were required for each tree (for variable mbd's). Volume computations were done separately for wood and bark combined, and for wood alone. The volume computations were converted to biomass using wood density factors. Defective and dead wood was also examined.

Wood and bark volume, to a 1.5-inch mbd, was computed for each tree using Newton's log formula (Husch and others 1972, p. 122) on each segment, and then segment volumes were summed. In some cases the segment measurements were inadequate for computing tree volume to an mbd larger than 1.5 inches. These cases required an estimate of segment length. I used a geometric scheme to estimate an unknown segment length when the desired mbd fell somewhere between the segment's large and small diameter measurements. I calculated the unknown segment length from the known segment length and known diameters, assuming segment shape to be a cone:[2]

$$X = L - \left(\frac{\text{mbd-SD}}{\text{LD-SD}} \right) L$$

where:

L = known segment length

X = unknown segment length

SD = small diameter of a segment

LD = large diameter of a segment.

In this fashion wood and bark volumes to variable mbd's of 2, 3, 4, 5, 6, 7, and 8 inches were computed using Newton's formula and the length approximation (X) when necessary.

Wood volume was computed by first converting the outside bark segment diameter measurements to inside bark diameter. I used a regression relationship developed from a subsample of segments (fig. 2):

$$\text{IBD} = -0.1501 + 0.93613(\text{OBD})$$

where:

IBD = inside bark diameter (inches)

OBD = outside bark diameter (inches).

The same procedure used for wood and bark volume computation was also used for computing wood volume. I also computed volumes to variable mbd's from 2 to 8 inches.

[2]A comparison of mean volumes computed for 1,122 segments using Newton's formula versus a cone frustrum formula showed a 0.14 percent difference; hence, the conic assumption is reasonable.

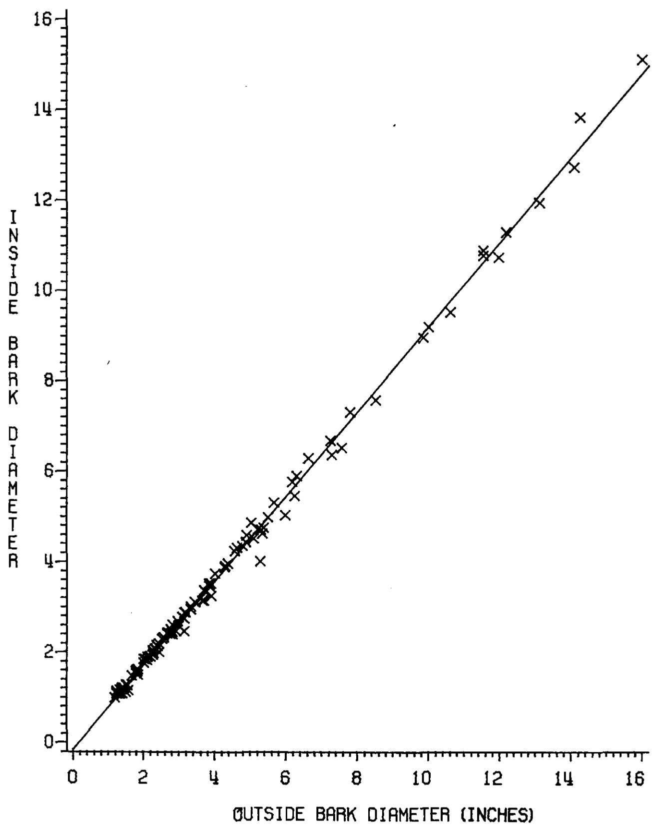

Figure 2.—Inside bark diameter plotted against outside bark diameter with the regression equation overlaid ($R^2 = 0.997$).

Biomass of the tree segments was computed using the physical relationship between volume, mass, and density. I determined specific gravities (the density of a material divided by the density of water, 62.4 lb/ft^3) instead of densities for 36 disks, three sampled from each of 12 trees. Specific gravity was determined on the basis of green volume and ovendry weight. Procedures for irregularly shaped blocks were used (Heinricks and Lassen 1970). Specific gravity did vary within a tree. However, I grouped the data as in table 1 for determining biomass because no reasonable way to apply more than one specific gravity value per tree was designed into the study.

Summary of the defective and dead wood showed no rot in live branches, but did reveal some dead material (table 2). For fuelwood management, dead cercocarpus limbs are just as valuable as live material because the wood is usually sound; hence, there is probably no need for net volume reductions.

Predicting Volume and Biomass

Capabilities to predict gross cubic foot volume and pounds of woody biomass to variable mbd's were developed. I also developed separate equations for wood and bark combined, and for wood only. Because the regression procedure was the same for wood and bark as for wood only, I omitted discussion about equations predicting just wood. An explanation follows for the development of a volume equation, a variable mbd equation, a biomass conversion, and a bark method.

I selected a simple linear equation predicting volume from DRC. Combinations of the variables height, crown diameter, and numbers of stems were examined for predicting volume, but none proved to be much better than the model based on DRC. Diameter at breast height (equivalent d.b.h. for multiple stems) appeared to be as good or better a predictor of volume as was DRC, but was not considered because d.b.h. measurements are incompatible with current woodland inventory procedures.

Because the relationship of volume to DRC is nonlinear, the volume equation was developed using a natural log transformation and simple linear regression (fig. 3 and table 3). I applied a positive correction of 5 percent for predicting the mean volume instead of median volume that results from application of log transformations (Flewelling and Pienaar 1981).

I developed another equation to predict volume to variable minimum branch diameters. Burkhart (1977) showed that for loblolly pine a ratio of volume to a desired upper stem diameter divided by total volume is a function of d.b.h. and upper stem diameter. In this study a ratio of mbd volume divided by total volume was regressed against the log transformations of DRC and mbd (table 3 and fig. 4).

Biomass equations were not developed because the best measure of tree weight obtainable within the study design was a conversion of volume to biomass using a constant wood density factor for all trees. Volume equations in table 3 can be converted to biomass equations by use of the appropriate wood density factor in table 1.

Table 1.—Density and specific gravity for curlleaf cercocarpus wood and bark

Component	Density	Mean	95 percent confidence[1] interval	Range	Sample[2] size
	Lb/ft^3	*Specific gravity*			
Bark and wood	43.68	0.70	±0.025	0.55-0.89	36
Wood	50.54	.81	± .022	.70- .94	36
Bark	22.46	.36	± .019	.29- .48	36

[1]The average specific gravity for curlleaf cercocarpus is expected to lie within the confidence interval unless a 1-in-20 chance has occurred in selecting the samples. The confidence intervals were based on the t-statistic, 11 degrees of freedom, and variances jackknifed by deleting one tree at a time.

[2]Samples are from 12 trees, but each tree was sampled at the top, midpoint, and butt.

Table 2.—Dead volume expressed as a percent of gross wood and bark volume to a 1.5-inch minimum branch diameter (mbd) and wood volume to a 1.25-inch mbd

Diameter class (DRC in inches)	Percent dead wood and bark	Percent dead wood	Percent sampling error[1]	Sample size
2	0	0	—	2
4	0	0	—	6
6	0	0	—	6
8	.3	.3	±38.9	6
10	2.3	2.1	±68.6	7
12	1.8	1.7	±98.6	6
14	2.7	2.5	±65.4	6
16	8.8	8.5	±106.7	5
18	8.1	7.8	±77.9	4
20	4.3	4.0	±377.1	3
22	11.0	10.4	—	1

[1]The sampling error is for wood and bark values (it is roughly the same for wood). Sampling error is expressed as a percentage of the average percent dead and implies the true value for percent dead lies within the sampling error unless a 1-in-20 chance has occurred in sample selection. The large sampling errors are due to the small sample sizes and due to data that are distributed both discretely and continuously.

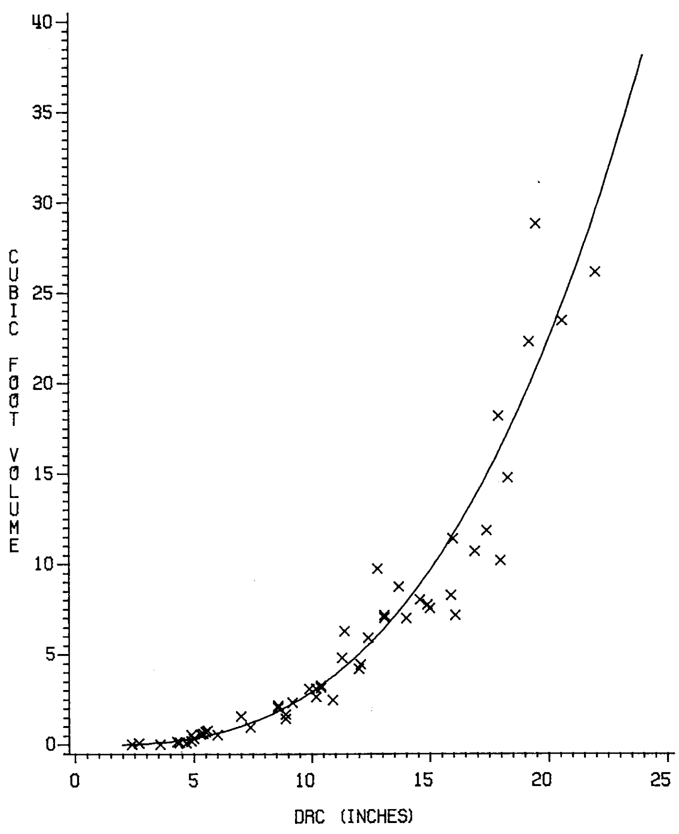

Figure 3.—Wood and bark volume data plotted against DRC, with the volume equation overlaid.

Table 3.—Equations for predicting curlleaf cercocarpus wood fiber products

Product	Equation	Equation #	R^2
Cubic foot volume of wood and bark to a 1.5-inch mbd	$V = 0.00356(DRC)^{2.920}$	(1)	0.96
Cubic foot volume of wood to a 1.25-inch mbd	$V = 0.00258(DRC)^{2.964}$	(2)	.96
Mbd ratio for wood and bark	$R = 0.6281 + 0.23875 \ln^{1}(DRC) - 0.47745 \ln(mbd)$	(3)	.78
Mbd ratio for wood	$R = 0.5210 + 0.25729 \ln(DRC) - 0.46192 \ln(mbd)$	(4)	.75

[1]ln is the natural log function.

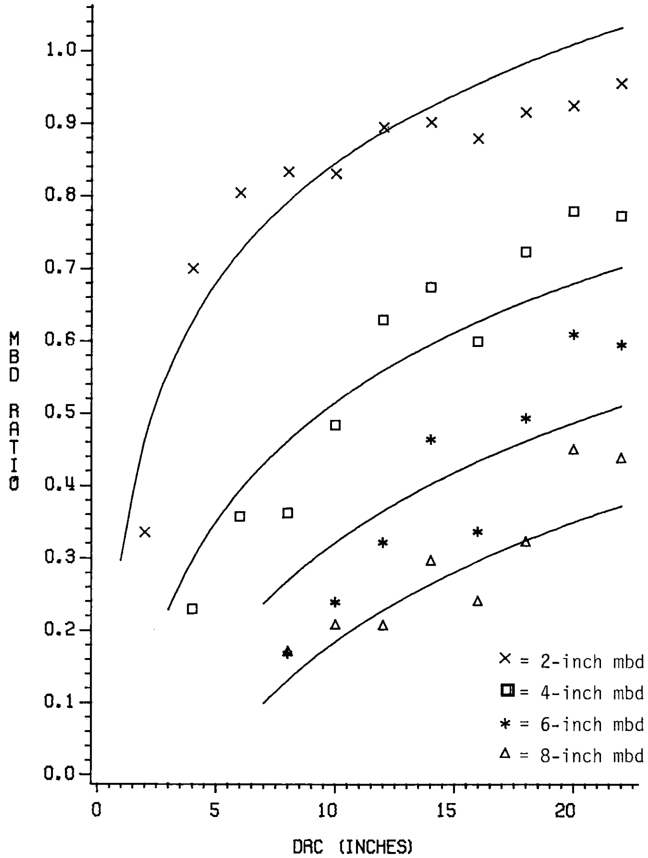

Figure 4.—The means within 2-inch DRC classes for the ratio of mbd volume to total volume are plotted for several mbd classes. The corresponding prediction equation is overlaid.

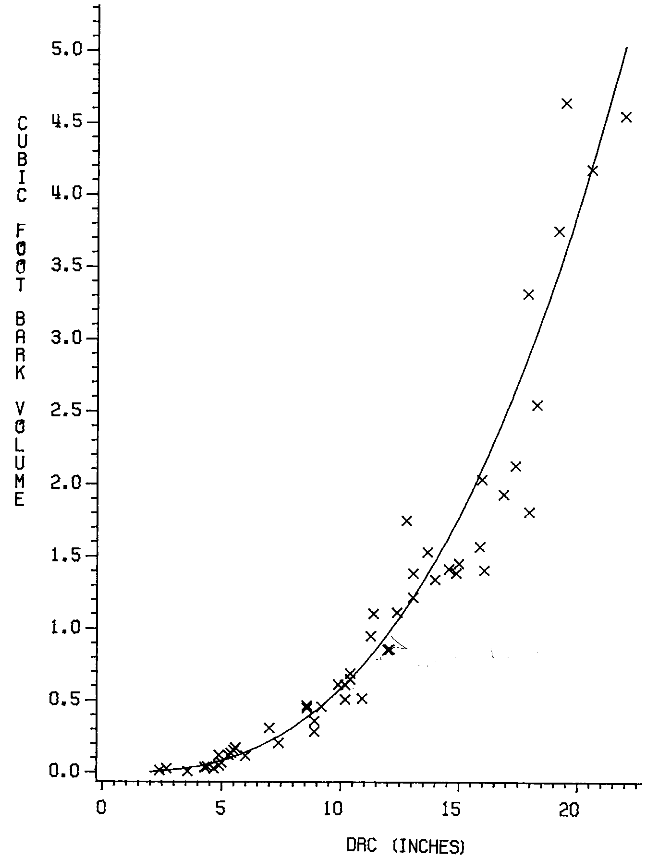

Figure 5.—Bark volume data plotted against DRC with the prediction of bark overlaid—eq. (1) minus eq. (2) from table 3.

Bark volume and biomass can be obtained by subtracting predictions for a wood equation from a wood and bark equation (fig. 5). This method only gives bark estimates to a 1.5-inch mbd because the subtraction method is incompatible with volume predictions for other mbd's.

In summary, the equations in table 3 and the wood density factors in table 1 can be used to estimate volume and biomass of cercocarpus wood and bark. Table 4 provides a guide and an example for computing these.

Table 4.—A guide to use the equations in table 3 and wood density factors in table 1 for the estimation of curlleaf cercocarpus wood volume and biomass

Product to be estimated	Wood and/or bark	Wood
Volume	Eq.(1)	Eq.(2)
Volume to a variable mbd	Eq.(1) × Eq.(3)	Eq.(2) × Eq.(4)
Biomass	Eq.(1) × wood and bark density	Eq.(2) × wood density
Biomass to a variable mbd	Eq.(1) × Eq.(3) × wood and bark density	Eq.(2) × Eq.(4) × wood density
Bark volume	Eq.(1) − Eq.(2)	none
Bark biomass	(Eq.(1) − Eq.(2)) × bark density	none
Bark volume and biomass to a variable mbd	none	none

An example for computing wood and bark biomass of a tree to a 4-inch mbd:

Given: DRC = 18 inches
mbd = 4 inches
wood and bark density = 43.68 lb/ft (from table 1)

Wanted: Pounds of wood and bark biomass for a 4-inch mbd

Step 1—Compute wood and bark volume for a 1.5-inch mbd

$$\text{Volume} = 0.00356(\text{DRC})^{2.92} = 16.48 \text{ ft}^3 \quad (1)$$

Step 2—Compute wood and bark 4-inch mbd ratio

$$\text{Ratio} = 0.6281 + 0.23875 \ln(\text{DRC}) - 0.47745 \ln(\text{mbd}) = 0.66 \quad (3)$$

Step 3—Compute biomass result

Result = Eq.(1) × Eq.(3) × wood and bark density
= 16.48 × 0.66 × 43.68
= 475 lb of wood and bark for a 4-inch mbd.

Reliability of the Equations

Determining reliability for equations developed in logarithmic units and for systems of equations can be difficult. The R^2 and standard error of regression are in log units and have little meaning for assessing cubic foot volume predictions. However, a technique called jackknifing is useful for estimating variances in complex situations (Mosteller and Tukey 1977; Schreuder and Brink 1983). The jackknife method involves computing a statistic (in this case regression coefficients) from a data set numerous times, each time deleting a different observation(s). Each computation is called a pseudo-value, when subtracted from the statistic using all data points:

$$y^*_j = (k)y_{all} - (k-1)y_{(j)}, \; j = 1,2,\ldots,k$$

where:

y^*_j = a pseudo-value
k = number of observations
y_{all} = the statistic based on all observations
$y_{(j)}$ = the statistic based on k-1 observations with observation j deleted.

A variance is easily calculated from the pseudo-values:

$$S^2 = \frac{\sum_{j=1}^{k} (y^*_j - \bar{y}^*)^2}{k-1}$$

where:

$\bar{y}^*$ = the arithmetic mean of y^*_j.

Once variances are computed, confidence limits can be calculated using the t-statistic:

$$\bar{y}^* \pm t_{\alpha/2:k-1}\, S/\sqrt{k}\,.$$

Using the jackknife theory presented above, I computed confidence limits by 2-inch diameter class (DRC) for predictions from three sets of equations: (1) wood and bark volume to 1.5-inch mbd, (2) wood volume to a 3-inch mbd, and (3) wood and bark biomass to a 3-inch mbd. These represent predictions for one, two, and three sets of equations, respectively. The confidence limits were constructed by diameter class because the variance of an estimate increases with tree size, which makes it inappropriate to use an average variance for all tree sizes.

Each jackknifed variance was based on 52 pseudo-values. Each pseudo-value required development of regression equations with one tree missing. The same tree was deleted for all regressions when a pseudo-value was based on more than one equation.

Table 5 contains predictions, percent of actual volumes, and the confidence intervals. Confidence intervals were constructed from jackknifing and expressed as a percent of a prediction. The percent of the actual volume lies within the confidence intervals most of the time. Also, the confidence intervals were similar whether one, two, or three equations were used, indicating that errors may not increase by using two or three equations in a series.

The small differences between the weighted averages of the actual and predicted values in the last row of table 5 indicate that the equation or systems of equations are best when averaging over all tree sizes. Some individual size classes have quite a large difference between predicted and actual estimates, but these average out when considering totals.

Table 5.— A comparison of actual curlleaf cercocarpus volume and biomass values with predicted values and with 95 percent confidence intervals (C.I.) from jackknifing predictions

			Wood volume in cubic feet to a 1.25-inch mbd			Wood volume in cubic feet to a 3-inch mbd			Wood and bark biomass in pounds to a 3-inch mbd		
Diameter class (DRC)	Average DRC	Trees[1]	Predicted value	Percent actual value	95 percent C.I.[2]	Predicted value	Percent actual value	95 percent C.I.[2]	Predicted value	Percent actual value	95 percent C.I.[2]
1.5- 2.9	2.55	2	0.04	−33	±39	—	—	—	—	—	—
3- 4.9	4.67	6	.22	29	±25	0.09	50	±43	5.7	63	±36
5- 6.9	5.47	6	.40	−17	±20	.18	−10	±33	11.3	−14	±28
7- 8.9	8.23	6	1.34	2	±12	.74	7	±17	44.4	−3	±15
9-10.9	10.17	7	2.50	8	±8	1.53	3	±11	89.2	3	±11
11-12.9	12.00	6	4.08	−16	±8	2.66	−27	±10	153.2	−26	±10
13-14.9	13.90	6	6.31	1	±9	4.36	−12	±11	247.2	−9	±11
15-16.9	15.88	5	9.54	30	±11	6.93	27	±14	388.3	27	±13
17-18.9	17.90	4	13.35	18	±14	10.09	9	±16	559.9	11	±15
19-20.9	19.77	3	17.91	−14	±16	13.99	−21	±19	770.4	−18	±18
>21	22.00	1	24.60	14	±17	19.90	7	±22	1,086.0	8	±20
Weighted averages over all diameter classes	12.04	—	7.30	5	±16	6.05	−3	±20	335.6	−1	±18

[1]Number of trees averaged for actual volume values.
[2]The confidence intervals are expressed as a percent of the predicted value. They imply the true value lies within the interval unless a 1-in-20 chance has occurred in selecting the sample.

DISCUSSION

The volume and biomass estimation methods given in this study should predict within about 20 percent of the actual values for individual trees. Better results can be expected for averages from a sample of trees. However, these inferences rely on the assumption that future samples of cercocarpus trees will have forms similar to those in this study. This is because the modeling techniques were based on empirical data manipulation with little biological reasoning to warrant extrapolation to other areas. This study, however, could provide insights useful in hypothesis building for future cercocarpus volume modeling research done from a more biological perspective.

Observation of the equations in table 3 indicates cercocarpus volumes may be proportional to DRC cubed. Other people have supported a hypothesis that a function of DRC is proportional to volume or biomass for pinyon-juniper and other woodland trees (Gholz 1980; Tausch 1980; Weaver and Lund 1982; Felker and others 1983).

Perhaps the best use of this study could be an application of the modeling techniques to a subsample of trees in a multistage or multiphase woodland inventory. DRC is the only variable that would need to be measured in the main large sample. Developing new equations for the subsample of trees would require considerable effort in destructive sampling, but a visual sampling method (Born and Chojnacky, in preparation) would alleviate this constraint. Such an application would rely heavily on well-established sampling theory and would shun uncertain equation extrapolations.

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Volume and biomass equations were developed for curlleaf cercocarpus (*Cercocarpus ledifolius* Nutt.) in the Egan and Schell Mountains near Ely, NV. The equations predict cubic foot volume of wood and bark for variable minimum branch diameters. Wood density factors are given to convert volume predictions to pounds of fiber biomass. The reliability of the equations was assessed using the jackknife technique to construct confidence intervals.

KEYWORDS: *Cercocarpus*, woodland, jackknife, specific gravity

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