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Dryland Forest Volume: Another Look at the Visual Segmentation Technique

David C. Chojnacky
J. David Born[1]

ABSTRACT

Dryland forests, also called woodlands, encompass more than 40 percent of the forest land in the Rocky Mountain States. Wood volume for these forests has been estimated using equations constructed from nondestructive visual segmentation data. Previous work has shown that segmentation data—where segments are classified by diameter and length instead of measured—are adequate for volume equation development. However, this study reports some newly discovered bias of 10 percent or more in segmentation procedures. An improved diameter class estimator is given to correct for some of the bias when calculating volumes from segmentation data. The rest of the bias seems caused by segment length estimation or field application of visual segmentation. Analyses and results are discussed specifically for pinyon-juniper data from Nevada, Utah, and New Mexico, but methodologies tested could have worldwide application to dryland forests.

KEYWORDS: volume sampling, *Juniperus osteosperma, Pinus monophylla,* exponential distribution

In the Rocky Mountain States, dryland forest types cover almost as much land area as Douglas-fir, ponderosa pine, spruce-fir, and lodgepole pine types combined. These pinyon, juniper, evergreen and deciduous oak, mesquite, and other shrublike species encompass more than 40 percent of the forest land in the Rocky Mountain States—Arizona, New Mexico, Nevada, Utah, Colorado, Wyoming, Idaho, and Montana (Waddell and others 1989). Wood volume for dryland forest (or woodland) inventories has been estimated from equations built from data sampled with a nondestructive technique commonly called "visual segmentation" (Born and Chojnacky 1985). Volume equations constructed from segmentation data seem adequate for inventory and management needs (Chojnacky 1985, 1988a, b; Chojnacky and Ott 1986). However, the segmentation technique has consistently underestimated volume, sometimes as much as 10 percent. Previously, this was thought to be from segments missed in field execution rather than deficiencies in the technique itself.

An interesting reversal in this pattern was found in juniper volume data collected for another purpose near Tooele, UT. These data showed visual segmentation overestimating volume compared to careful destructive volume measurement of the same trees. Closer examination showed consistent volume overestimates for all segment size classes of all trees in the sample. In this case, segmentation data overestimated volume 13 percent or more for all minimum branch sizes (fig. 1), not just certain segment sizes.

Although the Tooele study was not designed to evaluate visual segmentation, the discovery of overestimates instead of expected underestimates caused concern. The overestimates were particularly disturbing because no tree segments were thought to be missed in the Tooele data.

The purpose of this study was to reexamine Born and Chojnacky's (1985) pinyon-juniper destructive volume data to (1) look for bias in visual segmentation technique and (2) suggest possible bias corrections.

[1]Research forester and forester, Forest Survey, Intermountain Research Station, located at the Forestry Sciences Laboratory, Ogden, UT.

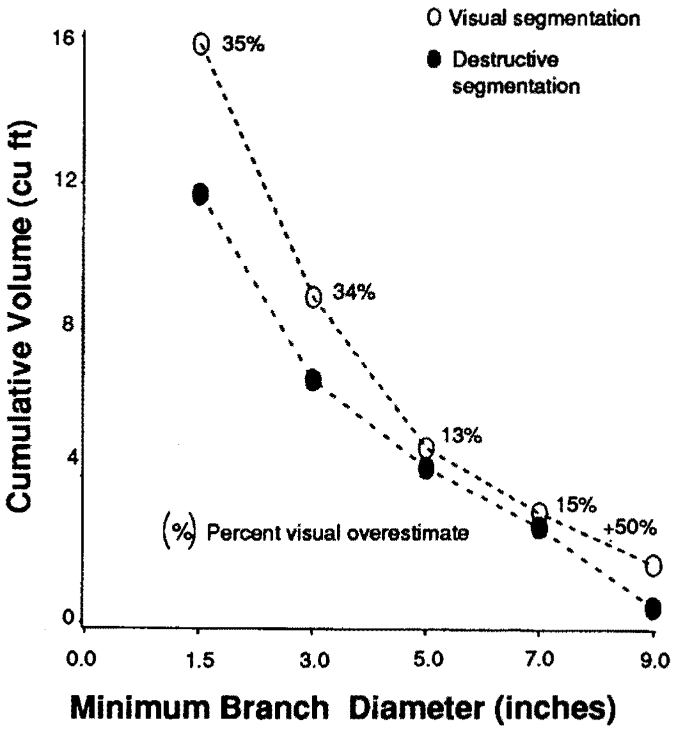

Figure 1—Visual segmentation overestimates volume when compared to destructive segmentation of eight juniper sampled near Tooele, UT. Data are grouped into several minimum-branch-diameter sizes.

Figure 2—Study locations.

DATA

Born and Chojnacky (1985) described the data for this study. To summarize, singleleaf pinyon (*Pinus monophylla* Torr. & Frem.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) were destructively sampled near 61 inventory plots throughout the Great Basin (fig. 2). About 6,500 wood segments—averaging about 3 feet long—were cut from 164 pinyon and 139 juniper. Wood segments included all stem and branch wood larger than 1.5 inches in diameter outside bark. Segment diameters at the endpoints and midpoint were measured. Prior to cutting, two to four independent visual volume estimates were also made on each tree.

ANALYSIS AND RESULTS

Clendenen (1979) first calculated volume from segmentation data by assuming cylindrical segments and then using class midranges for the necessary diameter and length dimensions. Class midranges were defined as the distance midway between class endpoints. For example, segments falling into the 3.0- to 4.99-inch diameter class received 4 inches for diameter, segments falling in the 1.5- to 2.49-foot length class received 2 feet for length, and so forth. Class midranges have since been used in segmentation volume calculations.

From previous work (Born and Chojnacky 1985), success of visual segmentation was assumed to depend on (1) summation of actual segment dimensions equaling the diameter and length class means and (2) correct classification of segment diameter and length classes. These assumptions are examined separately for segment diameters and segment lengths.

Segment Diameters

It would be reasonable to use midrange to estimate the mean of a diameter class only if diameters within that class were symmetrically distributed around the midrange. On the other hand, if segments were distributed in a J-shape with more small-diameter segments than large-diameter segments, class midrange would always overestimate diameter class mean (fig. 3).

Great Basin pinyon-juniper data were used to examine actual segment distribution patterns within diameter classes. Segment diameters, measured midway between segment endpoints from destructively sampled trees, were grouped into 2-inch classes to mimic visual segmentation's diameter classification. Results (table 1) showed segment

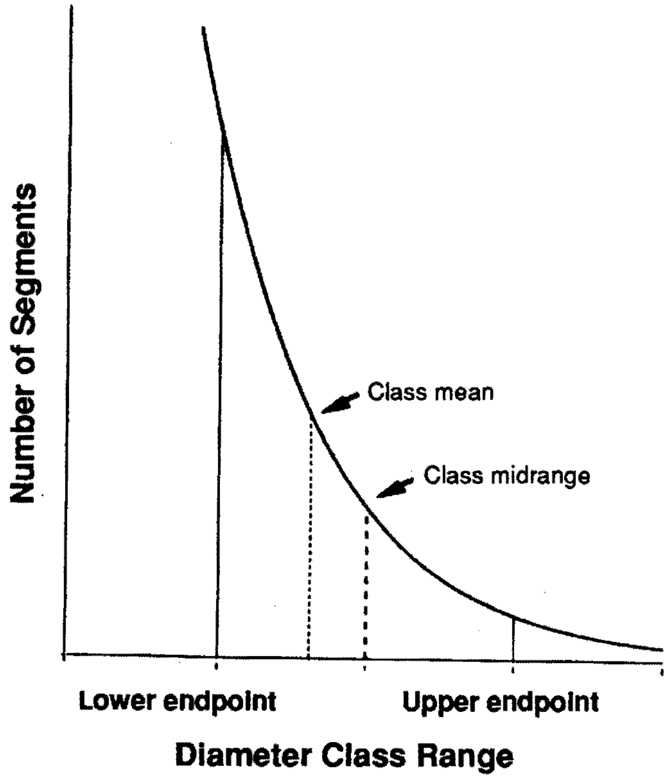

Figure 3—Hypothetical distribution of segment diameters where the class mean is less than the midrange.

Table 1—Comparing diameter class midranges to actual means for Great Basin segment data

Species	Number of segments	Segment diameter class	Class midrange	Mean	Midrange *minus* mean
		------------- *Inches* -----------			
Juniper	1,721	1.5- 2.99	2.25	2.16	0.09
	630	3.0- 4.99	4.00	3.77	.23
	218	5.0- 6.99	6.00	5.78	.22
	92	7.0- 8.99	8.00	7.82	.18
	42	9.0-10.99	10.00	9.70	.30
	21	11.0-12.99	12.00	11.94	.06
	15	13.0-14.99	14.00	13.71	.29
	4	15.0-16.99	16.00	15.45	.55
	1	17.0-18.99	18.00	18.40	–.40
	1	19.0-20.99	20.00	19.00	1.00
Pinyon	2,432	1.5- 2.99	2.25	2.23	0.02
	828	3.0- 4.99	4.00	3.76	.24
	258	5.0- 6.99	6.00	5.81	.19
	124	7.0- 8.99	8.00	7.85	.15
	65	9.0-10.99	10.00	9.65	.35
	36	11.0-12.99	12.00	11.80	.20
	12	13.0-14.99	14.00	13.80	.20
	13	15.0-16.99	16.00	15.97	.03
	7	17.0-18.99	18.00	17.69	.31
	5	19.0-20.99	20.00	20.26	–.26

diameter class means much different from class midranges. Most actual class means were about 0.1 to 0.3 inch smaller than class midranges, suggesting segment diameters are asymmetrically distributed with average value skewed toward the lower class endpoint.

Therefore, volume overestimates should result when using diameter class midranges to compute volume from correctly classified segment data. The Tooele juniper data (fig. 1) supported this finding. On the other hand, this finding was not supported by Great Basin segmentation data where volume underestimation seemed to be the norm. In retrospect, Great Basin visual segmentation data were probably confounded by technique error from missed segments. Also, the midrange diameter for the 1.5- to 3.0-inch class (Born and Chojnacky 1985) was incorrectly assigned 2 inches instead of its actual 2.25 inches. These compensations likely masked some of the overestimation problem in the Great Basin data.

Because segment diameters are not symmetrically distributed about the class midrange, an estimator for diameter class mean depends on distribution of segments within a class. An empirical cumulative frequency distribution of the segment class data resembles an exponential probability density function or J-shaped curve (fig. 4). Comparison of the segment data to randomly generated exponential data in a standardized quantile-to-quantile fashion (Q-Q plot in fig. 4) do not completely support the notion that segment data are exponentially distributed. However, the exponential probability density function is simple, and it appears a reasonable starting point for deriving an alternative to midrange as an estimator for segment diameter class mean.

New Diameter Class Estimator

Consider a mean interval estimator ($\bar{d}$) between a lower (l) and upper (u) endpoint of a segment diameter class. Assuming the segment diameters are exponentially distributed, this estimator is:

$$\bar{d} = \int_l^u x\ (\lambda e^{-\lambda x})\, dx \Big/ \int_l^u \lambda e^{-\lambda x}\, dx \qquad (1)$$

where

$\bar{d}$ = interval mean
l = lower endpoint of segment diameter class
u = upper endpoint of segment diameter class
$\lambda e^{-\lambda x}$ = the exponential probability density function.

After integrating, $\bar{d}$ reduces to:

$$\bar{d} = \frac{1}{\lambda}\left\{\frac{e^{-\lambda u}(-\lambda u - 1) - e^{-\lambda l}(-\lambda l - 1)}{-(e^{-\lambda u} - e^{-\lambda l})}\right\} \qquad (2)$$

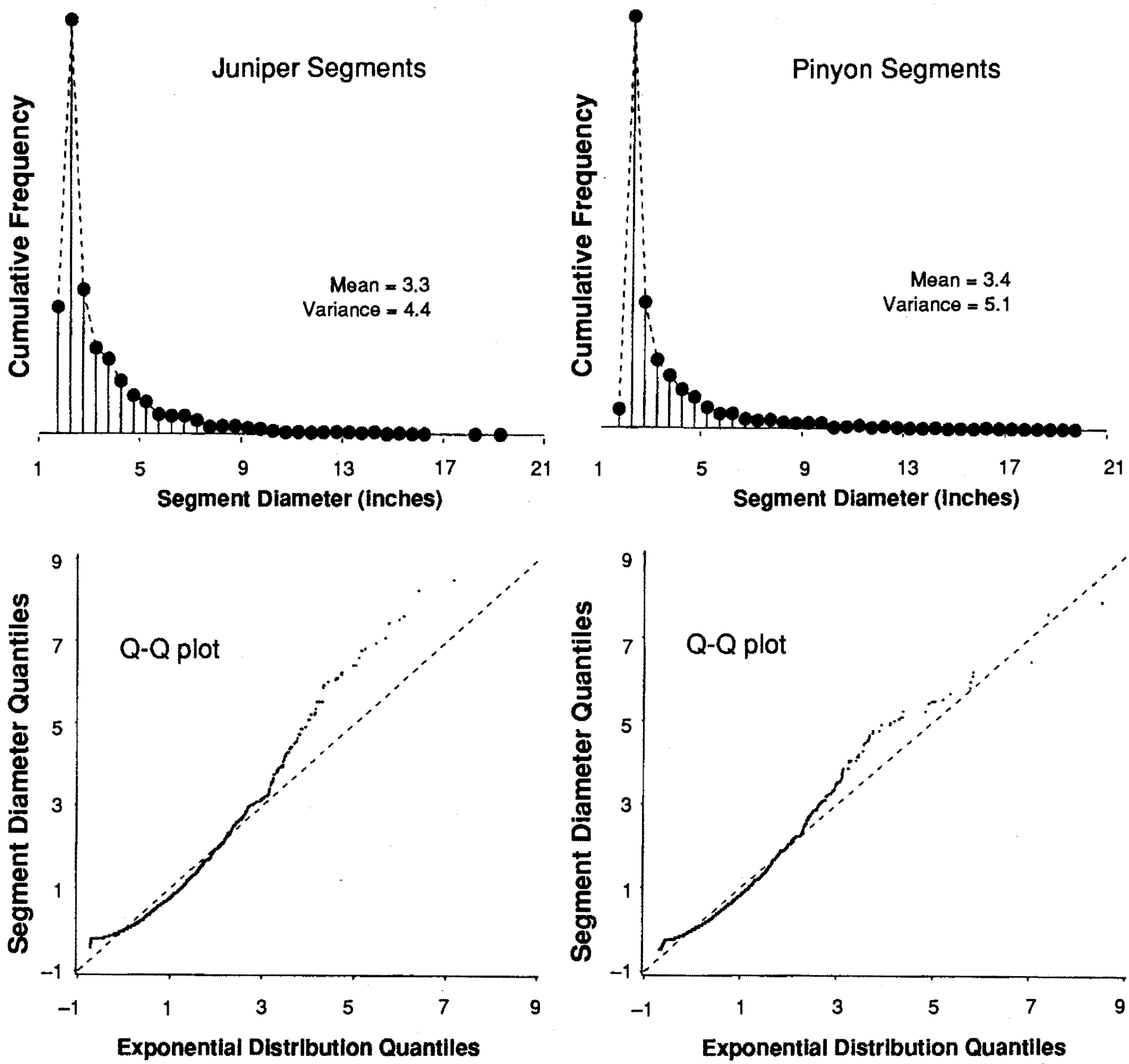

Figure 4—Cumulative frequency of Great Basin segment data (upper) and Q-Q plots comparing the cumulative frequency to randomly generated exponential data. The 45-degree dashed line is the standard for a perfect match between distributions.

Equation 2 can be simplified for a fixed diameter class width ($w = u - l$) by substituting $w + l$ for u:

$$\bar{d} = l + \frac{1}{\lambda} + w\left[\frac{1}{(1 - e^{\lambda w})}\right] \qquad (3)$$

where

λ = parameter from the exponential distribution
w = diameter class interval width or $u - l$.

This form of equation 3 shows $\bar{d}$ is simply the lower diameter class endpoint (l) plus some amount dependent upon the underlying exponential distribution's parameter λ and the segment diameter class width (w).

To apply equation 3 to segmentation data, an estimate of λ is needed. A λ for each species was calculated from equation 2. This was done by selecting an interval from l to u, calculating an arithmetic mean ($\bar{d}$) for that interval, and then solving for λ. After examination of the data, segments with midpoint diameters between 2.1 to 9.9 inches were selected. This range included 1,935 segments for juniper and 2,773 segments for pinyon. It spanned most of the data and avoided an apparent truncation problem found in segments with midpoint diameter 2.0 inches and smaller. The natural distribution of segments with midpoint diameters between 1.5 and 2.0 inches seemed disrupted possibly because of a definition limiting the minimum segment to at least 1 foot in length. Whatever the reason, there was an abrupt dropoff in small diameter segments for the juniper frequency distribution, and the dropoff was even more abrupt for pinyon.

An estimate of λ was determined from equation 2 by numerical iteration using data for the interval selected ($l = 2.1$, $u = 9.9$ for both juniper and pinyon; and $\bar{d} = 3.5846$ for juniper and $\bar{d} = 3.4905$ for pinyon). Results were $\lambda = 0.6523$ for juniper and $\lambda = 0.7027$ for pinyon.

The foregoing analyses of the segment diameter classes do not support using diameter class midrange in segment volume computation. A more appropriate alternative is $\bar{d}$, given in equation 3. Other, more flexible distributions such as the Weibull possibly could be used to derive better segment class mean estimators, but these likely would require difficult parameter estimations and might not result in closed-form solutions. Because the $\bar{d}$ estimates are close to actual segment class means data (in table 1), the improved estimators probably would not be worth while. For all segment classes except the smallest, $\bar{d}$ was within the 95 percent confidence interval of class mean data (table 2). Because there was some concern about missing segment data between 1.5 and 2.0 inches, it was not surprising that $\bar{d}$ fell below the lower 95 percent bound for the smallest segment diameter class.

Segment Lengths

Neither the Tooele nor Great Basin data were amenable to length class frequency distribution analysis such as that done for segment diameters. So it was impossible to examine alternatives to the mid-range estimator used for segment length classification. More elaborate "segment mapping" within trees is needed to mimic visual segmentation's length classification with destructive data. However, a preliminary analysis of this problem using segment lengths for all trees revealed some interesting results.

Segment lengths for all trees combined were summed for destructive data and compared to summed lengths for visual data. Summed lengths for both the destructive and visual data should be similar, if length classification in visual segmentation is a reasonable estimation procedure. In other words, if actual segment length measurements from the destructive data deviate equally above and below the length class midranges, then this data

Table 2—Comparing estimator $\bar{d}$ (eq. 3) to segment diameter class means for Great Basin Data

Species	Number of segments	Segment diameter class	Mean	$\bar{d}$ [2]	Confidence Interval[1] Lower	Confidence Interval[1] Upper	$\bar{d}$ *minus* mean
		-----	-----	*Inches*	-----	-----	-----
Juniper	1,721	1.5 - 2.99	2.16	2.13 *	2.14	2.18	–0.03
	630	3.0 - 4.99	3.77	3.79	3.72	3.81	.02
	218	5.0 - 6.99	5.78	5.79	5.70	5.86	.01
	92	7.0 - 8.99	7.82	7.79	7.69	7.95	–.03
	42	9.0 -10.99	9.70	9.79	9.54	9.86	.09
	21	11.0 -12.99	11.94	11.79	11.64	12.24	–.15
	15	13.0 -14.99	13.71	13.79	13.41	14.00	.08
	4	15.0 -16.99	15.45	15.79	14.87	16.03	.34
Pinyon	2,432	1.5 - 2.99	2.23	2.12 *	2.22	2.24	–0.11
	828	3.0 - 4.99	3.76	3.77	3.72	3.80	.01
	258	5.0 - 6.99	5.81	5.77	5.74	5.88	–.04
	124	7.0 - 8.99	7.85	7.77	7.76	7.95	–.08
	65	9.0 -10.99	9.65	9.77	9.53	9.78	.12
	36	11.0 -12.99	11.80	11.77	11.61	11.99	–.03
	12	13.0 -14.99	13.80	13.77	13.46	14.14	–.03
	13	15.0-16.99	15.97	15.77	15.61	16.33	–.20

[1] 95 percent confidence interval around segment diameter class mean.
[2] $\lambda = 0.6523$ for juniper, $\lambda = 0.7027$ for pinyon.
* $\bar{d}$ not included within 95 percent confidence interval.

summed should approximate data where segments are first classified into midrange classes (as in visual segmentation) and then summed. But neither data source—Great Basin nor Tooele—showed good correspondence between destructive and visual length classification. Great Basin visual data underestimated lengths, and the Tooele visual data mostly overestimated lengths (fig. 5).

Visual segmentation length underestimates for Great Basin data were likely because of missed segments, but this could not be shown with certainty. Overestimates in the Tooele data might be related to a subtle technique bias in classifying segment lengths. Length classes were narrowly defined into 1-foot sections, but actual identification of segments had considerable subjectivity. For example, a visual estimator could divide a 6-foot branch into three 2-foot segments, two 3-foot segments, six 1-foot segments, or some other combination totaling 6 feet.

Because of the subjectivity in segment length classification, a field person is not restricted to classifying a physical branch segment. Instead, the person is allowed to mentally place segment length classes on an actual branch. If the "mental length classes" are consistently below the class midrange or above the class midrange, these differences simply propagate throughout the data. This problem could even occur when segment length definitions are correctly applied. For example, a person could always classify segment lengths between the lower class endpoint and the class midrange—which is procedurally correct—and still end up consistently underestimating volume.

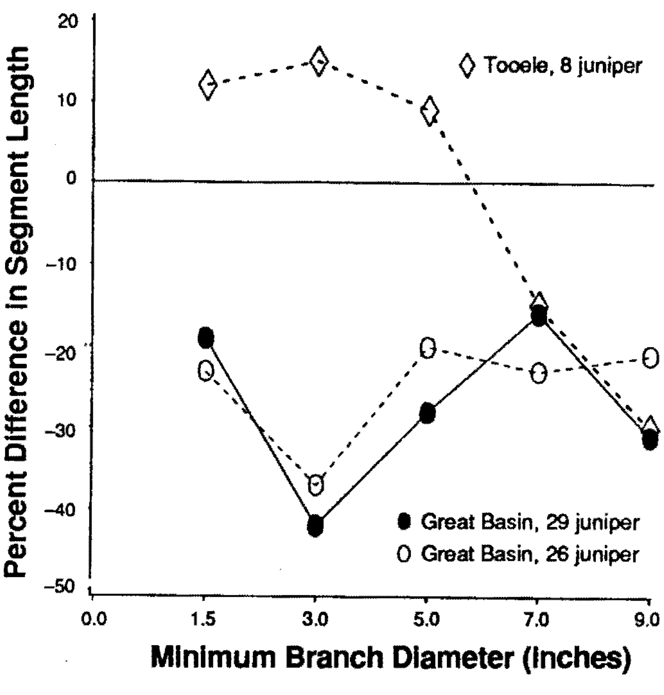

Figure 5—Cumulative segment lengths for visual minus destructive segmentation expressed as percentage of destructive. Numbers of segments in data decreased as minimum branch diameter (mbd) increased; for example, few segments were available for Tooele's 7- and 9-inch mbd juniper.

Perhaps more objectivity could be put into visual segmentation by defining segments to span a fixed distance. For example, the numerous branch forks in most dryland species could be used to define segments as a physical distance from fork to fork. This should give actual segment lengths an equal chance of being smaller or larger than length class midranges. The utility of this approach could be tested by collecting branch-mapped data amenable to computer resampling and frequency distribution analysis.

Another alternative to improve length classification would be to develop bias corrections. Double-sampling techniques could be used to develop bias corrections for each person doing visual segmentation.

CONCLUSIONS

Some visual segmentation data collected near Tooele showed volume overestimates (fig. 1) when underestimates were expected. Reexamination of Great Basin data (Born and Chojnacky 1985) revealed an overestimation bias in the way segment-diameter data have been used to compute segment volumes. A new segment diameter estimator ($\bar{d}$, in eq. 3) was recommended to replace diameter class midrange in volume computations. Using Huber's log formula (Husch and others 1982, p. 101) segment volume would be:

$$S_v = 0.005454\,\bar{d}^{\,2} l_{mr} \tag{4}$$

where

S_v = segment volume (ft³)
$\bar{d}$ = mean (from eq. 3) of segment diameter class (inches)
l_{mr} = midrange of segment length class (ft).

This alternative was derived by assuming segment diameters within pinyon and juniper trees are exponentially distributed (fig. 4). Although $\bar{d}$ lowered volume overestimates 4 to 8 percent in the Tooele data (compare fig. 1 to fig. 6), it was not a total solution.

Analysis of segment length classification showed it was easy for technique bias to affect visual segmentation (fig. 5). However, it seems that the problem might be rectified with another study in which segments are uniquely identified and mapped by "branch order" throughout the tree. If needed, one

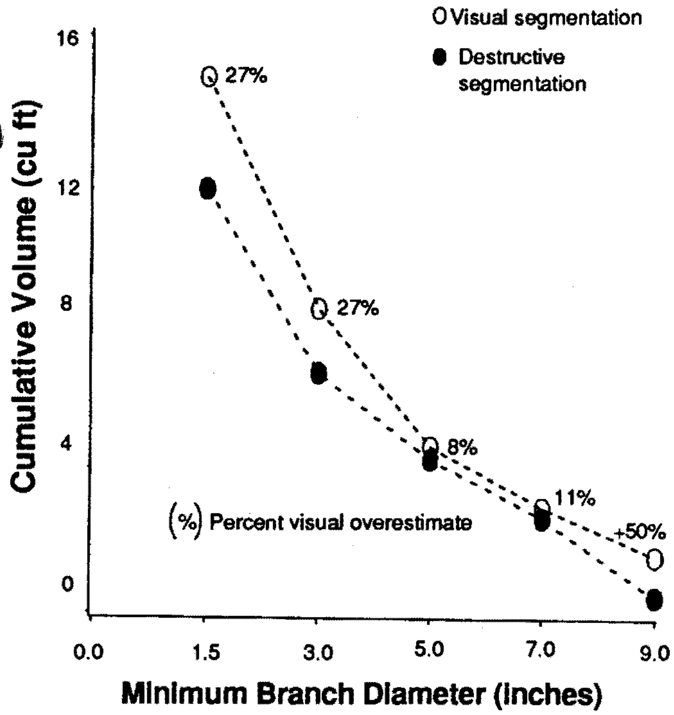

Figure 6—Visual segmentation still overestimates volume—even after application of the $\bar{d}$ estimator in equation 4—when compared to the Tooele destructive data. Compare to figure 1.

could then compare visual segmentation and destructive segmentation data, segment by segment. This would allow testing estimation properties of variable l_{mr} in equation 4. Perhaps an interval mean based on some underlying distribution—as was done for diameter—would be appropriate for segment length estimation.

In the meantime, visual segmentation users should use the segment diameter estimator ($\bar{d}$, in eq. 3) and attempt to classify segment lengths so that actual lengths have equal chance of being above or below the class midrange.

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