ACCURATELY DETERMINING LOG AND BARK VOLUMES OF SAW LOGS USING HIGH-RESOLUTION LASER SCAN DATA

R. Edward Thomas and Neal D. Bennett[1]

Abstract.—Accurately determining the volume of logs and bark is crucial to estimating the total expected value recovery from a log. Knowing the correct size and volume of a log helps to determine which processing method, if any, should be used on a given log. However, applying volume estimation methods consistently can be difficult. Errors in log measurement and oddly shaped logs can make log and residue volume estimates inaccurate. Laser log scanning systems consistently measure the surface points on a log to accuracies of 0.01 inch and finer. Using the measurement data from a laser scanning system and traditional volume equations, or using volume measurements directly from the laser scanning systems, provides highly accurate volume calculations. Such volume measurements are comparable to those obtained using water immersion and displacement methods.

INTRODUCTION

There is much more to a saw log than the lumber that is sawn from it. The remainder, often called residue, is composed of bark removed by a debarker, wood chips produced from grinding the slabs, and sawdust from sawing the lumber. Residue can be measured by cubic volume or weight. There may be as much as 500 pounds of residue for every 1000 board feet of lumber produced (Harkin and Rowe 1971). If the residue is not being used or sold, there is a disposal cost. It is important to grasp the economic value for each saw log that is purchased and to garner maximum utilization of all the components.

Bark has value, be it from selling as landscaping mulch, burning it to heat dry kilns, making charcoal briquettes or carbon filters, or converting it to biomass energy. When logs are purchased, they are priced individually according to size and grade. Various log scales are employed to determine the amount of lumber that can be acquired from each log. The method used when a log is scaled in a log yard excludes the bark content from the purchase price, resulting in it being a free commodity. Every log processed incurs a cost in separating the bark from the wood. Hopefully, the value of the bark exceeds this cost plus the cost of transportation to its end user. Proximity to a market to minimize transportation costs plays an important role in deciding a profitable end use for the bark. Most sawmills have an idea how much bark is produced by how many trucks they fill over a period of time, thus it is volume based or weight based if the trucks are weighed as part of the sales agreement.

Mensurational practices to determine individual log bark volume use equations that assume a log's form is approximate to a geometric form such as a cone, neiloid, or paraboloid. The most commonly used geometric formulas are from Huber and Smalian (Haygreen and Bowyer 1996). These formulas assume saw logs to be approximately the same shape as the frustum of a paraboloid (Fig. 1). The difference between Huber's and Smalian's formulas is Huber's formula assumes the average cross sectional area is located at the middle of the log while Smalian's formula takes the average cross sectional area of the large and small ends of the log.

[1] Research Scientist (RET) and General Engineer (NDB), U.S. Forest Service, Northern Research Station, Forestry Sciences Laboratory, 241 Mercer Springs Road, Princeton, WV 24740. RET is corresponding author: to contact, call 304-431-2324 or email at ethomas@fs.fed.us.

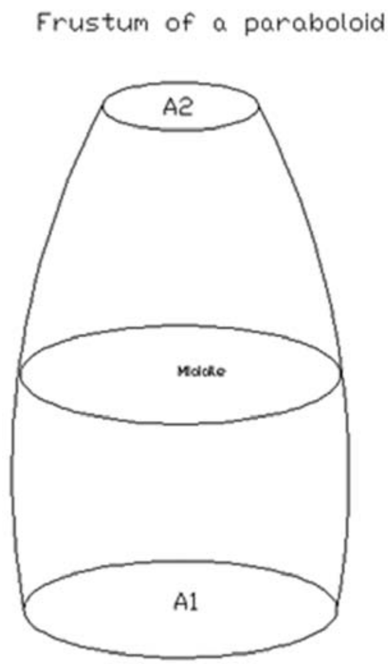

Figure 1.—Frustrum of a paraboloid, the common log shape assumed by the Huber and Smalian volume formulas.

The first step in using these equations to calculate bark volume is to calculate whole log volume outside of the bark. Then bark thickness, either measured or taken from published tables, is subtracted to determine log volume of wood under the bark. Bark volume is the difference between the two results. One other method (Dobie and Wright 1975) to determine bark volume is to assume the ratio of bark volume to whole log volume is equal to the ratio of twice bark thickness to log diameter measured outside of the bark.

To date, perhaps the most accurate examination of log volumes was performed by Martin (1984). Martin compared the log volume estimates using Smalian's, Huber's, and other formulas to actual log volume determined using a xylometer or log immersion tank. The volume of displaced water was then compared to the calculated volume of the different volume equations. Martin found that Huber's formula was the most accurate volume estimator with a mean absolute difference of 0.36 cubic feet.

Currently, the U.S. Forest Service research lab in Princeton, WV is conducting a line of research using a high-resolution laser log scanner to create detailed three-dimensional external log images. From this image data the total volume of a log can be very accurately determined. If bark thickness is known, the value can be subtracted from the raw data points to determine wood volume. Bark volume is the difference between total log volume and total wood volume. Determining bark volume of each log becomes a matter of programming the computer to allow a sawmill operator to accurately track the bark produced from each log as it is processed at the sawmill. Laser systems are currently being used in larger sawmills in the East for the purpose of judging the best opening face of a log or predicting lumber volumes that can be produced. Adding bark and volume calculators would be a benefit to the sawmill operator without any added cost to the laser system, thus giving the sawmill operator the ability to determine the economic value of each log and to garner maximum utilization of all the components

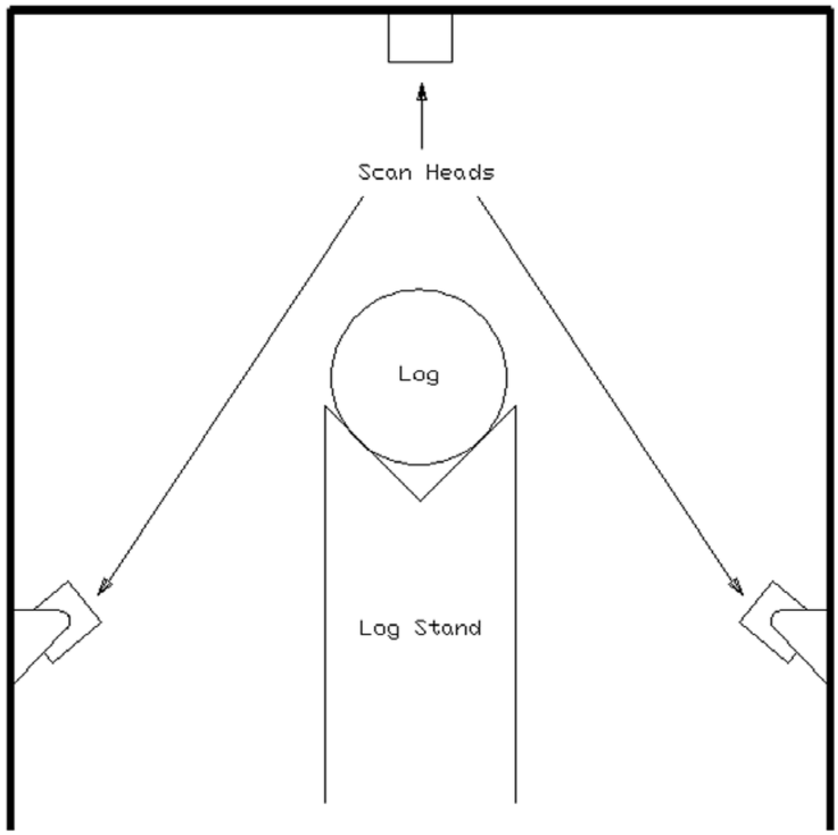

Figure 2.—Schematic diagram of high-resolution log scanner.

METHODS

A high-resolution laser log scanner was constructed for the purpose of scanning hardwood logs to allow automated detection of severe surface defects (Thomas and Thomas 2011). This scanner is composed of three industrial laser scan heads designed for the wood processing industry. The scanners are stationed at 120 degree intervals on a circle with a diameter of approximately 8 feet. This allows the three scanners to collect a complete surface scan of the log. The log is supported in V-stands every 5 feet at the center of the circle of scanners (Fig. 2). The scanner then passes over the log and collects a scan line around the circumference of the log every 1/16 inch. Resolution between points within each scan line varies depending on the size of the log, but is typically around 1/8 inch. All points are measured to the nearest 0.001 inch. A dot-cloud image sample of a scanned log (log 15A) is shown in Figure 3. The two vertical white marks are missing data due to shadowing of the log surface by the V-stands.

Two basic problems with the scanned log data include missing data and outlier data caused by dust, hanging bark, and portions of the V-stands. Outlying data points are removed using a multi-step process. First, the log data is geometrically centered about the z-axis, and the distances of all points to the z-axis are calculated. The mean and standard deviation of point distances to the z-axis are determined, and all points outside the interval mean ±2 standard deviations are marked as outliers. Next, all missing points and points identified as outliers are filled in using an average of a minimum of 100 neighboring points. These procedures remove most outlying data points and create an accurate log depiction for determining log characteristics.

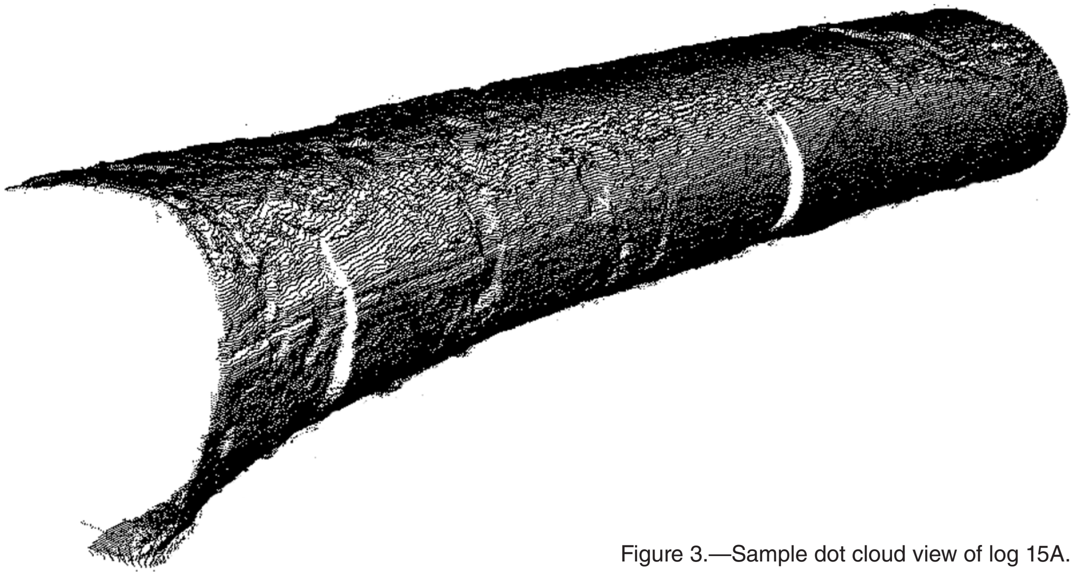

Figure 3.—Sample dot cloud view of log 15A.

Recall that each scan line represents a 1/16-inch thick slice of the log. Volume for a log is determined for each scan-line by calculating the volume of a series of triangles (Fig. 4). Using the center point as one point of a triangle and two adjacent edge points, the area for a portion of the scan is determined. Given the three points A, B, and C, the area of each triangle is calculated using Heron's equation (Page 2009):

$$area = 0.0625 * \sqrt{S * (S - AB) * (S - BC) * (S - CA)}$$

Where:

$$S = \frac{AB + BC + CA}{2}$$

and AB, BC, and CA are the lengths of the triangle's sides. Calculating the area for all triangles yields the total area for a single scan line or slice of the log. Adding the volume of all slices together yields the total volume of the log, bark included.

Recently, a series of yellow-poplar (*Liriodendron tulipifera* L.), red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), and sugar maple (*Acer saccharum* Marsh.) defects were collected and studied to determine the relationships among external log defect indicators and internal defect manifestations (Thomas 2008, Thomas 2009, Thomas 2012, Thomas[2]). In these studies, bark thicknesses and diameter outside bark (DOB) were recorded for each sample. Using this data, a series of linear regression analyses were performed to determine the correlation of DOB to bark thickness for each species (Thomas[3]). The bark thicknesses of red and white oak were estimated using the following equations:

Red oak: $\text{Bark Thickness} = 0.267 + DOB * 0.005$

White Oak: $\text{Bark Thickness} = 0.295 + DOB * 0.009$

[2] Thomas, R.E. [N.d.]. Predicting internal hard maple (*Acer saccharum*) log defect features using surface defect indicator measurements. Manuscript in preparation. On file with authors.

[3] Thomas, R.E.; Bennett, N. [N.d.]. Estimating bark thicknesses of common Appalachian hardwoods. Manuscript in preparation. On file with authors.

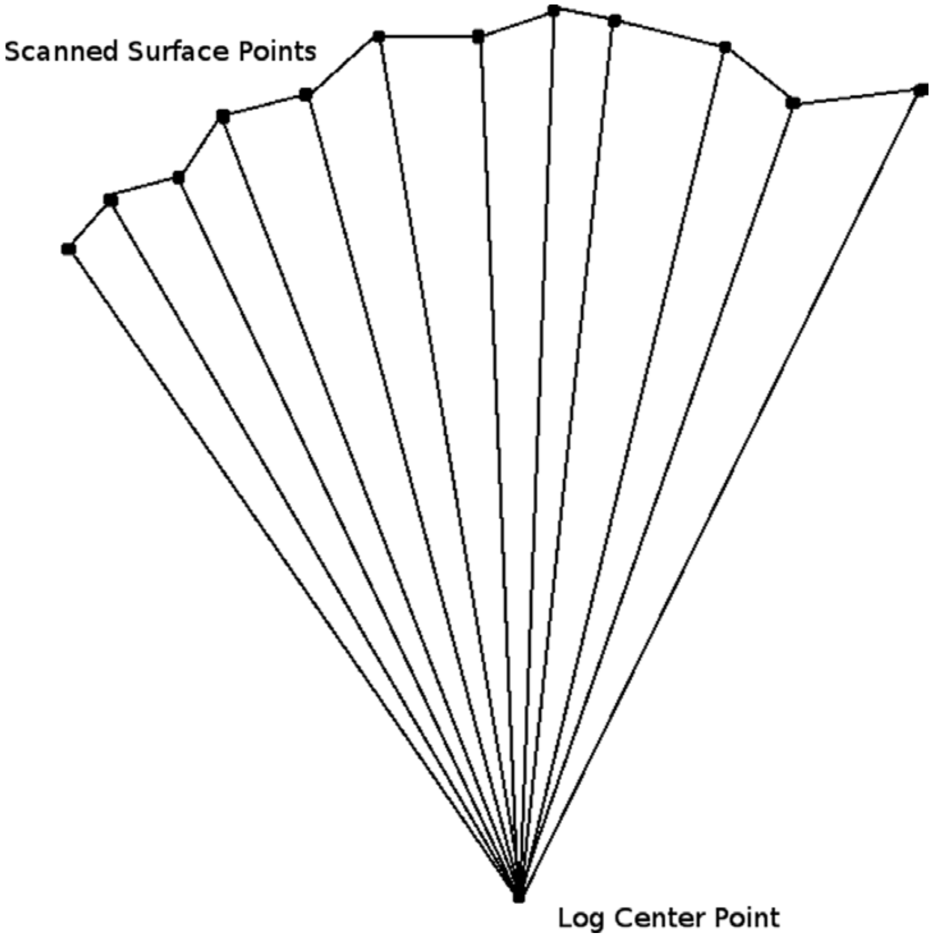

Figure 4.—Calculating the area of a series of triangles to determine log volume.

Using these bark thickness equations, the total bark volume as well as debarked log volume can be determined. To account for DOB changing along the length of the log, bark thicknesses are re-evaluated every foot along the log. To find debarked volume, the surface points are moved toward the center point a distance equivalent to the bark thickness. Debarked log volume is calculated using the modified surface point positions. Bark volume is the difference between total log volume and debarked volume.

Sixty-six white oak trees were randomly selected from three sites in West Virginia from which 249 logs were bucked. In addition, 32 red oak trees were randomly selected from an additional site in West Virginia from which 140 logs were bucked. All logs were scanned with the high-resolution laser scanner. From the total sample population of 369 logs, 20 white oak and 12 red oak logs were randomly selected for this volume study. During the analysis, one white oak log was identified as an outlier using Cook's distance (α = 0.05) (Cook and Weisberg 1982). This log was bucked near a fork and had significant taper from either end to the center and was shaped much like a dog bone. This log was removed from the sample, leaving a total sample size of 31 logs.

Table 1 lists the measurements and characteristics of the sampled logs. All measurements were taken using the laser scanner measurement system. Using the laser scan data, the diameter can be determined at any point along the length of a log. To find the diameter, the geometric center of the

Table 1.—Measurements and characteristics of sample logs

Log	Species	Length	Large end diameter	Small end diameter	Sweep	Eccentricity	Average taper per foot
		---------------------- *Inches*	----------------------				*Inches*
F-12C	White Oak	125.5	18.6	17.5	1.91	1.91	0.11
F-36A	White Oak	174.7	26.8	23.8	2.12	2.12	0.22
F-15B	White Oak	193.8	11.6	10.5	2.71	2.71	0.07
GC-39C	White Oak	100.3	14.2	12.5	0.85	0.85	0.21
GC-20C	White Oak	132.9	14.0	12.3	1.72	1.72	0.17
FA-12B	White Oak	150.6	15.1	13.7	3.83	3.83	0.12
FA-12A	White Oak	143.1	22.9	15.6	1.38	1.38	0.73
FA-6B	White Oak	194.9	19.7	17.3	3.02	3.02	0.15
F-11B	White Oak	198.4	13.2	12.1	0.93	0.93	0.07
GC-31A	White Oak	207.9	16.3	12.9	1.32	1.32	0.21
GC-28A	White Oak	149.3	17.9	13.6	1.84	1.84	0.36
GC-23C	White Oak	107.7	11.4	10.5	1.26	1.26	0.11
GC-38C	White Oak	153.9	11.3	10.2	1.83	1.83	0.09
F-13A	White Oak	198.3	21.6	15.5	1.16	1.16	0.38
F-31C	White Oak	125.8	18.9	17.1	2.14	2.14	0.17
FA-11C	White Oak	132.0	19.1	18.3	1.83	1.83	0.08
FA-7A	White Oak	195.1	24.0	18.6	2.11	2.11	0.34
FA-9A	White Oak	144.3	24.6	19.1	2.68	2.68	0.45
FA-11B	White Oak	119.2	19.5	18.3	1.13	1.13	0.15
27C	Red Oak	187.1	19.5	19.0	0.59	0.59	0.03
32A	Red Oak	126.3	21.5	18.7	1.01	1.01	0.28
8D	Red Oak	125.7	17.8	16.6	1.40	1.40	0.12
28B	Red Oak	125.9	14.2	13.2	0.92	0.92	0.09
9C	Red Oak	156.8	10.2	8.4	3.14	3.14	0.15
29D	Red Oak	126.3	15.8	8.8	2.38	2.38	0.70
11C	Red Oak	158.2	14.4	13.2	2.92	2.92	0.10
15A	Red Oak	152.1	18.8	14.4	2.21	2.21	0.37
15B	Red Oak	104.7	14.1	13.2	0.96	0.96	0.12
17A	Red Oak	126.1	21.2	17.8	1.15	1.15	0.33
17B	Red Oak	126.81	17.682	17.3	0.50	0.50	0.03
17C	Red Oak	126.38	17.192	16.9	0.73	0.73	0.03

scanned log circumference for a single slice of the data is determined. Next, the distances from the center point to all circumference points are calculated and the average distance or radius determined. The diameter is then twice the average radius. Sweep is measured as the maximum distance of a straight line running between both ends of the log. Eccentricity is an index indicating how elliptical or out of round the log is. The eccentricity index is calculated using the following formula (Mason and Hazard 1947):

$$eccentricity = \frac{\sqrt{MajorDiameter^2 - MinorDiameter^2}}{MajorDiameter}$$

For example, a perfectly round log will have an index of 0.00, a log with a major diameter of 16 and a minor diameter of 14 would have an eccentricity index of 0.48. The greater the index value, the greater the degree of eccentricity or ellipticality. Taper per foot is the difference between large and small end diameter outside bark measurements divided by the scaled log length, and the greater the number, the greater the degree of taper present in the log.

Traditionally, log volumes have been estimated using one of several possible methodologies (Haygreen and Bowyer 1996), including Huber's (Eq. 1) and Smalian's (Eq. 2) geometric methods shown below:

$$Volume = L \, x \, A \qquad (1)$$

$$Volume = \left(\frac{A_1 + A_2}{2}\right) x \, L \qquad (2)$$

Where L is log length, A is the cross sectional area at the middle of the log, and A_1 and A_2 are the cross sectional areas of the large and small ends of the log, respectively.

Huber's and Smalian's formulas (Eqs. 1 and 2) find the volume of the log. To find the bark volume, the cross-sectional areas must be calculated twice, once with the bark and once excluding the bark. Subtracting the excluded bark volume from total volume yields bark volume. Another way to determine bark volume is to use Dobie and Wright's formula (Dobie and Wright 1975) listed below (Eq. 3) which assumes the ratio between double bark thickness and log diameter outside bark is the same ratio as bark volume to total log volume.

$$Bark \, Volume = \frac{DOB^2 - DIB^2}{DOB^2} \, x \, 100 \qquad (3)$$

DOB is the diameter measured outside the bark and DIB is diameter measured inside the bark. We used DOB and DIB measurements that were averages of the midpoint and small and large end diameters. To get bark volume from the Dobie and Wright equation (Eq. 3), you still have to determine total log volume by one of the previously described methods.

Using the 2011 R statistical package (R Foundation for Statistical Computing, Vienna, Austria), Anderson-Darling normality tests (α=0.05) (Anderson and Darling 1952) were performed to determine if the variables and volumes involved in this study were normally distributed. The tests revealed that sweep, eccentricity, scanner determined volumes, Smalian calculated volumes, and the Huber calculated volumes were normally distributed. However, log taper and the differences between the scanner volumes and both the Huber and Smalian calculated volumes were not normally distributed.

Paired-t tests were used to compare Huber and Smalian calculated volumes to the scanner determined volumes. As these comparisons involved two tests, the significance level was adjusted for each individual test using the Bonferonni correction (Abdi 2007). An overall significance level of 0.05 was used with an adjusted significance of 0.025 for each individual test.

To determine if sweep, taper, or eccentricity had a significant relationship to the differences between scanner calculated volume and the Huber and Smalian volume estimation methods, a series of simple linear regression analyses were performed. Sweep, taper, and eccentricity were the independent variables and the dependent variable was the volume difference. The correlation for each independent variable was analyzed separately. Cook's distance (Cook and Weisenberg 1982) was used to determine if any individual observation had a high influence over the regression. The residuals from each analyses were tested using the Anderson-Darling normality tests (α=0.05) (Anderson and Darling 1952) to determine if the residuals were normally distributed. In all cases where a log feature had a significant correlation to a volume difference, the residuals had a normal distribution.

Due to the non-normal distributive nature of the bark volumes, Wilcoxon signed rank tests (α = 0.05) were used to compare the results of the different bark volume estimation methods (Wilcoxon 1945). Five tests were performed comparing the scanner determined bark volume to the volumes calculated using the Smalian, Huber, and the Dobie and Wright equation variants. The significance level for the tests was adjusted using the Bonferroni correction (Abdi 2007).

RESULTS AND DISCUSSION

Table 2 lists the log volumes as determined by the scanner data and estimates using Smalian's and Huber's formulas. For whole log volumes, comparing the scanner volumes to Smalian estimated volumes shows a mean difference of -1.02 cubic feet with a maximum observed difference of -7.39 cubic feet. Volume estimates using Huber's formula were closer to the observed scanner volumes with a mean difference of 0.09 cubic feet and a maximum difference of 3.61 cubic feet. The Smalian maximum difference occurred on log F-36A which has a large degree of taper caused by butt swell. The maximum difference with Huber's equation occurred on log FA-7A which also has a large degree of taper. Using the R statistical package, two paired t-tests (α = 0.05) were performed with the significance level for the tests being adjusted using the Bonferroni correction (Abdi 2007). In these tests, the Smalian and Huber estimated volumes were compared independently to the scanner volumes. The tests revealed that the means of the scanner and Smalian volumes were significantly different while those of the Huber were not significantly different from the scanner data.

Overall, results for debarked log volumes followed similar trends as whole log volumes (Table 2). Comparing scanner volumes to Smalian estimated volumes showed a mean difference of -0.94 cubic feet with a maximum observed difference of -7.12 cubic feet. Huber's debarked log volumes also were closer to the scanner volumes with a mean difference of 0.13 cubic feet and a maximum difference of 3.47 cubic feet. As before, the maximum differences for the Smalian and Huber volume methods occurred on the same logs that had the maximum whole log differences. Two paired t-tests (α = 0.05) were performed to compare the Smalian and Huber estimated volumes to the scanner volumes. As before, the significance levels for the tests were adjusted using the Bonferroni correction (Abdi 2007). These tests revealed that the means of the scanner, Smalian, and Huber volumes were significantly different.

To determine what log features, if any, had a significant correlation to the difference between the scanner-based volume methodology and the Huber or Smalian volume estimations (rightmost columns Table 2), three simple linear regression analyses were performed. These analyses tested the relationship of log sweep, eccentricity, and taper to the differences between the scanner-based volumes and the Huber and Smalian volumes. It was found that sweep and eccentricity had no significant correlation to the differences. While Huber's volume error was not significantly correlated to taper, Smalian's volume error was weakly correlated to taper with an R^2 of 0.10. Thus, it appears that in general, Smalian volume estimation equations are slightly less accurate when used with tapered logs.

Table 2.—Volume measurements of sample logs using three different measurement methods

Log	Scanner whole log volume	Scanner debarked log volume	Smalian whole log volume	Smalian debarked log volume	Huber whole log volume	Huber debarked log volume	Scanner vs. Smalian whole log difference	Scanner vs. Huber whole log difference	Scanner vs. Smalian debarked difference	Scanner vs. Huber debarked difference
	Cubic feet									
F-12C	20.3	18.7	18.5	17.0	18.6	17.1	1.72	1.62	1.67	1.58
F-36A	43.6	40.5	50.9	47.6	46.0	42.9	-7.39	-2.49	-7.12	-2.39
F-15B	10.5	9.4	10.8	9.6	10.7	9.5	-0.24	-0.21	-0.17	-0.14
GC-39C	7.4	6.8	8.2	7.4	6.6	5.8	-0.71	0.89	-0.54	0.98
GC-20C	9.2	8.3	10.4	9.4	9.2	8.2	-1.23	-0.03	-1.14	0.00
FA-12B	15.6	14.2	14.3	12.9	14.3	12.9	1.30	1.30	1.35	1.35
FA-12A	18.8	17.2	24.9	23.1	16.9	15.3	-6.05	1.99	-5.81	1.92
FA-6B	31.9	29.4	30.4	28.0	33.0	30.4	1.43	-1.12	1.38	-1.06
F-11B	14.5	13.0	14.5	13.0	15.0	13.5	-0.04	-0.54	-0.02	-0.49
GC-31A	18.8	17.2	20.4	18.5	17.8	16.1	-1.58	0.98	-1.39	1.06
GC-28A	14.6	13.2	17.1	15.6	13.9	12.5	-2.56	0.69	-2.43	0.68
GC-23C	5.8	5.2	5.9	5.2	5.8	5.2	-0.06	-0.01	-0.04	0.01
GC-38C	7.4	6.6	8.1	7.2	7.0	6.1	-0.72	0.44	-0.61	0.49
F-13A	24.8	22.9	31.9	29.4	25.1	22.8	-7.10	-0.27	-6.52	0.05
F-31C	20.3	18.7	18.6	17.0	21.3	19.7	1.69	-1.09	1.64	-1.03
FA-11C	19.6	18.0	21.0	19.3	18.8	17.2	-1.34	0.78	-1.25	0.78
FA-7A	34.5	31.8	40.9	38.0	30.9	28.3	-6.40	3.61	-6.17	3.47
FA-9A	32.2	29.9	31.8	29.5	34.8	32.3	0.39	-2.58	0.38	-2.47
FA-11B	19.6	18.1	19.4	17.8	21.5	19.9	0.20	-1.90	0.20	-1.81
27C	32.4	30.1	31.6	29.2	32.6	30.2	0.83	-0.18	0.85	-0.13
32A	22.8	21.1	23.2	21.6	22.7	21.1	-0.47	0.03	-0.45	0.04
8D	15.3	14.1	16.8	15.5	15.6	14.3	-1.51	-0.29	-1.42	-0.25
28B	10.7	9.7	10.8	9.7	10.7	9.7	-0.05	0.02	-0.03	0.04
9C	6.2	5.4	6.2	5.4	6.6	5.8	-0.05	-0.44	0.03	-0.33
29D	12.3	11.2	9.4	8.4	12.7	11.6	2.92	-0.41	2.79	-0.33
11C	13.1	11.9	13.7	12.4	12.6	11.3	-0.58	0.57	-0.48	0.61
15A	16.6	15.1	19.3	17.8	15.3	13.9	-2.75	1.23	-2.61	1.21
15B	9.2	8.3	8.9	8.0	9.2	8.3	0.30	-0.03	0.31	-0.01
17A	20.2	18.7	22.0	20.4	19.7	18.2	-1.74	0.54	-1.67	0.53
17B	17.1	15.7	17.7	16.3	17.1	15.7	-0.59	-0.04	-0.55	-0.02
17C	17.5	16.1	16.7	15.4	17.9	16.5	0.73	-0.40	0.74	-0.35
Mean							-1.02	0.09	-0.94	0.13
Maximum difference							-0.04	-0.01	-0.02	0.01
Minimum difference							-7.39	3.61	-7.12	3.47

In addition to the bark volume as determined by the scanner, we examined five different approaches to estimating bark volume. Two methods were simply the difference between whole log and debarked volume estimates calculated using the Smalian and Huber formulas. The other three methods used the Dobie and Wright bark estimation formula where bark volume is estimated directly using the scanner data and by using the Smalian and Huber whole log volume estimates.

Table 3 contains the bark volume estimates for these methods. The rightmost column contains the standard deviation of the different bark volume calculation methods for each log. Higher standard deviation values indicate logs that have the greatest volume discrepancies among the different volume estimation methods. Six of seven logs with the six highest standard deviation values (>0.10) were all butt logs. In addition, all seven logs had high degrees of taper (Table 1), indicating that one or more methods were more error prone when estimating the volume characteristics of butt logs, specifically those with taper or butt swell. This observation was consistent given the earlier finding that taper is significantly correlated with whole log volume estimation error. The results indicated that there were no significant differences between the means of the scanner methodology and the Dobie and Wright Huber-based and the Huber methods. The means of all other methods were significantly different from the scanner methodology.

SUMMARY AND CONCLUSION

Whole log and debarked volumes as determined by the scanner were most comparable to the volumes calculated using Huber's formula, with mean differences of 0.09 and 0.13 cubic feet, respectively. These results are similar to those found by Martin (1984), where Huber's formula more accurately estimated volume than Smalian's formula. Recall that Smalian's formula is based on an average of large and small end cross-sectional area, while Huber's formula is based on the midpoint cross-sectional area. Thus, the volume of logs with a large degree of taper, specifically butt logs, will be overestimated using Smalian's formula.

While the mean differences between the Huber and scanner volume methods were acceptably small, one must remember that the diameter and length measurements were from the laser scanning system. The laser scanner measures surface point locations accurate to 0.01 inch. As such, these measurements provide very accurate input data for Huber's formula. Field measurements for estimating volume will not likely be this accurate. All volume equations are dependent on accurate measurements of log diameter and length. Any error in measuring either is magnified when volume is calculated.

Calculating bark volume using the scanner-based methodology yields a solid volume. This removes the normal concerns of particle size and compaction when measuring bark volume. Using weight to measure residue also has problems. The moisture content of the bark varies among logs and from day to day. Similarly, there are specific gravity differences between species. Using the data from the laser scanner provides the most accurate way of determining bark and log volume. In mills where the logs are scanned at the headrig after debarking, it would be trivial, in terms of both cost and effort, to estimate bark thickness based on the log's diameter and calculate total bark volume or weight at a specific moisture content. Even in situations where DOB varied significantly along the log, the scanner-based method described here would still provide accurate bark and log volume estimates.

Table 3.—Bark volumes as calculated from scanner and estimation formulas

Log	Calculated bark thickness	Scanner bark volume	Smalian bark volume	Huber bark volume	Dobie and Wright bark volume using scanner	Dobie and Wright bark volume using Smalians	Dobie and Wright bark volume using Hubers	Mean	Standard deviation
	(*Inches*)	---------- *Cubic feet* ----------							
F-12C	0.383	1.61	1.54	1.55	1.71	1.56	1.55	1.59	0.06
F-36A	0.419	3.45	3.31	3.15	3.05	3.57	3.06	3.26	0.21
F-15B	0.319	1.14	1.20	1.20	1.18	1.21	1.21	1.19	0.03
GC-39C	0.335	0.65	0.80	0.71	0.76	0.83	0.67	0.73	0.07
GC-20C	0.334	0.95	1.03	0.97	0.94	1.06	0.94	0.98	0.05
FA-12B	0.357	1.35	1.37	1.38	1.51	1.38	1.38	1.39	0.06
FA-12A	0.375	1.60	1.84	1.53	1.57	2.07	1.40	1.67	0.24
FA-6B	0.384	2.53	2.46	2.57	2.59	2.48	2.65	2.55	0.07
F-11B	0.337	1.49	1.50	1.53	1.49	1.49	1.55	1.51	0.03
GC-31A	0.347	1.72	1.87	1.75	1.79	1.94	1.70	1.80	0.09
GC-28A	0.354	1.35	1.48	1.34	1.34	1.57	1.27	1.39	0.11
GC-23C	0.322	0.65	0.67	0.67	0.66	0.67	0.67	0.66	0.01
GC-38C	0.314	0.81	0.92	0.85	0.85	0.94	0.81	0.86	0.05
F-13A	0.379	2.07	2.49	2.23	2.08	2.68	2.11	2.28	0.25
F-31C	0.380	1.59	1.53	1.65	1.68	1.54	1.73	1.62	0.08
FA-11C	0.380	1.58	1.67	1.58	1.60	1.71	1.53	1.61	0.07
FA-7A	0.390	2.74	2.89	2.53	2.67	3.16	2.35	2.72	0.28
FA-9A	0.407	2.50	2.29	2.41	2.44	2.41	2.53	2.43	0.08
FA-11B	0.386	1.56	1.55	1.63	1.57	1.55	1.69	1.59	0.06
27C	0.363	2.33	2.34	2.37	2.40	2.34	2.40	2.36	0.03
32A	0.364	1.63	1.65	1.63	1.66	1.69	1.63	1.65	0.02
8D	0.350	1.25	1.34	1.29	1.24	1.36	1.26	1.29	0.05
28B	0.337	1.01	1.03	1.03	1.03	1.03	1.03	1.03	0.01
9C	0.317	0.74	0.81	0.84	0.80	0.80	0.87	0.81	0.04
29D	0.341	1.08	0.93	1.14	1.32	1.01	1.37	1.14	0.17
11C	0.336	1.20	1.30	1.24	1.27	1.32	1.21	1.26	0.05
15A	0.345	1.42	1.55	1.39	1.41	1.65	1.31	1.45	0.12
15B	0.337	0.86	0.85	0.87	0.88	0.85	0.88	0.87	0.01
17A	0.359	1.51	1.58	1.50	1.51	1.64	1.45	1.53	0.07
17B	0.353	1.36	1.40	1.37	1.36	1.41	1.36	1.38	0.02
17C	0.353	1.35	1.35	1.40	1.40	1.34	1.43	1.38	0.04
Mean	0.357	1.52	1.57	1.53	1.54	1.62	1.52		

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