The Presence and Nature of Ellipticity in Appalachian Hardwood Logs

R. Edward Thomas,* John S. Stanovick, and Deborah Conner

The ellipticity of hardwood logs is most often observed and measured from either end of a log. However, due to the nature of hardwood tree growth and bucking practices, the assessment of ellipticity in this manner may not be accurate. Trees grown on hillsides often develop supporting wood that gives the first few feet of the log butt a significant degree of ellipticity, while the rest of the log may be more circular. Good log bucking methods dictate that a log be bucked near a fork or a large knot, creating a higher-valued lower log and a jump cut or a lower-valued upper log. This practice and the additional supporting (buttress) wood below the knot can make the upper end of a log exhibit ellipticity. In this study, 703 hardwood logs from Appalachian forests were scanned using a high-resolution laser scanner, and the ellipticity and the angle of the greater axis was recorded for every foot along each log. Approximately one-third of the logs exhibited moderate to severe eccentricity on the small end. However, most logs (99%) did not exhibit significant ellipticity along the entire length. Furthermore, the mean length of the elliptical zone for all species was 3.3 feet.

Keywords: Appalachian; Hardwoods; Ellipticity; Ovality; Eccentricity

*Contact information: USDA Forest Service, Northern Research Station, 480 Cornbread Ridge Road, Princeton, WV, USA; *Corresponding author: R Edward Thomas <ethomas@fs.fed.us>*

INTRODUCTION

The out-of-roundness of a log is commonly referred to as the ellipticity, ovality, or eccentricity. The ellipticity of a log is defined as the ratio between the greater diameter of the log and the lesser diameter (Fig. 1). Though the impact of ellipticity on hardwood and softwood log recovery has been studied by several researchers (Biging and Wensel 1988; Bond *et al*. 2007; Rappold *et al.* 2007; Todoroki *et al.* 2007), the prevalence of ellipticity in hardwood logs has historically not been a topic of great study.

There are two common methods of quantifying the ellipticity of a log. Equation 1 is a geometric equation that is calculated using the greater (*G*) and lesser (*L*) axis measurements (Fig. 1) (Stewart 1999).

$$ovality = \frac{\sqrt{\frac{G}{2} - \frac{L}{2}}}{\frac{G}{2}} \quad (1)$$

Stewart's equation is 0 when the log outline is a perfect circle and approaches 1 as the degree of ellipticity increases. The second method, Eq. 2, is simply the geometric ratio between the greater and lesser axes where *L* is perpendicular to *G* (Biging and Wensel 1988). Using Eq. 2, the ellipticity ratio is 1 when the log section is perfectly circular and tends to 0 as the degree of ellipticity increases.

$$ovality = \frac{L}{G} \quad (2)$$

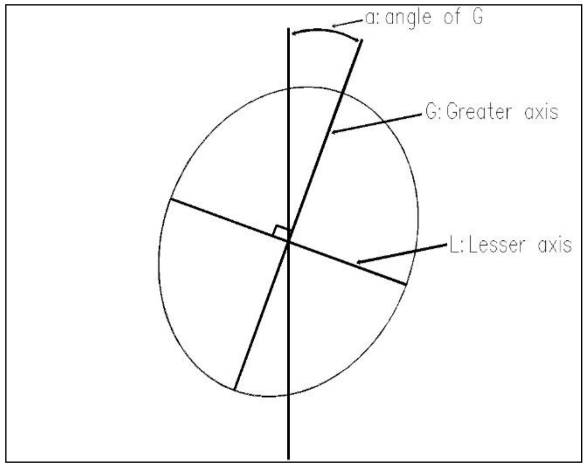

Fig. 1. End view diagram of an elliptical log section showing greater and lesser axes

The most thorough examination of the prevalence and degree of ellipticity in hardwood logs was performed by Bond *et al.* (2007). In their study, they measured the small ends of 1,440 logs from a site in Ohio and a site in West Virginia. They found that approximately 45% of saw logs were non-round and had a small end ellipticity index in excess of 0.4, using Eq. 1. An ellipticity index of this degree indicates a moderately elliptical log and corresponds to a difference in the greater and lesser axis measurements of 1 in to 1.5 in, depending on average log diameter. This corresponds to an ellipticity index of 0.9 or less when using Eq. 2. Logs with a difference of 3 in or more in axis measurements typically have an ellipticity index of 0.8 or less and are regarded as severely elliptical. Bond *et al.* (2007) concentrated their study on the ellipticity of the small ends of the logs. This was done because the ellipticity measurements of the large ends of butt logs were suspect due to butt swell, flare, and uneven cuts.

However, the Bond *et al.* (2007) study did not examine the ellipticity along the length of the log. Thus, it is not known if the ellipticity measurement recorded at the small end of the log is an accurate indication of overall log ellipticity. When hardwood trees are bucked or crosscut to make saw logs, the decision process may affect the assessment of ellipticity at the log ends. Pickens *et al.* (1992) found that two of the most common methods of improving hardwood log quality during bucking are to: 1) place large defects towards the ends of the log to improve clear cutting yields, and 2) create cull or jump-cut sections that contain large defects to improve the quality of adjacent logs. Placing large defects in a cull section could make the ends of adjacent logs appear oval-shaped due to woody buttressing below the defect or fork. Thus, depending upon the type and size of defect and the scope of the flare in the tree that surrounds the defect, the appearance of eccentricity could be introduced.

This study examined the occurrence of ellipticity on saw logs of four different Appalachian hardwood species employing measurements from a high-resolution laser scanning system. This method allowed the determination of the greater and lesser axes measurements and the calculation of ellipticity at any point along the length of a log.

EXPERIMENTAL

Data Collection

Logs from four species, hard maple (*Acer saccharum* l.), red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), and yellow-poplar (*Liriodendron tulipifera* L.) were randomly selected from six sites in central and southern West Virginia. The terrain of the sites ranged from steeply to gently sloping. A total of 226 hard maple logs were bucked from 66 trees collected from two sites. Similarly, a total of 238 white oak logs were bucked from 67 trees collected from two additional sites. For yellow-poplar, 61 logs were bucked from 15 trees collected from a single site. An additional 17 yellow-poplar logs were randomly selected from the landing of a second site, making a total of 78 logs. For red oak, 144 logs were bucked from 34 trees collected from a single site. An additional 17 red oak logs were randomly selected from the landing of a second site, for a total of 161 logs. Table 1 lists the number of logs collected and scanned by species and log grade. The logs were graded to the US Forest Service rules (Rast *et al.* 1973) using the grading module of the RaySaw computer program (Thomas 2013). All logs had a small end diameter of 8-inches or greater. The logs were bucked to standard lengths of 8, 10, 12, 14, or 16 feet.

Table 1. Numbers of Logs by Species and Log Grade

Log Grade	Hard Maple	White Oak	Red Oak	Yellow-Poplar	All Species
Veneer	5	1	5	0	11
Factory 1	50	41	22	15	109
Factory 2	31	70	56	33	231
Factory 3	72	78	62	14	222
Below Grade	68	48	16	16	130
Total	226	238	161	78	703

All logs were imaged and diameters measured (outside bark) using the high-resolution laser scanner developed by the US Forest Service in Princeton, WV (Thomas *et al*. 2008). The high-resolution scanner surrounds the log every 0.0625-inch along the length of the log with a scan line. Each scan line was composed of 300 to 500 data points, depending on the diameter of the log. On average, there was a data point every 0.10 in around the log. Figure 2 shows a data point cloud of a scanned white oak log. The data cloud shown in Fig. 2 is composed of over 1 million data points.

Data Processing

A computer program was developed to process the laser scan data and determine the ellipticity, using Eq. 2, for every foot of log length. In addition, the program determined the angle of the greater axis (Fig. 1) for every foot. Using this methodology, the angle and severity of every elliptical zone were recorded on each log. For moderately and severe elliptical zones, the total length and position of the zone were recorded. An area of a log is regarded as moderately elliptical if the ellipticity index is less than 0.90, and severely elliptical if the index is less than 0.80. For the purposes of this paper, the term "substantially elliptical" refers to moderately elliptical and worse log zones. If two substantially elliptical zones were separated by one foot or less, then the two zones were joined and regarded as a continuous elliptical length. However, the angles of the greater axis were kept as reference points to the direction of the ellipticity for each foot along the length of the elliptical zone.

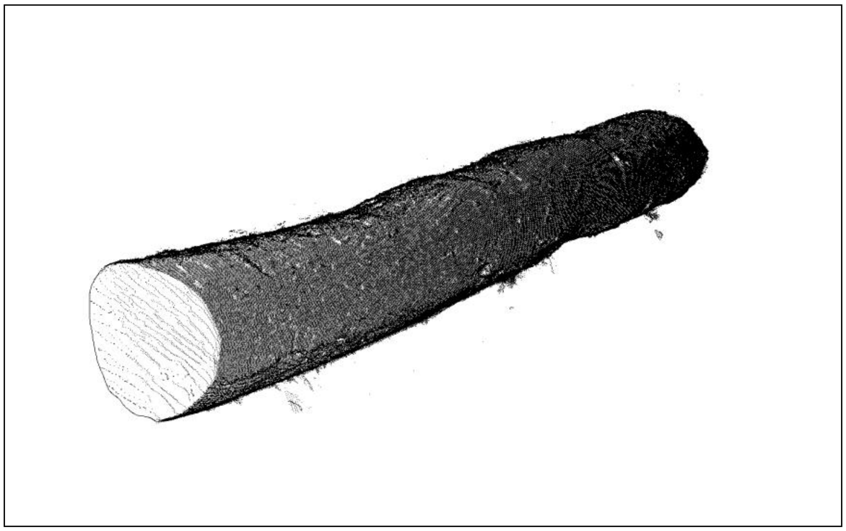

Fig. 2. Dot cloud view of a high-resolution laser scanned white oak log

Statistical methods

A generalized linear mixed model was used via PROC GLIMMIX (SAS 2011) to analyze the nested completely randomized design. The fixed effects were species, log, and the associated interaction. The random effect was foot nested within log. To account for the correlation between foot ellipticity within a log, the Toeplitz covariance structure was used; such an approach assumes that foot measurements closer together within the same log are more correlated than foot measurements further apart. The beta distribution was used, and the logit link function as the response variable ellipticity was a percentage. The Kenward-Rogers option was used as the denominator degrees of freedom method. Residuals were evaluated for the homogeneity of variance assumption. After the first model run, this assumption was not met for species, so the group=species was added as an option in the random statement, and a separate variance estimate was calculated for each species. LSMEANS was used to evaluate the fixed effects. The analyses were limited to the first five logs of each tree to keep LSMEANS estimable. This eliminated 193 observations from the dataset or 2.2 percent of the data, of which 76 percent where white oak observations. The significance level used was alpha less than 0.05.

RESULTS AND DISCUSSION

The average ellipticity indices over every foot for all logs and species by log grade are given in Table 2. Given the limited number of veneer grade logs in this study, it is not wise to discuss their indices in depth. However, for all other grades, the average ellipticity index showed that on the whole, the sample was above the threshold to be considered elliptical. Yellow-poplar logs were the closest to being a perfect circle with an overall mean ellipticity index of 0.929. This corresponds to a 1-inch difference between the greater and lesser axes on a 15 in diameter log. All other species showed approximately the same degree of ellipticity with a mean index ranging from 0.901 to 0.907 (Table 2). This index range corresponds to a difference of 1.4 inch between the greater and lesser axes for the same 15 inch diameter log. With the exception of the veneer grade logs, the lower the grade or quality of the log, the greater the deviation in ellipticity indices.

Overall, the observed ellipticity indices were least variable with yellow-poplar. Examining the ellipticity of all species, it was found that the ellipticity of yellow-poplar was significantly different from the other species and that the ellipticity of the other species was not significantly different from one another. Using Least Square Means, the differences among log position and species were examined. For yellow-poplar and red oak, there no significant differences in ellipticity between adjacent logs. Where there were no significant differences between adjacent hard maple and white oak logs, the ellipticity of the two uppermost logs was significantly different from the two lowest logs for these species.

Table 2. Mean Ellipticity Indices and Sample Standard Deviations by Species and Log Grade

Log Grade	Hard Maple		White Oak		Red Oak		Yellow-Poplar		All Species	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Veneer	0.864	0.099	0.939	0.022	0.924	0.031	-	-	0.898	0.076
Factory 1	0.917	0.047	0.914	0.063	0.907	0.052	0.941	0.038	0.917	0.055
Factory 2	0.922	0.051	0.914	0.063	0.905	0.060	0.932	0.042	0.917	0.057
Factory 3	0.896	0.070	0.902	0.076	0.894	0.069	0.924	0.046	0.899	0.071
Below	0.894	0.069	0.884	0.095	0.900	0.060	0.911	0.050	0.893	0.076
All	0.907	0.063	0.906	0.073	0.901	0.063	0.929	0.044	0.908	0.066

The number of logs that exhibited significant ellipticity is presented in Table 3 along with the position (small-end, large-end, or middle) of the elliptical zone. Table 4 presents this information as a percentage based on the entire species and overall count of significantly elliptical logs. Most ellipticity was found on the small end of the log, which consisted of 222 logs or 31.58% of the entire sample. For most species, with the exception of white oak, the percentage of logs exhibiting ellipticity ranged from 35.9% to 47.2%. This population percentage is similar to the results found by Bond *et al.* (2007), where 45% of all sampled logs had significant small end ellipticity.

Table 3. Number of Logs by Species Exhibiting Significant Ellipticity

	Number of logs exhibiting ellipticity					Total Number of Logs
Species	Both Ends	In Middle	Small End	Large End	Full Length	
Hard Maple	6	46	103	26	5	186
White Oak	8	39	15	19	2	83
Red Oak	3	24	76	12	1	116
Yellow-poplar	0	15	28	1	0	44
All Species	17	124	222	58	8	429

The laser measurement data showed that ellipticity occurred about 18% of the time in the middle of the log and about 8% of the time at the large end of the log (Table 4). However, ellipticity existed on both ends of only 17 logs, or 2.42% of the log sample. Full-length ellipticity was encountered less frequently and was found in only 8 logs or 1.14% of the sample.

It was found that the more severe the ellipticity was, the poorer the performance of the model. Examining the residuals showed that 35% of the greatest residuals were from the ends of the log, with 26% from the small end and 9% from the large end. This indicates that where the log is cut influences the appearance of ellipticity at the log ends.

Table 4. Incidence of Significant Ellipticity by Species, Location, and Overall

	Percentage of Logs Exhibiting Ellipticity				
Species	Both Ends	In Middle	Small End	Large End	Full Length
Hard Maple	2.65%	20.35%	45.58%	11.50%	2.21%
White Oak	3.36%	16.39%	6.30%	7.98%	0.84%
Red Oak	1.86%	14.91%	47.20%	7.45%	0.62%
Yellow-poplar	0.00%	19.23%	35.90%	1.28%	0.00%
All Species	2.42%	17.64%	31.58%	8.25%	1.14%

Given that the full-length ellipticity occurred in approximately 1% of the sample, an obvious question emerges: "How long are elliptical zones?" Table 5 presents the mean lengths of elliptical zones found in the log sample. The mean length of small-end ellipticity ranged from 2.7 ft to 3.6 ft with an overall mean of 3.3 ft. The mean length of all elliptical zones ranged from 3.2 ft to 3.5 ft with an overall mean of 3.4 ft. Table 6 presents counts of logs by length of continuous significant ellipticity. The majority of the elliptical zones, or 267 of 414 (65% of those logs with elliptical zones), on the sample logs were 3 ft or less. If this is expanded to include zones that were 4 ft or less, then this includes 76% of all elliptical zones observed. Elliptical zones measuring 6 ft or longer were found on 17% of logs containing elliptical zones. Zones of 8 ft or longer were less frequently encountered and appeared on only 9 % of those logs containing ellipticity and 5% of the entire sample (Table 6).

Table 5. Mean Lengths of Significant Elliptical Zones Observed in Sample Logs

Species	Mean Length of Elliptical Zone (feet)			
	All Zones	Small End	Large End	In Middle
Hard Maple	3.4	3.3	4.2	3.9
White Oak	3.2	2.7	3.3	4.4
Red Oak	3.5	3.6	3.0	4.0
Yellow-poplar	3.3	3.3	1.0	3.1
All Species	3.4	3.3	3.5	4.1

The high-resolution laser scanner provided the ability to accurately measure and determine ellipticity that was previously not possible. As such, this study is the first to examine ellipticity along the entire length of a log. The rarity of full-length ellipticity discovered in our log sample leads us to believe that there is not sufficient reason to sort or process logs exhibiting ellipticity in any special manner. Further, we believe that common log bucking practices can make logs that are round for most of their length appear elliptical on one or both ends.

Table 6. Population Count of Logs by Length of Continuous Significant Ellipticity

Continuous Length of Significant Ellipticity (ft)	Number of Logs					As a % of All Elliptical Logs	As a Percent of All Logs
	Hard Maple	White Oak	Red Oak	Yellow-poplar	Total		
3 ft or Less	85	92	65	25	267	64.5%	37.98%
4	21	15	12	1	49	11.8%	6.97%
5	11	8	7	2	28	6.8%	3.98%
6	10	8	4	0	22	5.3%	3.13%
7	4	3	4	1	12	2.9%	1.71%
8	5	4	6	3	18	4.3%	2.56%
9	2	1	2	1	6	1.4%	0.85%
10	2	1	1	0	4	1.0%	0.57%
11	1	2	0	1	4	1.0%	0.57%
12	1	0	1	0	2	0.5%	0.28%
13	0	0	0	0	0	0.0%	0.00%
14	0	0	0	0	0	0.0%	0.00%
15	0	0	0	0	0	0.0%	0.00%
16	0	1	1	0	2	0.5%	0.28%
Total					414		
Zones	17	15	11	1	44		

CONCLUSIONS

1. Though ellipticity was observed on the small end of nearly 32% of all logs in the sample (Table 4), the mean length of elliptical zones was only 3.3 ft (Table 5). Further, 76% of all elliptical zones were 4 ft long or shorter.
2. While it is not uncommon to find an elliptical log end, it is relatively rare to find full-length ellipticity, which occurred only on 8 of 703 logs.
3. The occurrence and nature of ellipticity in yellow-poplar sample was significantly different from the other species examined.
4. The ellipticity of uppermost hard maple and white oak logs is significantly different from logs cut from the lower section of the tree.
5. The lengths and occurrence of elliptical zones found in this study would not be expected to have a great impact on the value and volume of lumber sawn from such a sample. The ellipticity study by Bond *et al.* (2007) tends to confirm this observation. In the Bond *et al.* (2007) study, they found "…no differences in … lumber grade recovery relative to the major and minor axes between round and highly elliptical logs…" based on an examination of the small ends of their sample logs.

REFERENCES CITED

Bond, B. H., Wiedenbeck, J. K., and Ese-etame, R. (2007). "The occurrence of log ellipticality and its impact on lumber value and volume recovery," in: *Proceedings, 15th Central Hardwood Forest Conference*, Knoxville, TN, USA, pp. 451-459.

Biging, G. S., and Wensel, L. C. (1988). "The effect of eccentricity on the estimation of

basal area and basal area increment of coniferous trees," *Forest Sci.* 34(3), 621-633.
Pickens, J. B., Lee, A., and Lyon, G. W. (1992). "Optimal bucking of northern hardwoods," *Northern J. of Appl. For.*," 9(4), 149-152.
Rast, E. D., Sonderman, D. L., and Gammon, G. L. (1973). "*A Guide to Hardwood Log Grading. Gen. Tech. Rep NE-1*, USDA Forest Service, Northeastern Forest Experiment Station, Broomall, PA, USA.
Thomas, R. E, Thomas, L. H., and Shaffer, C. A. (2008). "Defect detection on hardwood logs using high-resolution laser scan data," in: *Proceedings of the 15th International Symposium on Nondestructive Testing of Wood*, Duluth, MN, USA, pp. 163-167.
Thomas, R. E. (2013). "RAYSAW: A log sawing simulator for 3D laser-scanned hardwood logs," in: *Proceedings, 18th Central Hardwood Forest Conference,* Morgantown, WV, USA, pp. 325-334.
Todoroki, C. L., Monserud, R. A., and Parry, D. L. (2007). "Lumber volume and value from elliptical western hemlock logs," *Forest Prod. J.* 57(7/8), 76-82.
Rappold, P. M., Bond, B. H., Wiedenbeck, J. K., and Ese-Etame, R. (2007). "Impact of elliptical shaped red oak logs on lumber grade and volume recovery," *Forest Prod. J.* 57(6), 70-73.
SAS Institute Inc. 2011. SAS/STAT® 9.3 User's Guide. Cary, NC: SAS Institute Inc.
Stewart, J. (1999). *Calculus: Early Transcendentals* (4th ed.), Brooks/Cole, Pacific Grove, CA, USA.

Article submitted: April 13, 2017; Peer review completed: August 5, 2017; Revised version received and accepted: September 18, 2017; Published: September 25, 2017.
DOI: 10.15376/biores.12.4.8443-8450