An Acoustics Operations Study for Loblolly Pine (*Pinus taeda*) Standing Saw Timber with Different Thinning History

Charles Essien,[a] Qingzheng Cheng,[a] Brian K. Via,[a,]* Edward F. Loewenstein,[b] and Xiping Wang [c]

There is currently a request from landowners in southeastern USA to provide a nondestructive tool that can differentiate the quality between stands of 25 and 30 years of age subjected to different thinning treatments. A typical site with various thinning regimes was used to vary the wood quality and to determine whether acoustics had the ability to separate for stiffness differences at a given age and local geography. A stand at age 29 with three different spacing (prior thinning) levels was chosen. Three hundred trees (100 per treatment) were randomly selected and acoustically tested for sound velocity using the Time-of-Flight (ToF) method for unthinned, thinned, and twice-thinned stands, respectively. The key finding of the study was that the estimated stiffness of the previously thinned treatments was actually greater than that of the unthinned group, despite having diameters as much as 28% larger. During a forest cruise, knowing that a higher-diameter stand is similar or higher in stiffness could raise the dollar value and harvest priority.

Keywords: Acoustic velocity; Stiffness; Thinning regimes; Loblolly pine

*Contact information: a: Forest Products Development Center, SFWS, Auburn University, 520 Devall Drive, Auburn, AL, 36849 USA; b: School of Forestry & Wildlife Sciences, Auburn University, 602 Duncan Drive, Auburn, AL 36849 USA; c: Forest Products Laboratory, USDA, 1 Gifford Pinchot Drive, Madison, WI 53726 USA; *Corresponding author: bkv0003@auburn.edu*

INTRODUCTION

In 2013, the design values for visually graded southern pine were adjusted in an attempt to reflect the material strength and stiffness of today's market (ALSC 2013). On average, these values dropped, making U.S. southern yellow pine (SYP) lumber less competitive on the international market. The reasons for these lower values were likely the acceleration of growth, coupled with earlier harvest, and perhaps, changes in supply patterns under a cyclic economy (Butler *et al.* 2016). SYP is now harvested 10 to 15 years earlier than in decades past, resulting in a higher juvenile wood core and perhaps lower mean outerwood stiffness properties (Butler *et al.* 2016). As a consequence, the market appears to be in disequilibrium, with sawmills demanding better-quality material while forestry suppliers demand a higher dollar value for the additional growth necessary to reach previous stiffness values. In response, some manufacturing facilities in the state of Alabama have gone as far as placing a specific age limit to ensure a higher-quality log. However, such a technique is inefficient because there may be some stands at a lower age that can meet Southern Pine Inspection Bureau SPIB stiffness values (Butler *et al.* 2016). As such, a measurement system that could partition higher performing stands, regardless of age, could be helpful in the fight to transition the southern U.S. from a quantity-based market to a quantity- and quality-based market.

Improved genetics is part of the solution for lower rotation ages and a higher stiffness. However, most improvements have already been made in other traits, and making improvements for stiffness will invariably lower gains in other traits (Via *et al.* 2004). Additionally, in the event of significant genetic gains, the landowner may just lower the rotation age to improve profits, as has been done in the past (Butler *et al.* 2016). The rotation age needed to meet design values can also vary by up to ± 10 years, depending on various genetic and environmental factors (Biblis *et al.* 1993, 1995). Finally, unless grown outside the U.S. (Moya *et al.* 2013), any genetic gains will take approximately 25 years to be realized in the field from seedling to sawtimber harvest. As such, being able to quantify and inventory the potential stiffness of a southern pine stand through some rapid techniques would perhaps be more efficient and allow for stands to be harvested at the right stiffness, as opposed to some specified age.

Thinning is also sometimes assumed by manufacturers to lower the quality of the wood. This perception is not necessarily true for sawtimber, as the ratio of latewood to earlywood changes drastically from the time of thinning to the time of harvest. After thinning, for the next few years, less latewood is produced, and the stiffness is also reduced because of the lower density and higher microfibril angle of earlywood. Then, the density trend with age typically returns to the regular trajectory (Giroud *et al.* 2015). For example, after thinning, an increase in microfibril angle is only persistent for a few years for Douglas fir, but it then continues to decrease with time (Erickson and Arima 1974). For southern pine, reductions in latewood production are also only prevalent for less than three years after thinning, resulting in only a temporary loss of stiffness (Larson *et al.* 2001).

Acoustics is a well-established method that has been utilized in manufacturing, and more recently, to determine the quality of standing trees and logs (Zhou *et al.* 2013; Gonçalves *et al.* 2013). The use of acoustics for trees is particularly interesting because management decisions about which trees or stands to harvest could be made, resulting in a more efficient use of raw material. Gonçalves *et al.* (2013) demonstrated that a time-of-flight method could be highly correlated to the deflection of a tree stem tested under a cantilever test scheme. As such, the differentiation of stands should be possible with a good sample size per stand. To date, the instrumentation has been commercialized by acoustics manufacturers, but industrial use has not caught on in the United States. Historically, a lack of use of acoustics in the southeastern U.S. may be attributable to the high stiffness associated with southern pine grades (Butler *et al.* 2016). However, with the recent change in U.S. southern pine design values, manufacturers are paying closer attention to the source of the raw material, in hopes of regaining product value through machine stress rated (MSR) grading. Unfortunately, MSR grading is not as useful if the surrounding wood basket is low in stiffness because of a high concentration of young plantation wood. For example, Dahlen *et al.* (2013) found three mills that could not meet stiffness requirements because of high variation in raw materials between mills.

The objective of this study was to investigate whether there was a difference in time-of-flight signals/acoustic stiffness for three stands of similar geography and age but vastly different spacing regimes. Furthermore, the hypothesis (common assumption on the part of manufacturers) was tested that thinning results in lower quality/stiffness later in the growth cycle.

EXPERIMENTAL

Materials and Methods

The study was conducted on a permanent loblolly pine research plot established to investigate the long-term effects of silvicultural operations on growth, tree health, and site productivity. The site is located in Auburn, AL (Fig. 1) with site index of 23 – 30m for 50 year base age. The 20-ha stand was established in 1986 at a density of 1875 seedlings per ha using a mechanized planter. Part of the stand was row-thinned to approximately 1139 seedlings per ha in 1999, and part of the thinned plot was subsequently thinned to 854 seedlings per ha in 2008. The acoustic measurements were performed in 2014.

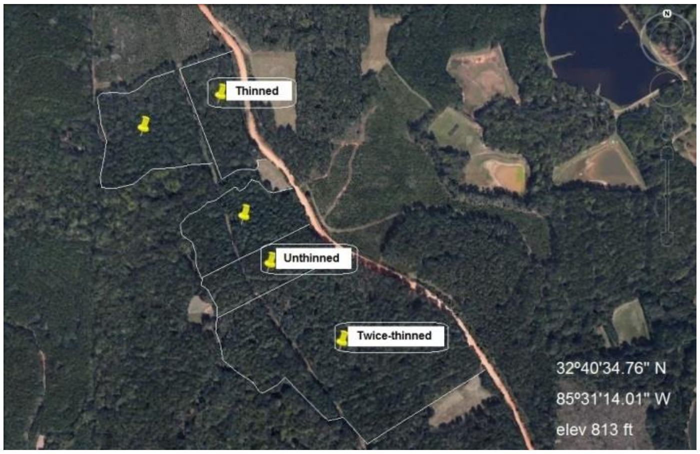

Fig. 1. Location of the plots within the study area

One hundred trees were randomly selected from each of the thinning regimes—unthinned, thinned, and twice-thinned. The three plots were located on the same topography and site conditions. The trees were selected to reflect the true stocking density of each thinning regime, and the trees were clustered. Diameter at breast height (DBH) was measured at 1.3 m from the ground. The selected trees were acoustically tested using the Director ST 300 instrument (Fibre-gen, Christchurch, New Zealand), which relies on the time-of-flight (ToF) principle. The accelerometers (the transmitter and the receiver) were positioned 120 cm apart (60 cm above and below the diameter at breast height) and inserted at a 45° angle to the tree trunk, parallel to each other, on the same side of the tree, and about 2 cm deep into the wood (Wang *et al.* 2001; Mora *et al.* 2009; Isik *et al.* 2011).

Acoustic measurements were taken from both the northern and southern sides of the trees to test aspect effects. Three readings were taken on the same position of each side, for a total of six readings per tree. Data were checked for consistency and normality. The three readings each from the northern and the southern parts of each tree were averaged. The data were then grouped into diameter frequency classes of 5-cm DBH intervals, except for the 20- to 25-cm class, which had a 6-cm DBH interval. A standard mixed model procedure with restricted maximum likelihood method in SAS was used to estimate the means of diameter and velocity of each thinning regimes. The velocities (V) were converted into dynamic modulus of elasticity (MOE) using the equation MoE = $V^2\rho$ and a constant green density (ρ) of 847 kg/m^3 (Forest Products Laboratory 2010). Constant green density was used because according to Raymond *et al.* (2008) it introduces a non-significant marginal error as compared to using green densities of each thinning regimes. Data analyses were performed using SAS (version 9.4; Cary, NC) and Excel Analysis ToolPak (2010; Microsoft, Redmond, WA) at an α level of 5%.

RESULTS AND DISCUSSION

Diameter Distribution

The diameter distribution of the selected trees for each thinning regime is presented in Fig. 2. The DBH frequency classes follow the typical probability density function of the Weibull distribution (Lorimer and Krug 1983). The diameter modal classes for the unthinned, thinned, and twice-thinned plots were 31 to 35 cm, 31 to 35 cm, and 36 to 40 cm, respectively. The mean diameters were 30.3, 34.2, and 38.7 cm for unthinned, thinned, and twice-thinned stands, respectively (Fig. 3). The diameter of the twice-thinned stand was approximately 28% and 13% higher than those of the unthinned and thinned stands, respectively, and the diameter of the thinned stand was approximately 13% higher than that of the unthinned stand. The diameter growth of the twice-thinned stand was significantly higher than those of the thinned and unthinned stands, and the thinned stand was also significantly higher than that of the unthinned stand (Table 1; Fig. 3). This result is in agreement with several previous studies on the effect of thinning treatment on the diameter growth of trees (Tappeiner *et al.* 1982; Wang *et al.* 2000; Carson *et al.* 2014).

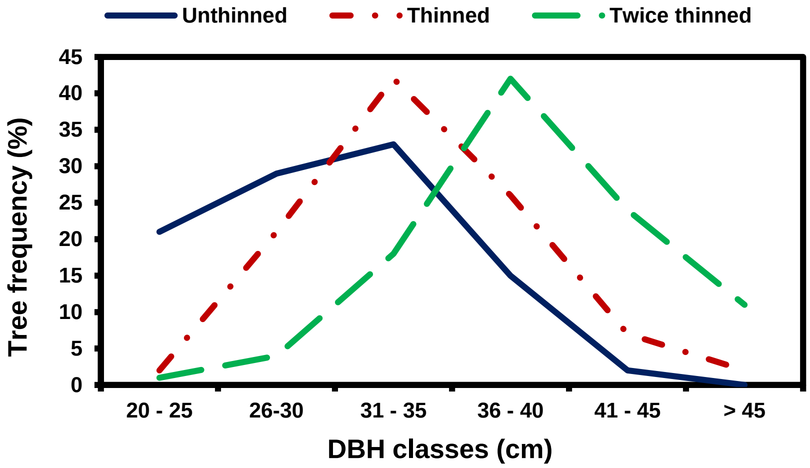

Fig. 2. DBH frequency distribution curves for the various thinning regimes

Generally, tree plantations are established at a higher planting density than required for the final crops and are typically subsequently thinned once or twice during the rotation (Tappeiner *et al.* 1982). The higher level of initial planting density limits excessive branching and allows for full occupancy of the site as soon as possible to maximize productivity and minimize weed competition. Thinning operations provide early income to the landowner to offset the cost of stand establishment, along with promoting diameter growth of the remaining trees. High initial planting density is used to ensure that the crops attain their maximum height growth as early as possible, yet thinning operations are used to optimize the radial growth of the trees. It is clear from the results of this study that thinning operations successfully promote larger diameter growth of trees (Edmond *et al.* 2000).

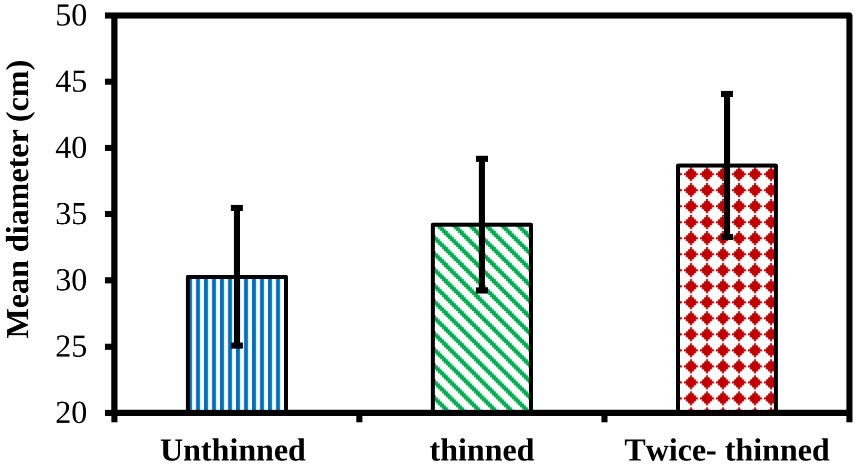

Fig. 3. Mean DBH of the stands of various thinning regimes. Error bars are standard deviation.

Table 1. Analysis of Variance of Diameter the Fixed Effect of the Mixed Model

Treatment	Estimate	Standard error	t-value	Pr> l t l
Unthinned	30.28	0.3667	82.58	<.0001
Thinned	34.22	0.508	7.76	<.0001
Twice thinned	38.67	0.529	101.49	<.0001

Effects of Thinning Treatments

The velocity frequency distribution patterns were different from the diameter frequency distribution (Fig. 4). The thinned stand had a bimodal distribution curve, with 26 to 30 and 41 to 45 cm as the modal classes. The twice-thinned stand had a modal class of 31 to 35 cm. On the other hand, the unthinned portion had a nearly linear velocity increase with diameter (Fig. 4). This indicates that the trees with smaller diameter in each thinning category have lower velocity.

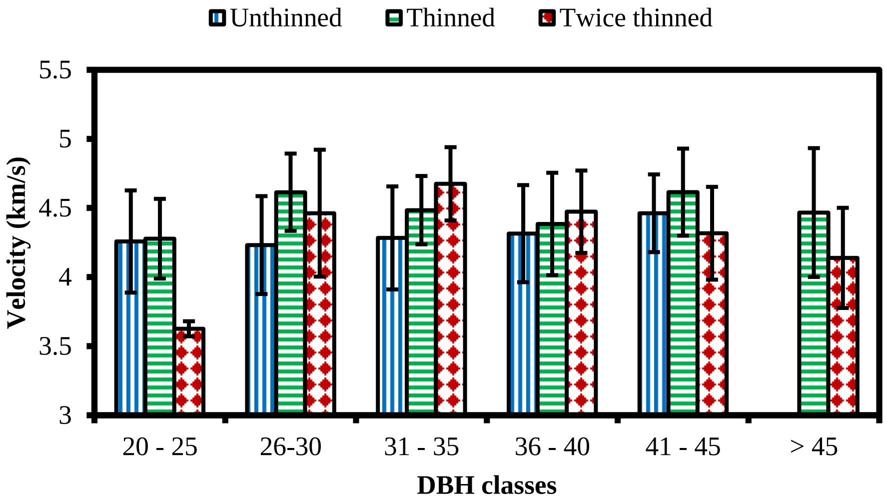

Fig. 4. Mean acoustic velocity of the stands for the various thinning regimes against the diameter classes. The error bars are standard deviation.

The mean acoustic velocity of the thinned stand was 5.6% and 2.3% higher than the unthinned and twice-thinned stands, respectively, while that of the twice-thinned stand was 3.4% higher than that of the unthinned stand (Table 2; Fig. 5). The acoustic velocities of the thinned and twice-thinned stands were significantly higher that of the unthinned stand (Table 2). There was a significant difference between the thinned and twice-thinned stands (p=0.019) (Table 2). Generally, trees from the thinned stands had higher acoustic velocity than those from the unthinned stand (Table 2; Fig. 5). This result confirms previous studies that thinning increased the acoustic velocity of stands in the long term (Carter *et al.* 2005). However, in the short term (between 2 and 3 years), thinning is likely to cause a decrease in velocity because of the reduction in the intra-tree competition for water, light, and nutrients, which subsequently causes increased growth, hence the production of thin-walled fibers and low-density and high- microfibril angle (MFA) wood (Briggs and Smith 1986). Thinning promotes growth and if performed at a later age may lead to the production of a higher volume of mature wood, which generally has higher density and acoustic velocity than an unthinned stand (Carter *et al.* 2005). Bendtsen (1978) asserted that the effect of rapid growth alone on wood properties was minor in comparison with the difference between the properties of juvenile wood and mature wood. Carter *et al.* (2005) explained further that the lower velocity observed in unthinned stands might be due to earlier caesura of the production of latewood resulting from high inter-tree competition. The reduced production of latewood would lead to a lower proportion of latewood in the outerwood of the tree detected by the acoustic tool, hence recording lower acoustic velocity values for the unthinned stand (Fig. 5).

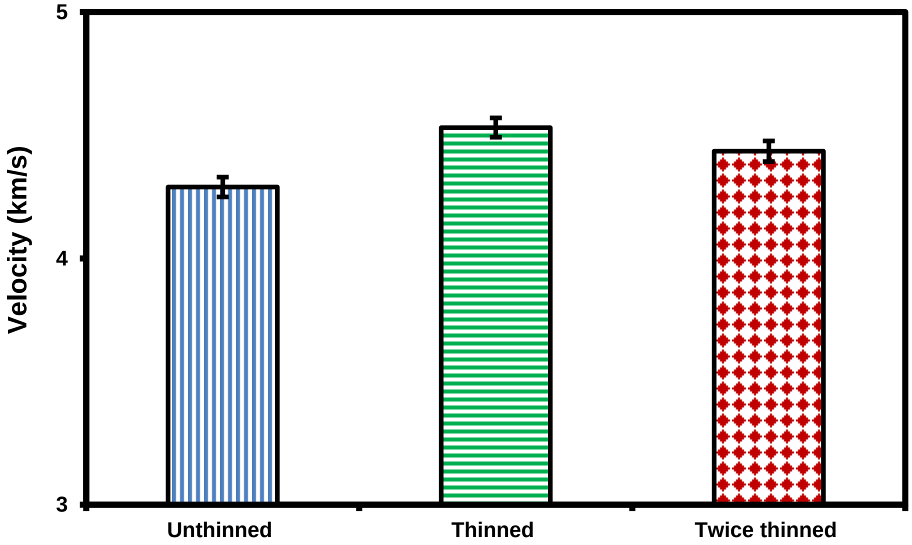

Fig. 5. Mean acoustic velocity of unthinned, thinned and twice thinned stands. Different letters indicate significant at α = 0.05 The error bars are standard deviation

The acoustic velocity of the thinned stand was statistically different from that of the twice-thinned stand (Fig. 5). These results confirm some reports that a heavily-thinned stand had significantly lower acoustic velocity than a moderately thinned one (Wang *et al.* 2000; Raymond *et al.* 2008; Carson *et al.* 2014). This difference may be due to the high proportion of the mature latewood laying the path of flight of the acoustic tool in the thinned stands compared to the twice-thinned. The time–of–flight acoustic tool is sensitive to the outerwood, primarily mature and dense wood, therefore it is probable that the twice-thinned stand might not have enough mature wood within the 2-cm range detected by the acoustic tool as compared to the thinned stand. This result implies that it is plausible for larger diameter trees emanated from stands subjected to the same thinning treatment to exhibit higher acoustic velocity than small diameter trees from the same stand.

Table 2. Analysis of Variance of the Fixed Effect of the Mixed Model

Treatment	Estimate	Standard error	t-value	Pr> I t I
Unthinned	4.29	0.0412	-3.52	0.0005
Thinned	4.53	0.0409	2.35	0.019
Twice thinned	4.43	0.0298	148.98	<.0001

The thinning treatment significantly affected the stiffness of the trees (Table 3). The thinned and twice-thinned stands had significantly higher stiffness than the unthinned stands ($p<0.0001$ and $p=0.007$, respectively). The thinned stand was approximately 11% and 4% higher in stiffness than the unthinned and the twice-thinned stands, respectively, while the twice-thinned stand was approximately 6% higher in stiffness than the unthinned stand. The mean stiffness of the thinned stand was higher than that of the twice-thinned stand. These results conform to those of a study by Wang *et al.* (2001). They found that thinning operations increased dynamic MOE in thinned stands as compared with the non-thinned stands on the same sites. However, as stated earlier, thinning of southern pine in the short term (between 2 and 3 years) has been found to negatively affect the stiffness because of the production of low-density and high-MFA wood (Larson *et al.* 2001). This effect diminished with time because of the production of mature and dense wood years after the thinning operations. Therefore, it is possible that as the tree grows beyond 10 years after the second thinning, the stiffness of the thinned and the twice-thinned stands may converge, thereby rendering the diameter growth gained with the twice-thinned stand advantageous.

Table 3. Descriptive Statistics of Modulus of Elasticity Variation among Tree Stands

	Unthinned	Twice-Thinned	Thinned
Mean	15.86^a	16.85^b	17.56^b
Standard Error	0.21	0.25	0.242
Coefficient of Variation	13.0	14.71	13.76
Sample Variance	4.27	6.14	5.844
Range	9.21	13.20	9.599
Minimum	11.20	9.09	12.38
Maximum	20.41	22.29	21.98
95% Confidence Interval	15.40–16.31	16.39–17.30	17.11 – 18.02
Count	100	100	100
Different letters indicate significance at α=0.05.			

CONCLUSIONS

1. Thinning affects diameter at breast height (DBH) and acoustic velocity. Thinning operations increased the acoustic velocity, stiffness, and DBH of a plot of 29-year-old loblolly pine. The study should be replicated in other parts of southern USA to authenticate this results.
2. Each of the thinning categories exhibited different velocity frequency trajectory with diameter growth. Hence, models developed for predicting wood properties using acoustic velocity could indicate the thinning history of the stand. This information will be very useful in timber bidding and cruising decision making processing.
3. The invention of this acoustic tool provides forest managers an opportunity to plan timber harvesting activities when the trees had fully recovered their velocity trajectory after the thinning operations. This will help landowners to harvest the trees to meet the expected stiffness class of the product manufacturers which will subsequently improve the value of the trees.

ACKNOWLEDGMENTS

The authors appreciate the technical and logistical support from the Silvicultural Laboratory of the School of Forestry and Wildlife Sciences, Auburn University. We are thankful to Dr. Chengfeng Zhou, Gifty Acquah, and Yusuf Celikbag, along with other graduate students in the Forest Products Development Center, for their immense support and constructive criticism during the writing of the manuscript.

REFERENCES CITED

ALSC (2013). American Lumber Standard Committee: Board of Review Board of Review Minutes. American Lumber Standards Committee, Germantown

Bendtsen, A. B. (1978). "Properties of wood from improved and intensively managed trees," *Forest Prod. J.* 28(10), 61-72.

Biblis, E. J., Brinker, R., Carino, H. F., and McKee, C. W. (1993). "Effect of stand age on flexural properties and grade compliance of lumber from loblolly pine plantation timber," *Forest Prod. J.* 43(2), 23-28.

Biblis, E. J., Carino, H., Brinker, R., and McKee, C. W. (1995). "Effect of stand density on flexural properties of lumber from two 35-year-old loblolly pine plantations," *Wood Fiber Sci.* 27(1), 25-33.

Briggs, D. G., and Smith, W. R. (1986). "Effects of silvicultural practices on wood properties - A review," in: *Douglas-fir: Stand Management for the Future*, C. D. Oliver, D. P. Hanley, and J. A. Johnson (eds.), College of Forest Resources, University of Washington, Seattle, WA, pp. 108-117.

Butler, M. A., Dahlen, J., Daniels, R. F., Eberhardt, T. L., and Antony, F. (2016). "Bending strength and stiffness of loblolly pine lumber from intensively managed stands located on the Georgia lower coastal plain," *Eur. J. Wood Wood Prod.* 74(1), 91-100. DOI: 10.1007/s00107-015-0956-3

Carson, S. D., Dave, J., Cown, D. J., Russell, B., McKinley, R. B., and Moore, J. R. (2014). "Effects of site, silviculture and seedlot on wood density and estimated wood stiffness in radiate pine at mid-rotation," *New Zealand J. For. Sci.* 44(1), 26-37.

Carter, P., Briggs, D., Ross, R. J., and Wang, X. (2005). "Acoustic testing to enhance western forest values and meet customer wood quality needs," in: *Productivity of Western Forests: A Forest Products Focus*, C. A. Harrington and S. H. Schoenholtz (eds.), Gen. Tech. Rep. PNW-GTR-642, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 121-129

Dahlen, J., Jones, P. D., Seale, R. D., and Shmulsky, R. (2013). "Mill variation in bending strength and stiffness of in-grade southern pine No. 2 2× 4 lumber," *Wood Sci. Tech.* 47(6), 1153-1165. DOI : 10.1007/s00226-013-0564-5

Edmonds, R. L., Agee, J. K., and Gara, R. I. (2000). *Forest Health and Protection*. McGraw-Hill, New York, NY.

Erickson, H. D., and Arima, T. (1974). "Douglas fir wood quality studies. Part II. Effects of age and stimulated growth on fibril angle and chemical constituents," *Wood Sci. Tech.* 8, 255-65.

Forest Products Laboratory. (2010). *Wood Handbook-Wood as an Engineering Material*, General Technical Report FPL-GTR-190, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.

Giroud, G., Defo, M., Bégin, J., and Ung, C. H. (2015). "Application of near-infrared spectroscopy to determine the juvenile-mature wood transition in black spruce," *Forest Prod. J.* 65(3), 129-138. DOI: 10.13073/FPJ-D-14-00045

Gonçalves, R., Pedroso, C. B., and Massak, M. V. (2013). "Acoustic and bending properties in *Pinus elliottii* beams obtained from trees of different ages," *J. Wood Sci.* 59(2), 127-132. DOI :10.1007/s10086-012-1311-5

Isik, F., Mora, C. R., and Schimleck, L. R. (2011). "Genetic variation in *Pinus taeda* wood properties predicted using non-destructive techniques," *Ann. Forest Sci.* 68, 283-293. DOI: 10.1007/s13595-011-0035-9

Larson, P. R., Kretschmann, D. E., Clark, A. I., and Isebrands, J. G. (2001). *Formation and Properties of Juvenile Wood in Southern Pines: A Synopsis*, General Technical Report FPL-GTR-129, USDA, Forest Service, Forest Products Laboratory, Madison, WI.

Lorimer, G. C., and Krug, A. G. (1983). "Diameter distribution in even – aged stands of shade-tolerant and midtolerant tree species," *American Midland Naturalist* 109(2), 331-345

Mora, C. R., Schimleck, L. R., Isik, F., Mahon Jr., J. M., Clark III, A., and Daniels, R. F. (2009). "Relationship between acoustic variable and different measures of stiffness in standing *Pinus taeda* trees," *Can. J. For. Res.* 39(8), 1421-1429. DOI:10.1139/X09-062

Moya, L., Laguarda, M. F., Cagno, M., Cardoso, A., Gatto, F., and O'Neill, H. (2013). "Physical and mechanical properties of loblolly and slash pine wood from Uruguayan plantations," *Forest Prod. J.* 63(3), 128-137.

Raymond, C. A., Joe, B., Anderson, D. W., and Watt, D. J. (2008). "Effect of thinning on relationships between three measures of wood stiffness in *Pinus radiata*: Standing trees *vs*. short clear specimens," *Can. J. For. Res.* 38(11), 2870-2879. DOI :10.1139/X08-124

Tappeiner, J. C., Bell, J. F., and Brodie, J. D. (1982). "Response of young Douglas fir to 16 years of intensive thinning," Research Bulletin 38: Forest Research Laboratory, Oregon State University, Corvallis, OR.

Via, B. K., Stine, M., Shupe, T. F., So, C. L., and Groom, L. (2004). "Genetic improvement of fiber length and coarseness based on paper product performance and material variability–A review," *IAWA J.* 25(4), 401-414. DOI :10.1163/22941932-90000373

Wang, S. Y., Lin, F. C., Jane, M. C., Lin, C. J., and Hung, C. P. (2000). "Effect of thinning and pruning on DBH and ultrasonic wave velocity in *Taiwania cryptomerioides*," *World Conference on Timber Engineering*, Whistler, BC, Canada. July 31- August 3, 2000.

Wang, X., Ross, R. J., McClellan, M., Barbour, R. J., Erickson, J. R., Forsman, J. W., and McGinnis, G. D. (2001). "Nondestructive evaluation of standing tree with a stress wave method," *Wood Fiber Sci.* 33(4), 522-533

Zhou, Z. R., Zhao, M. C., Wang, Z., Wang, B. J., and Guan, X. (2013). "Acoustic testing and sorting of Chinese poplar logs for structural LVL products," *BioResources* 8(3), 4101-4116. DOI: 10.15376/biores.8.3.4101-4116

Article submitted: April 4, 2016; Peer review completed: June 12, 2016; Revised version received and accepted: July 13, 2016; Published: July 19, 2016.
DOI: 10.15376/biores.11.3.7512-7521