PREHARVEST VENEER QUALITY EVALUATION OF DOUGLAS-FIR STANDS USING TIME-OF-FLIGHT ACOUSTIC TECHNIQUE

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Abstract. Acoustic technology has been successfully used as a nondestructive technique for assessing mechanical properties of various wood products and species as well as in tree selection and breeding based on stiffness. In an ongoing endeavor to optimize merchandizing and enhance timber value recovery, seven second-growth Douglas-fir stands of similar age classes in western Oregon were sampled, totaling 1400 trees and more than 3000 logs. The objectives of this research were to 1) investigate the spatial variability of time-of-flight (TOF) acoustic velocities in standing Douglas-fir trees; 2) develop relationships between average Director ST300® (ST300) TOF acoustic velocities of standing Douglas-fir trees and actual veneer produced; and 3) determine the influence of diameter at breast height (DBH) on TOF sound speeds. Spatial location of the stands in terms of their latitude, longitude, or altitude had no predictive capability regarding their veneer quality. Standing tree TOF acoustic velocity and the actual G1/G2 veneer produced using a stress-wave grade sorter had no significant correlation. Significant differences were found among the three different ST300 tools used along the duration of the study as well as between the two opposite side measurements within trees. DBH correlated poorly with both acoustic velocity and G1/G2 veneer recovery.

Keywords: *Pseudotsuga menziesii,* stiffness, impact-based tool, sound velocity, dynamic modulus of elasticity.

INTRODUCTION

Over the last few decades, as demand for high-quality timber has been rapidly increasing, the availability of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and other softwood old-growth saw logs has been diminishing across North America, and timber resources have gradually shifted to intensively managed young growth stands (Adams et al 2002; Zhang et al 2004). As a result of the higher proportion of juvenile wood, younger stands usually yield lower-quality timber (Gartner 2005) with greater variability in product performance (Carter et al 2005). It has been long recognized that, because world log markets are becoming increasingly competitive and complex, the successful transformation of managed second-growth stands into quality products is crucial for the existence of a robust forest industry (Kellogg 1989; Barbour and Kellogg 1990; Eastin 2005). Good measurements and predictions of both the external and internal properties of the wood in each stem are essential to optimally match logs to markets (Clarke et al 2002). Assessing a forest stand quality (Acuna and Murphy 2006); determining its most appropriate use, time of harvest, and processing technique; and consequently distributing the products to the right location are all important management decisions to achieve reduced costs and increased product values (Murphy et al 2005).

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Wood modulus of elasticity (MOE), also known as stiffness, is one of the most important mechanical properties and is the most frequently used indicator of the ability of wood to resist bending and support loads. MOE has long been recognized as a critical product variable in both solid wood and pulp and paper processing (Eastin 2005) despite its high variability dependent on site, genetics, silviculture, and location within the tree and stand. It is a particularly important parameter in the conversion of raw timber material into veneer and plywood products, requiring high-stiffness wood. With the ever-growing use of engineered wood products such as roof trusses and laminated veneer lumber (LVL), the demand for high-MOE lumber and veneer has increased.

Nondestructive testing (NDT) instruments that are compact, easy to operate, and are based on acoustic principles have been developed for measuring stiffness of logs and standing trees (Dickson et al 2004). Acoustic NDT has been successfully used for evaluation of mechanical properties of various wood products (structural lumber, poles, pulp logs, decay detection, etc) and species as well as in tree selection and breeding based on stiffness (Huang et al 2003). Past research has indicated high correlation between yield of structural grades of lumber and acoustic velocity of standing trees (Wang et al 2001; Lindstrom et al 2002; Grabianowski et al 2006; Lasserre et al 2007; Wang et al 2007a) and processed logs (Ross et al 1997; Joe et al 2004; Waghorn et al 2007; Wang et al 2007b; Amishev and Murphy, in review). The most widely implemented acoustic techniques among industry and researchers are "time of flight" (TOF) for standing trees and "resonance-based" for logs (Lindstrom et al 2002). Originally intended for decay detection in trees, TOF is currently the most popular method for directly measuring stiffness on standing trees (Andrews 2002) with the caveat that it measures acoustic velocity only in the outerwood portion between the inserted probes in the lower part of the tree (Wagner et al 2003).

To date, very little research has investigated the correlation between stress-wave acoustic velocities in raw timber and those in veneer produced from that timber, especially for Douglas-fir. Rippy et al (2000) found moderate correlations between acoustic speeds in Douglas-fir logs and those in veneer produced from those logs; Amishev and Murphy (in review) found strong correlations between in-forest acoustic measurements on Douglas-fir logs and the actual veneer recovered from those logs based on an in-line commercialized Metriguard® stress-wave grade sorter (Metriguard Inc, Pullman, WA). The authors of this article are aware of ongoing research efforts by the University of Washington Stand Management Cooperative (Newsletters SMC 2008) to investigate the relationship between stress-wave velocities in standing Douglas-fir trees and acoustic speeds in veneer produced from those trees (84 trees, producing 186 wood logs and more than 5000 veneer sheets). At the time of preparing this article, however, no results were available and no other published research was found with the exception of Wagner et al (1998 cited in Wagner et al 2003), who reported a low coefficient of determination ($R^2 = 0.14$) between standing Douglas-fir trees and the produced veneer.

The objectives of this study were to 1) investigate the spatial variability (within stands and between stands) of TOF acoustic velocities in standing Douglas-fir trees; 2) develop relationships between average TOF acoustic velocities of standing Douglas-fir trees measured using the Director ST300® (Fiber-gen Inc, Christchurch, New Zealand) tool and actual veneer produced; and 3) determine the influence of diameter at breast height (DBH) on TOF sound speeds over a range of sites in western Oregon.

MATERIALS AND METHODS

Study Sites

In Summer 2006, six Roseburg Forest Products Company (RFP), Roseburg, OR stands, located in the coastal range of Oregon (A, near Bellfountain; D and E, near Elkton; and F, near Lorane) and cascade range (B, near Sutherlin; and

C, near Tiller) were used as part of two studies evaluating novel technologies for in-forest measurement of wood properties. In summer 2007, a seventh stand (G, near Corvallis), located within the Oregon State University McDonald–Dunn College Forest, was also harvested as part of these studies. All sites were second-growth Douglas-fir stands of similar age class (50–70 yr) chosen to cover a range of elevations and tree sizes (Table 1). Site G had been commercially thinned on three occasions. Sites A to F had no commercial thinning but may have received a precommercial thinning. Two hundred trees from each stand were sampled, totaling 1400 trees converted into more than 3000 logs. Only veneer-grade log lengths were cut (5.5, 8.2, and 10.7 m); no sawlogs or pulp logs were produced. Before felling, each tree was numbered for unique identification and DBH was measured and recorded. On a subsample of approximately 100 (varying because of either measuring additional nonselected trees or unavailability of a working TOF tool) randomly selected trees, acoustic velocity of the standing trees was measured using the ST300.

After felling, measurements included: total tree length (if broken, the tree length was measured to the point of breakage), merchantable length, largest branch diameter on each 6.1-m segment of the tree, acoustic velocity of the whole stem with and without the branches (using the Director HM200® tool), and acoustic velocity of each log from the stem. Approximately 100-mm-thick disks at different heights from the tree were collected for green density measurements from a subsample (40 trees per stand) of the trees, totaling more than 800 disks.

After the in-forest measurements on the logs were completed, the logs were transported to a veneer mill, debarked, cut into 2.4-m bolts, kiln-heated, shape-scanned, and peeled into veneer sheets. The sheets were then scanned for defects and moisture, sorted into moisture classes, dried, and then sorted into several veneer grades (G1, G2, G3, AB, C+, C, D, X, and XX) based on in-line acoustic measurement of wood stiffness using the Metriguard® grade sorter. Percentage veneer recovery in all grades was calculated.

Acoustic Velocity Measurement Tools

The acoustic velocity of the standing trees was measured using the ST300, which was specifically designed for measuring TOF acoustic velocity in standing trees (Wang et al 2004). The system and working protocol that were followed in this research are described in detail by Wang et al (2007a). Measurements were taken on two faces of each tree and multiple readings (at least three) were taken in each hitting position to get a consistent "averaged" measurement. A total of three ST300 tools were used in the duration of the study. Tool 1 (borrowed from Forest Products Laboratory, Madison, WI) was used to measure all trees in sites A, B, and C and some trees at sites D and E. Partly through sites D and E, Tool 1's rubber cover fell off making it unusable. As a result of time and logistics constraints involving several entities and project tasks, sending the instrument for repair and waiting for its return was not a feasible option. Hence, a new factory-upgraded version of this instrument (Tool 2) was borrowed from RFP to finish off sites D and E and to measure all the trees in site

Table 1. *Characteristics of the seven study sites.*

Site	Elevation of the site (m)	Stand age (yr)	DBH range of trees selected (cm)[a]	Site location latitude/longitude
A	180	62	19.3–96.8 (52.2)	44°24.04′N/123°23.24′W
B	900	66	16.5–69.6 (36.3)	43°22.58′N/123°03.54′W
C	1040	56	17.5–79.0 (50.7)	42°58.56′N/122°48.52′W
D	220	54	14.2–66.8 (39.5)	43°40.09′N/123°43.19′W
E	120	51	15.5–59.4 (32.0)	43°40.16′N/123°44.58′W
F	290	53	16.3–77.2 (38.9)	43°48.40′N/123°18.34′W
G	280	72	15.0–78.5 (41.6)	44°42.55′N/123°19.58′W

[a] Average DBH in parentheses.
DBH = diameter at breast height.

F. After these sites were finished, the instrument was returned to RFP. The next year, yet a newer factory-upgraded version of the tool (Tool 3) was borrowed from RFP for measuring all trees in site G because they had sent their old one (Tool 2) to the manufacturing company for upgrading.

Wang et al (2007a) also describe the resonance-based acoustic tool (HM200) used to measure longitudinal wave velocity in the logs. They point out that the latter method is a well-established NDT technique "for measuring long, slender wood members." Results, based on log measurements with the HM200 in stands A to G, are presented in a separate paper (Amishev and Murphy, in review).

Data Analysis

Statistical analyses of the data were undertaken following either a simple linear least squares regression analysis or a stepwise multiple regression methodology described by Ramsey and Shafer (2002). They included the following steps: graphical analysis of the data, examination of the correlation matrix, fitting of the linear model, exploration of the residuals, significance test of the variables, and improvement of the final regression model. Mean separations were examined using Fisher's least significant difference method. Both SAS® 9.1 statistical software (SAS Institute Inc 2004) and the Data Analysis Tool Pak of MS Excel (Microsoft, Redmond, WA) were used for the analysis, and a p value of 0.05 was used as the threshold for determining significance of explanatory variables.

RESULTS AND DISCUSSION

Stand F had the largest number of trees sampled (105) with the ST300 tool, whereas only 90 trees were sampled in stand D because of temporary unavailability of a TOF acoustic tool. Stand A produced the largest number of logs (292), whereas stand B yielded the least (190). The average log length was 9.2 m ranging from 8.6 m for site F to 9.4 m in sites B and G. ST300 acoustic velocity averaged 4.36 km/s for all 698 trees and ranged from 3.16 to 6.26 km/s (Table 2). The variation and distributions of the ST300 acoustic velocities and the log lengths across all sites are shown in Figs 1 and 2, respectively. The ST300 acoustic velocity data were approximately normally distributed around the mean for each stand (Fig 1).

Components of variations in ST300 acoustic velocity (Table 3) indicate that the major source of variation was that between the different stands, contributing more than 43% of the total variation. Variation between trees totaled 31%, whereas variation between the two sides within trees contributed less than 14%. These statistics are similar to what Toulmin and Raymond (2007) reported for components of variance in acoustic velocity measurements in radiata pine stands using the TreeTap TOF tool. Although not recorded, substantial variability was observed from hit to hit within each side of a tree;

Table 2. *Stem and log summary statistics for the seven study sites.*

Study sites	Trees sampled	Log count	Log length	ST300 acoustic velocity		
	Total no.	Total no.	(average m)	Average	Minimum	Maximum
				(km/s)		
A	101	292	9.3	4.15	3.25	4.75
B	102	190	9.4	4.15	3.28	4.83
C	100	225	9.0	3.99	3.16	4.67
D	90	200	9.3	4.25	3.57	5.34
E	100	194	9.3	4.63	3.56	6.26
F	105	231	8.6	4.60	3.78	5.54
G	100	192	9.4	4.78	3.38	5.68
Overall	698	1524	9.2	4.36	3.16	6.26

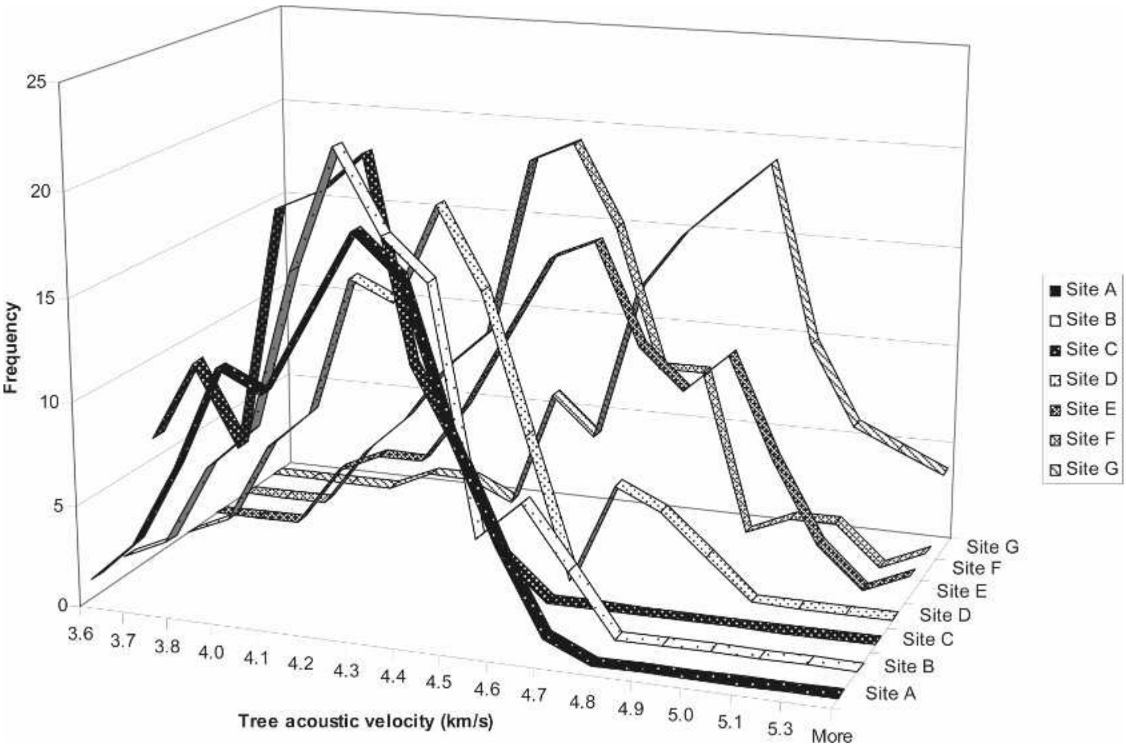

Figure 1. Distribution of the ST300 tree acoustic velocities across the seven study sites.

Mahon et al (in review) showed that variation from hit to hit using the "same-face method" contributed almost as much as the between tree variation in standing tree acoustic velocities. They also suggested that using the "opposite-face method" would likely reduce this variation by more than 60% using the FAKOPP Tree-Sonic microsecond timer device (Fakopp Enterprises, Agfalva, Hungary).

Investigating the spatial variability of the standing tree sound velocity revealed that site C had the lowest ST300 acoustic velocity, and site G was found to be significantly higher than all the other stands based on Fisher's least significant difference (LSD) method (Fig 3). The average sound velocities for site E and site F were not significantly different and the same was true for sites A and B. No significant difference was found between sites in the coastal and those in the cascade ranges of western Oregon. No significant trend was observed in terms of geographic spatial location of the sites (latitudinal, longitudinal, or altitudinal).

The quantity and the quality of the produced veneer were not the same among the different sites (Fig 4). Although the overall G1 and G2 (the highest quality grades) veneer grade recovery percentage for sites A, B, D, and E was about the same (approximately 50%), the other three sites (C, F, and G) were considerably lower (32, 37, and 37%, respectively). No significant relationship was observed between G1/G2 veneer recovery and the spatial location of the sites. This highlights the variation in internal wood properties between stands and emphasizes the need for preharvest stand quality information to make informed management decisions.

Investigating the relationship between stand average ST300 acoustic velocity and actual G1/G2 veneer recovery percentage yielded a nonsignificant regression model with no correlation ($R^2 = 0.03$) between them. This result suggests

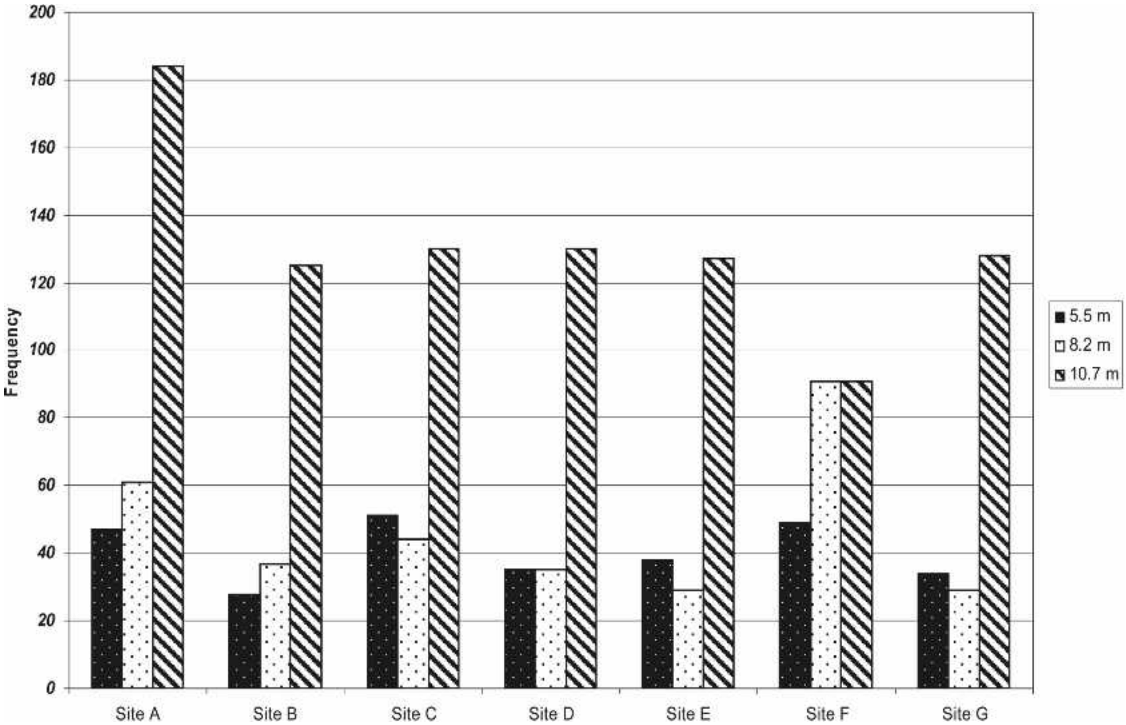

Figure 2. Distribution of the veneer log lengths produced across the seven study sites.

Table 3. *Components of variation for differences between stands, between trees, and between sides of a tree and their percentage contribution to the total variation.*

	Variance (σ^2) components				
	Between			Random	
	Stands	Trees	Sides	error	Total
Variance	0.090	0.065	0.029	0.024	0.208
Percentage of total	43.2	31.2	13.9	11.8	100

that stand average acoustic velocities for Douglas-fir measured by the TOF method using the ST300 may be of limited value in efforts to identify stand quality in terms of veneer stiffness parameters before harvest. This is in agreement with the findings of Wagner et al (1998, cited in Wagner et al 2003), who reported a low coefficient of determination (R^2 = 0.14) between standing Douglas-fir trees and the produced veneer. When correlating standing tree stress wave velocity and lumber cut from logs in radiata pine, Matheson et al (2002) found mixed results, reporting correlations of R^2 = 0.33 (control seedlot) and R^2 = 0.01 (orchard lot). Joe et al (2004) also reported moderate relationships between *Eucalyptus dunni* standing tree acoustics and machine-graded MOE (R^2 = 0.40 to 0.44). In a more recent study, Grabianowski et al (2006) reported that standing tree acoustic velocities correlated well with lumber cut both adjacent to the bark and corewood with R^2 values of 0.89 and 0.74, respectively. Wang et al (2007a) suggested that the acoustic velocity of standing trees measured by the TOF method may be used with confidence to derive equivalent log acoustic velocity (and corresponding lumber stiffness), reporting coefficients of determination ranging from 0.71 to 0.93 for five conifer species. Our findings indicate that this might not be true for Douglas-fir with a coefficient of determination R^2 value of 0.25 between sound velocities of 698 standing trees measured by the TOF method (ST300) and the corresponding speeds in the butt logs measured by the resonance-based method (HM200), which, in turn,

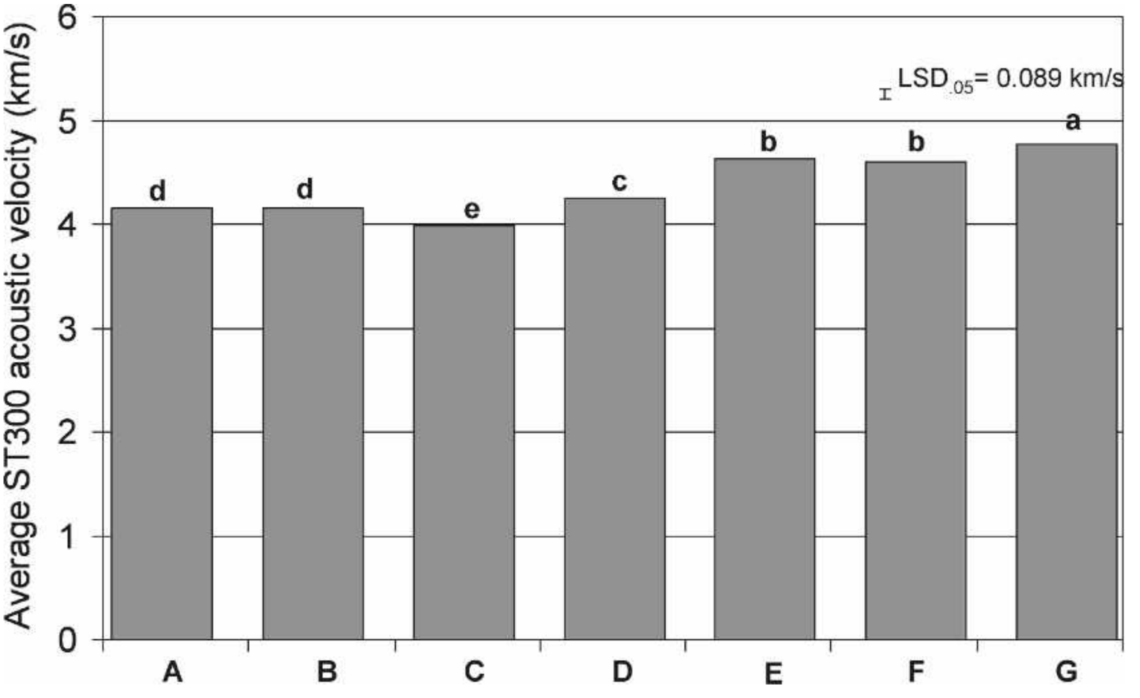

Figure 3. Director ST300 acoustic velocity averages for the seven study sites (A–G). $LSD_{.05}$ = least significant difference between stand velocity means at $p = 0.05$ level of significance. Means with the same lower case letter (a–e) are not significantly different.

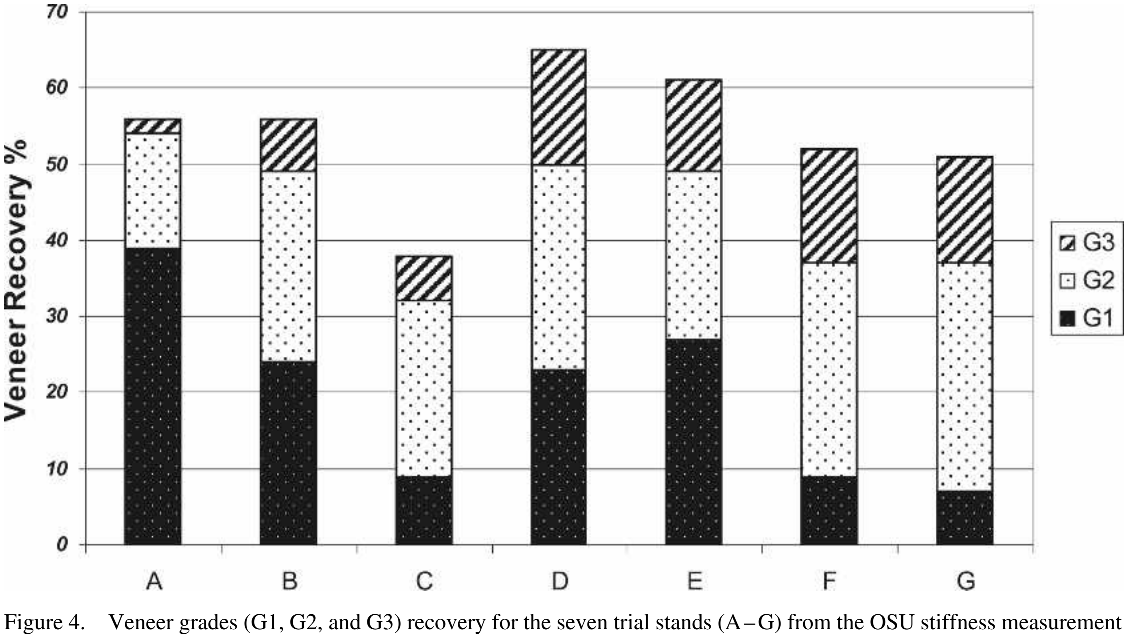

Figure 4. Veneer grades (G1, G2, and G3) recovery for the seven trial stands (A–G) from the OSU stiffness measurement study.

were found to be strongly correlated to actual veneer recovery (Amishev and Murphy, in review).

As mentioned earlier, during the study, we had the "misfortune" of having to change our standing tree acoustic velocity device and ended up using a total of three ST300 tools. The first (Tool 1) was used on a total of 425 trees (all trees in sites A, B, and C; 75 trees in site D; and 47 trees in site E), the second factory-upgraded version of the device (Tool 2) was used on 173 trees (15 trees in site D, 53 in site E, and all trees in site F), whereas the third upgraded tool (Tool 3) was used for site G. This fact certainly limits the power of our conclusions in terms of the reliability of TOF acoustic device tree measurements to predict the end-use veneer characteristics produced. In fact, an ANOVA anlaysis and means separation procedure revealed a significant difference among the three tools in terms of their averaged measurements (4.13, 4.71, and 4.78 km/s for Tools 1, 2, and 3, respectively; $LSD_{.05}$ = 0.059 km/s). Significant differences were also found between acoustic velocity measurements taken on one side of the trees and those on the opposite side, although the choice of tree sides for the measurements was not related to any factor (eg, windward and leeward, north and south).

The fact that Tools 1 and 2 were both used in two of the stands (D and E) enabled us to actually attribute the velocity differences to the difference between the tools, and analyzing the data certainly supported that hypothesis (Table 4). Investigating the relationship between G1/G2 green veneer recovery fraction and the (Tools 1 and 2) ST300 acoustic velocity measurements, with Tool 2 included as an indicator variable yielded a model with an adjusted coefficient of determination R^2 of 0.43 and a p value of 0.107. Results indicated that Tool 2 was a significant variable affecting the intercept of the relationship. Considering the significant effect of the different tools on the standing tree measurements, the relationship between average acoustic velocities for each tool × site (where applicable) and actual veneer recovery was investigated (Fig 5). Although no statistically significant relationship was found for any one of the tool × site averages, an interesting trend was observed between the fitted linear correlation lines for Tools 1 and 2 (Tool 3 linear correlation line was hypothesized to follow the same slope as that of Tools 1 and 2, going through its only data point for site G). It is possible that these tools have similar slopes but different intercepts. In other words, there might be a potential for those devices to produce data compatible with the final veneer characteristics, but there was great inconsistency between the different tools. Latter trials with even newer versions of the ST300 in additional RFP Douglas-fir stands conformed to our findings on these devices (Donald Persyn, RFP Oregon logging manager, personal communication), ie, acoustic velocity measurements between different tools of this brand on the same tree were not consistent to a satisfactory degree and there was poor correlation between those and log acoustic velocity measurements (and respective green veneer recovery).

Table 4. *Summary for the regression between G1/G2 green veneer recovery (%) and the explanatory variables: ST300 acoustic velocity (km/s) measurements and Tool 2 (indicator variable).*

Coefficients	Value	Standard error	t Stat	p value
Intercept	−145.98	72.33	−2.018	0.0996
ST300 velocity	46.48	17.43	2.667	0.0445
Tool 2	−30.70	11.73	−2.617	0.0472

Other research studies have investigated the significance of DBH on the relationship between standing tree acoustic velocity and lumber machine-graded MOE. Joe et al (2004) found no significant relationships when correlating DBH with acoustic velocity and machine-graded MOE values. When examining the relationship among acoustic velocity, outerwood density, and DBH in radiata pine stands aged 8, 16, and 25 yr, Chauhan and Walker (2006) reported R^2 values of 0.02, 0.07, and 0.18, respectively. Toulmin and Raymond (2007) also reported minimal relationships between DBH and standing tree acoustic velocities in radiata pine with R^2 values of 0.07, 0.09, and 0.04 for 10-, 15-, and 20-yr-

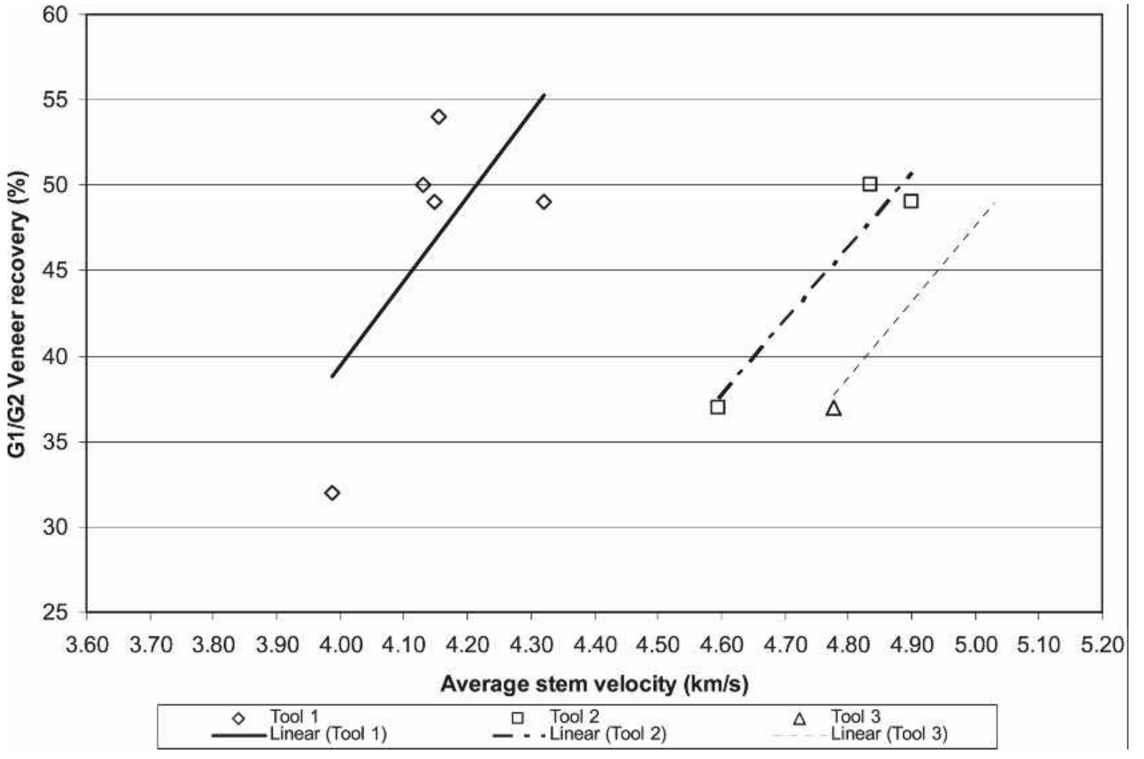

Figure 5. Relationship between tool × site average stem velocity and G1/G2 veneer recovery.

old stands, respectively. When regressing standing tree acoustic velocity to tree DBH, we found similar values for the R^2 averaging 0.21 for all trees, ranging from 0.07 for trees from site G to 0.32 for site A trees. In other words, DBH seems to have limited predictive capability in terms of tree acoustic velocity and hence wood stiffness.

Other research studies have reported that acoustic velocity may be influenced by other factors such as initial stand spacing, genotype, climatic conditions, silvicultural treatments, management intensity, and even temperature. Those factors and their effects were not investigated in our study.

It is important to emphasize that this research is associated with several limitations influencing its power and scope of inference; only one brand and three different tools of the same brand were used along the duration of the study producing confounding effects on the results; analysis was performed only on a stand average level in terms of the veneer recovery and on an individual tree level in terms of resonance acoustic velocity relationships; only one end product—green veneer—was considered and produced regardless of other external and internal tree attributes.

This research has primarily focused on the use of acoustic technology for evaluating internal properties of Douglas-fir stands in terms of their veneer quality. Acoustic techniques have been successfully used and implemented for nondestructive evaluation of mechanical properties of other wood products (structural lumber, poles, pulp logs, decay detection, and so on) and species as well as in tree selection and breeding based on stiffness (Huang et al 2003). Recent research studies have also found the use of acoustic tools to be viable in assessing stiffness in Douglas-fir veneer-grade logs (Amishev and Murphy, in review), radiata pine sawlogs and green lumber (Grabianowski et al 2006), structural lumber logs and boards (Carter et al 2006), and young seedling clones (Lindstrom et al 2004), *Eucalyptus dunnii* veneer, and LVL logs and structural lumber boards (Joe et al 2004).

However, in a congruous manner with the results reported by Wagner et al (1998, cited in Wagner et al 2003), this research contradicts the general agreement about the usefulness of the TOF acoustic technology, and more specifically the ST300, in a particular case, accomplishing a reliable preharvest evaluation of Douglas-fir stands in terms of veneer quality. No published literature was found to investigate the relationship between stress wave velocity in standing trees and veneer quality in Douglas-fir. According to results reported for other species and purposes, it is assumed that this relationship exists. Therefore, it is possible to conclude that this article is an indirect evaluation of the ST300 and not the TOF acoustic technology as a whole, the results of which were shown to be rather poor.

There may be several possible explanations about this poor relationship. The age of the sampled stands is certainly one of them. Chauhan and Walker (2006) pointed out that there is greater uncertainty in ranking trees for their whole-tree stiffness in older stands using the FAKOPP TreeSonic TOF instrument; the coefficient of determination R^2 dropped from 0.91 to 0.75 when acoustic velocities in standing trees were compared with those in their corresponding butt logs for 16- and 25-yr-old radiata pine stands, respectively. Briggs et al (2008) reported correlation coefficients R^2 between butt logs and standing tree acoustic velocities ranging from 0.42 to 0.64 for 85 Douglas-fir trees ranging in age from 32 to 51 yr. Considering the fact that the stands sampled in our study ranged from 51 to 72 yr, the coefficient of determination R^2 of 0.25 between sound velocities of the 698 standing trees measured by the TOF method (ST300) and the corresponding speeds in the butt logs measured by the resonance-based method (HM200) certainly follows the pattern of increasing variability and uncertainty in sorting standing trees with increasing tree age. One explanation for that is the increased variability within the radial structure of the tree and the fact that TOF instruments measure outerwood properties, whereas the resonance tools sense whole-section properties.

Another possible reason for having poor relationships between TOF acoustic velocities on standing trees and resonance velocities (and corresponding veneer recovery) measured on the butt logs of the same trees may be the highly variable low-stiffness wood zone that forms from the base to approximately 2.7-m stem height (Xu and Walker 2004; Xu et al 2004) in radiata pine trees and similar findings were suggested (Briggs et al 2008; Amishev and Murphy, in review) for Douglas-fir.

Knots and distorted grain around them usually influence (lower) the acoustic velocity and produce variation between tree faces (Briggs et al 2008). However, the stands sampled in our study were largely devoid of any branches between the two measuring probes of the TOF instrument. Their presence in the produced logs and green veneer, however, may have influenced the sorting decisions and the consequent veneer recovery, possibly contributing to that poor relationship. Acoustic velocity decreases with increasing moisture content up to the fiber saturation point and is constant beyond; standing living trees are usually above that point and differences in moisture content between trees would have minimal, if any, effect on acoustic readings. Green density of the sampled stands was measured and despite the inherent variability, it had minimal effect on acoustic velocity and veneer recovery.

CONCLUSIONS

The objective of this study was to determine whether TOF acoustic technology could be used for preharvest veneer quality assessment of Douglas-fir stands in terms of stiffness requirements and whether spatial and within tree characteristics could be good predictors or influence the accuracy of those measurements in second-growth Douglas-fir stands in Oregon. Standing tree acoustic velocity using the Director ST300®

TOF device and the actual G1/G2 veneer produced using an in-line commercialized Metriguard® stress-wave grade sorter were found to have no significant correlation. Significant differences were found among the three different ST300 tools used along the duration of the study as well as between the two opposite side measurements within trees. Substantial variability in velocity readings was observed from hit to hit in each measurement position within tree sides. Hence, ST300 TOF acoustic devices did not prove to be a promising and valuable tool in assessing standing tree veneer quality early in the supply chain on a single-tree or whole-stand basis. Spatial location of the stands in terms of their latitude, longitude, or altitude had no predictive capability regarding their veneer quality. The same was true for DBH according to its poor correlation with both acoustic velocity and G1/G2 veneer recovery.

Segregation of logs based on acoustic tools that measure stiffness is already being used by some forest companies to make informed management decisions and improve the value of lumber recovery (Dickson et al 2004). Although preliminary results from our acoustics trials show that in-forest sorting of logs is likely to lead to improvements in recovery of higher value Douglas-fir veneer grades (Amishev and Murphy, in review), preharvest veneer quality evaluation of Douglas-fir stands using the ST300 is, at this stage, not reliable. Although several possible explanations about this poor relationship are suggested, more efforts are required and continue to be invested to identify the reasons for the large variability and inconsistency of the ST300 on Douglas-fir trees.

Our initial studies strive to address an array of questions related to the technical feasibility of using acoustic technology in forest environments. Much more work, however, needs to be undertaken to examine the costs, benefits, and economic viability of this technology.

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