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Acoustic Assessment Technologies for Optimal Wood Products and Biomass Utilization

Brian K. Brashaw
Natural Resources Research Institute, University of Minnesota Duluth, Duluth, MN, USA, bbrashaw@nrri.umn.edu

Xiping Wang
USDA Forest Service, Forest Products Laboratory, Madison, WI, USA, xwang@fs.fed.us

Dean Fellman
Center for First Americans Forestlands, College of Menominee Nation, Keshena, WI, USA, dfellman@menominee.edu

Robert J. Ross
USDA Forest Service, Forest Products Laboratory, Madison, WI, USA, rjross@fs.fed.us

Huadong Xu
Northeast Forestry University, Harbin, China, xuhuadong8215@yahoo.com

Abstract

The College of Menominee Nation collaborated with University of Minnesota Duluth and USDA Forest Products Laboratory to advance research on robust nondestructive evaluation technologies capable of predicting the wood properties of trees, stems, and logs, and assessing the value of stands and forests. A comprehensive assessment of the acoustic properties for two important wood species (white pine and sugar maple) was completed. This assessment showed a natural variation in acoustic velocity that could be determined in standing trees using commercial acoustic equipment. The variation in acoustic velocity can be used to sort trees and logs into quality grades than can be used to direct the material into appropriate product classifications. A strong relationship between radial stress wave velocity and cross-section quality was shown for both white pine and sugar maple using the Fakopp microsecond timer. Resistance microdrilling of the radial cross section showed an excellent relationship between the mean resistance and the measured green density of the tree. This could importantly be used to accurately predict weight measures of the stand for use in potential carbon credits or biomass estimation.

Keywords: nondestructive evaluation, trees, logs, acoustic velocity

Introduction

Objective

The objectives of the research project were: 1. Identify implementation strategies and guidelines for use with standing trees, stems and logs for regional application across the varied forest cover types; 2. Develop a nondestructive approach to accurately determine green wood density for individual species within a localized forest stand; and 3. Establish a new partnership between the College of Menominee Nation and the University of Minnesota Duluth, both Land Grant Institutions with a benefit to faculty, staff and students of both Institutions.

General information

Acoustic technologies have been well established as material evaluation tools in the past several decades and their use has become accepted in the forest products industry for on-line quality control and products grading (Pellerin and Ross 2002). Recent research developments on acoustic sensing technology offer further opportunities for wood manufacturers, forest owners, and tribal nations to evaluate raw wood materials (standing trees, stems, and logs) for general wood quality and properties (Wang et al. 2000, 2004, 2007). This strategic information can be used by forest owners and managers to make economic and environmental management decisions on treatments for individual trees and forest stands, improve thinning and harvesting operations, and efficiently allocate timber resources for optimal utilization. For example, the information could be used to sort and grade trees and logs according to their suitability for structural applications and for a range of fiber properties of interest to paper makers. Another example is to determine the relationships between environmental conditions, silvicultural treatments and wood fiber properties so that the most effective forestry treatment can be selected for future plantations for desired fiber quality.

The USDA Forest Product Laboratory (FPL) work on the use of acoustic speed to assess standing timber and log quality began in earnest in 1993. Since that time, the FPL and their cooperators have tested over 1500 trees and logs from various sites in the United States (Alaska, Michigan, Missouri, Oregon, Washington, Louisiana, and Wisconsin), Australia, and New Zealand. Because of the well-known relationship between acoustic speed and wood product quality, FPL focused their research efforts on examining the fundamental relationships between: 1. Standing tree assessment and log quality and 2. Measurements made on logs and resulting product (round wood, veneer, lumber) quality. Numerous publications have been prepared that document our results. Excellent correlations have been observed between acoustic measurements made on trees/logs and resulting product quality. Most recently, members of this project team published a cover story in the Forest Products Journal (Wang et al 2007) noting that the precision of acoustic technology has been improved to the point where tree quality and intrinsic wood properties can be predicted and correlated to structural performance of the final products.

A unique partnership was created for this project with the Menominee Indian Tribe of Wisconsin. Specifically, funds for the project were obtained in a grant application submitted by the College of Menominee Nation (CMN) to the USDA NIFA Tribal Grants Research Program. This research program links 1994 land grant institutions (CMN) with 1862 land grant institutions (UMD).

The Menominee reservation lands are comprised of 235,523 acres (219,000 acres forested), or approximately 357.96 square miles, and include over 407 miles of improved and unimproved roads, 187 rivers and streams, and 53 lakes. The business arm of the tribe is Menominee Tribal Enterprises (MTE), who has demonstrated expert ability to manage, harvest and process timber from the world renowned Menominee Forest - an award winning sustainable forest located on the Menominee Nation Reservation in central Wisconsin. Important species for this mill include white pine (*Pinus strobus*) and sugar maple (*Acer saccharum*), the two focus species assessed in this project.

Research Methods

Literature review of data set relationships between acoustic properties of trees, stems, logs, and products.

A comprehensive literature review of existing acoustic tree data sets was completed by the project team (Gao et al 2012). In addition to this information, a review was completed of previous research where the specific gravity or density was predicted for trees, logs and lumber using a wide variety of NDE equipment and technologies. This review provided excellent insight on the development of an experimental procedure that could be used for stress wave timing and resistance microdrilling of both harvested discs and standing trees.

Assessment of Menominee Nation species using acoustic-based technologies

Standing trees

In cooperation with CMN, MTE, and USDA Forest Service staff, several stands were identified for evaluation. The target stands included species of importance to the Menominee Nation including white pine and sugar maple. One pine and two hardwood stands were selected. Approximately 35 white pine and 50 sugar maple trees were marked by MTE and CMN staff and identified by a painted number on the bark. Each of these trees were measured using the following methods:

1. Measure diameter at breast height (dbh).
2. Determine stress wave transmission time perpendicular to the grain using a Fakopp Microsecond Timer. Each tree was measured at 90 degrees to each other and taken at dbh.
3. Conduct a microsecond drilling at one of the Fakopp testing locations.
4. Determine longitudinal velocity using a fibre-gen STS 300 standing tree tool. The lower probe was inserted at a 30 degree angle through the tree bark approximately 2 ft above the ground and the upper probe 1.3 meters above the lower probe.

Photographs of the nondestructive testing equipment used to assess standing trees for this project is shown in Figure 1.

Figure 1—Nondestructive equipment used to assess standing trees. Top - stress wave timer; Middle - resistance microdrill; Bottom - standing tree acoustic.

Harvest

Following the experimental testing, each tree was felled by a private sawyer and bucked into typical log lengths. A 3-4 inch thick disc was obtained from most trees, cut from each tree after the first log was cut. It was marked by tree number and species, and then bagged in plastic to minimize drying. Each of the discs collected after felling was taken to UMD NRRI for resistance microdrilling and determination of green density. Figure 2 shows a representative white pine and hard maple tree after felling. Figure 3 shows a disc collected after the tree was sawn into logs. All logs numbered as to tree and log number. For example, 2-1 referred to tree number 2 - log number 1. The logs were then skidded to a log landing.

Figure 2—Harvested trees cut into logs. The left image shows a white pine tree with a 3 inch thick disc cut and the right image shows a sugar maple tree after harvest.

Logs

The logs were transported to MTE and placed into the mill storage yard. Each of the logs was laid out with the number visible on the top of the log. Each log was bar-coded by the MTE staff and visually assessed to determine the diameter, defect amount and volume. The project team completed log assessments approximately two weeks after the trees were harvested. The length and diameter at both ends were measured with a tape measure. The longitudinal stress wave velocity was measured using a fibre-gen HM 200. The HM 200 was firmly placed in contact with one cut end of the log. The log was impacted with a hammer, resulting in the display of the quality of the received signal and the velocity. Photographs were taken for the visual assessment of both ends of each log and along the length. The fibre-gen ST 300 was also used to test the velocity of each log. The probes were inserted into a log in the same manner that was done in the forest. The send and receive probes were approximately 1.3 meters apart and in visual alignment. Figure 3 shows the NDE testing completed for each of the white pine and sugar maple logs.

Figure 3—Assessment of the harvested white pine and sugar maple logs in the MTE log yard using a commercial longitudinal acoustic measuring tool (top) and standing tree tool (bottom).

Disc assessment

Discs were collected from twenty-five trees of the white pine and sugar maple trees harvested during this project. These discs were full size and taken from above the first log, typically 3 m (10 ft) above ground level. Standard procedures were developed for measuring the discs with a resistance microdrill and a Fakopp Microsecond Timer. The procedure was to:

1. Draw a grid at 90 degrees onto the surface of the sample.
2. Insert Fakopp probes directly across from each other, in the same plane and through the bark and into sound wood. Take 3 measurements with the Fakopp and record the average.
3. Measure each cookie in both directions with the Fakopp.
4. A RINNTECH Resistograph was used conduct drilling at the midpoint of the sample near the location where the Fakopp measurement was taken.
5. Each disc was then cut into a 2-inch wide strip. The strip was measured to determine green density.

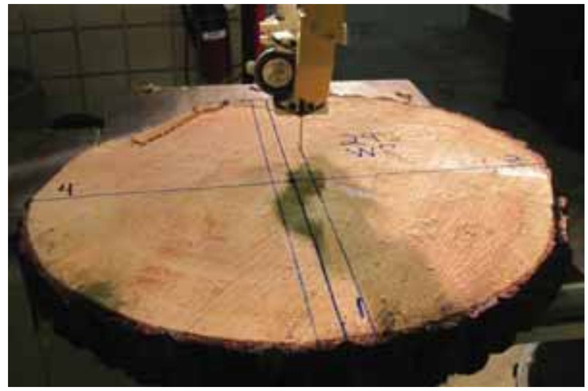

Figure 4—White pine disc being cut into a strip to determine specific gravity after microdrilling.

Figure 4 shows a marked disc being cut to determine green density of a 2 in wide section.

Results and Discussion

Standing trees

Descriptive statistics were used to determine the mean, minimum, maximum, and standard deviation for each species diameter, longitudinal stress wave velocity (ST 300), and transverse stress wave velocity (Fakopp Microsecond Timer - FMT) for each of two measurements taken at 90 degrees to each other. The summary of this data is available in table 1 for the white pine and table 2 for the hard maple. Graphical representation for the species diameter, longitudinal and radial velocities are shown in figures 5-8.

Table 1—Descriptive statistics for white pine trees evaluated during the study.

Stand parameters	Units	Number	Mean	Standard Deviation	Minimum	Maximum
Diameter	in	30	30.7	6.0	18.0	42.5
	cm	30	78.0	15.2	45.7	108.0
Longitudinal Velocity (ST 300)	ft/s	30	12,474	1,317	8,124	15,111
	m/s	30	3,802	402	2,476	4,606
Transverse Velocity 1 (FMT)	ft/s	28	3,438	594	2,394	4,753
	m/s	28	1,048	181	730	1,449
Transverse Velocity 2 (FMT)	ft/s	28	988	160	722	1,261
	m/s	28	3,242	524	2,369	4,136

Table 2—Descriptive statistics for sugar maple trees evaluated during the study.

Stand parameters	Units	Number	Mean	Standard Deviation	Minimum	Maximum
Diameter	in	51	22.2	5.6	11.1	35.4
	cm	51	56.3	14.1	28.2	89.9
Longitudinal Velocity (ST 300)	ft/s	51	13,487	1,249	10,207	15,515
	m/s	51	4,111	381	3,111	4,729
Transverse Velocity 1 (FMT)	ft/s	51	5,187	1,236	1,815	6,806
	m/s	51	1,581	377	553	2,075
Transverse Velocity 2 (FMT)	ft/s	51	5,016	1,201	2,291	7,063
	m/s	51	1,529	366	698	2,153

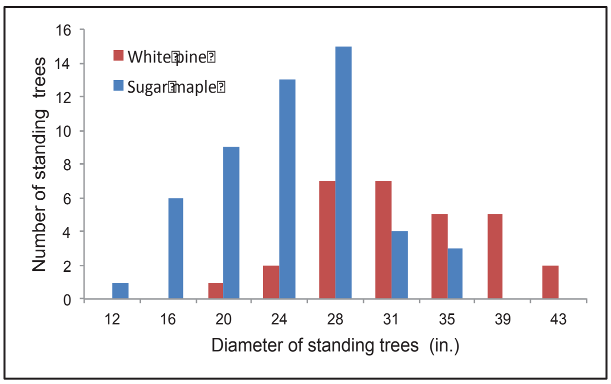

Figure 5—Diameter distribution of the white pine and sugar maple trees measured during this study. Note: 1 in = 2.54 cm.

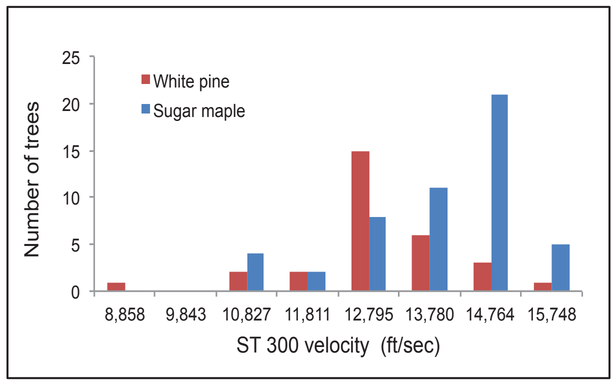

Figure 6—Longitudinal velocity distribution of the white pine and sugar maple trees measured during this study. Note: 1 ft/s = 0.305 m/s.

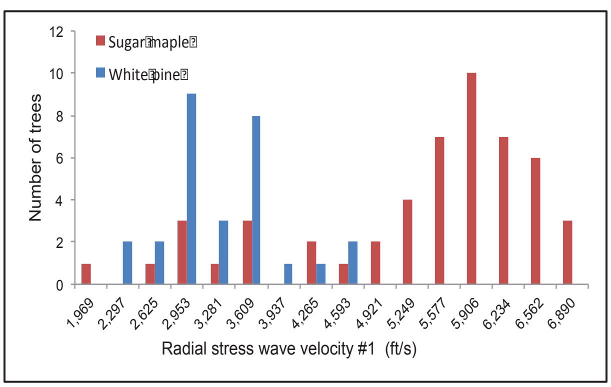

Figure 7—Radial velocity distribution of the white pine and sugar maple trees measured during this study. Note: 1 ft/s = 0.305 m/s.

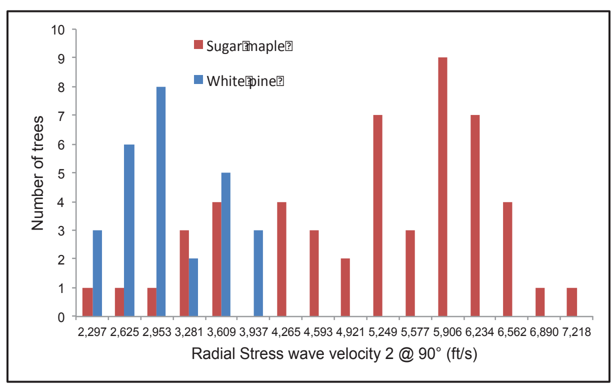

Figure 8—Radial velocity distribution of the white pine and sugar maple trees measured during this study. Note: 1 ft/s = 0.305 m/s.

The diameter of the white pine was larger than the hard maple and the mean longitudinal velocity was greater for the sugar maple. Within each species, there was a range of velocities noted, an important factor needed to create potential log velocity classes. For the transverse velocity, there was also variability in the velocities measured. This was a function of the presence of decay in the cross-section of the wood. The combination of velocities measured in these species can allow forest managers to make informed decisions on the quality of individual trees or stands during timber cruising or marking for harvest.

Logs

Descriptive statistics were used to determine the mean, minimum, maximum, and standard deviation for each species diameter, longitudinal stress wave velocity (HM 200 and ST 300). The summary of this data is available in table 3 for the white pine and table 4 for the hard maple. Graphical representation for the species diameter and longitudinal velocity are shown in figures 9-11.

Table 3—Descriptive statistics for the white pine logs evaluated during the study.

Parameters	Units	Number	Mean	Standard Deviation	Minimum	Maximum
Diameter	in.	149	23.1	5.9	12.4	40.3
	cm	149	58.6	15.1	31.5	102.2
Length	ft	149	13.9	2.4	8.8	16.9
	m	149	4.2	0.7	2.7	5.2
Longitudinal Velocity (HM200)	ft/s	149	10,914	819	8,497	12,467
	m/s	149	3,326	252	2,5890	3,800
Longitudinal Velocity (ST300)	ft/s	146	13,31	1,429	7,520	17,126
	m/s	146	4,058	436	2,292	5,220

Table 4—Descriptive statistics for the sugar maple logs evaluated during the study.

Parameters	Units	Number	Mean	Standard Deviation	Minimum	Maximum
Diameter	in.	127	18.9	3.9	10.3	29.2
	cm	127	48.0	9.9	26.0	74.0
Length	ft	127	12.3	2.2	7.8	16.8
	m	127	3.8	0.7	2.4	5.1
Longitudinal velocity (HM200)	ft/s	127	11,132	800	7,907	12,697
	m/s	127	3,425	195	3,020	3,870
Longitudinal velocity (ST300)	ft/s	122	14356	1655	10387	18045
	m/s	122	4376	505	3166	5500

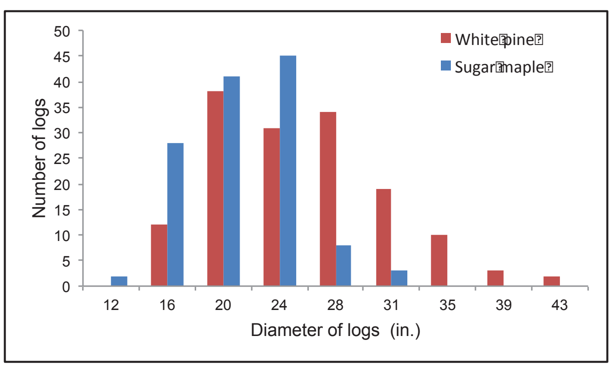

Figure 9—Diameter distribution of the white pine and sugar maple logs measured during this study. Note: 1 in = 2.54 cm.

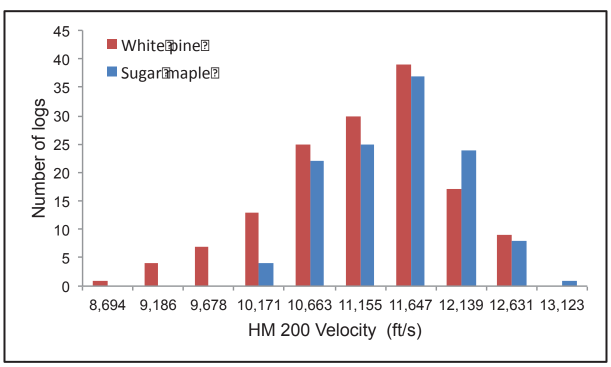

Figure 10— Longitudinal velocity distribution of the white pine and sugar maple trees measured using the HM 200 during this study. Note: 1 ft/s = 0.305 m/s.

This data showed that there was a useful range of velocity measures as determined using the HM 200. The data collection from the ST 300 was to increase the data sets for research purposes, as the ST 300 is not specifically designed for logyard measures. The white pine logs had the greatest variability, as it has the potential for low longitudinal velocity due to poor quality wood containing significant knot whorls in the upper sawlogs or due to internal decay. Additional analyses were completed to assess the relationship between the velocity measurements that were completed on the logs using the ST300 and the HM200. Figures 12 and 13 show the relationship for white pine and sugar maple respectively. The correlation coefficient for the relationship between the velocity as determined from both pieces of equipment was about same for the white pine (0.37) and sugar maple (0.39) logs. It must be noted that the HM measures the full length of the log while the ST only measured 1.3 m.

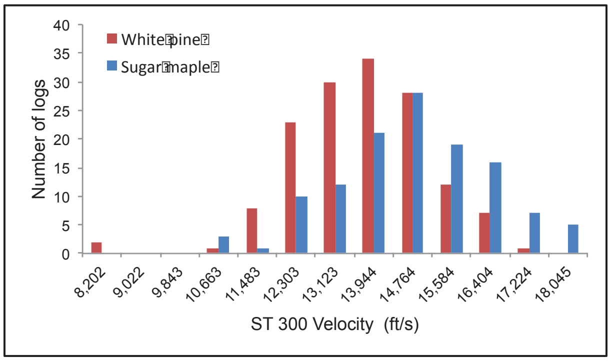

Figure 11— Longitudinal velocity distribution of the white pine and sugar maple trees measured with the ST 300 during this study. Note: 1 ft/s = 0.305 m/s.

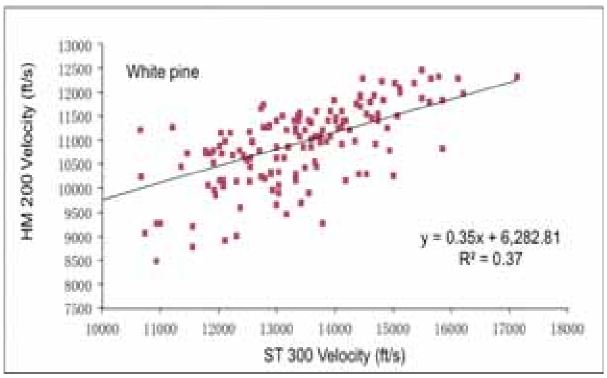

Figure 12—Relationship between the longitudinal velocity measurements obtained for the white pine logs with the HM200 and the ST300 acoustic tools used in this study. Note: 1 ft/s = 0.305 m/s.

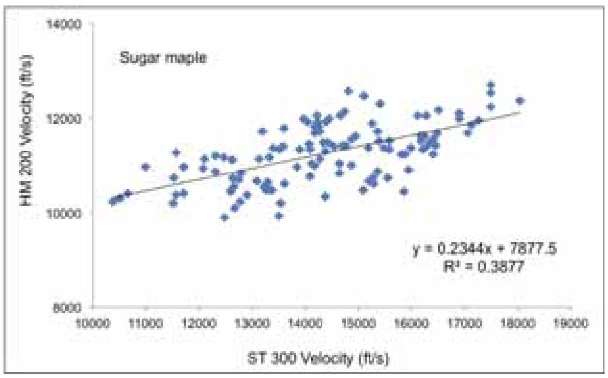

Figure 13—Relationship between the longitudinal velocity measurements obtained for the sugar maple logs with the HM200 and the ST300 acoustic tools used in this study. Note: 1 ft/s = 0.305 m/s.

The data also showed that the velocity was the highest for the second log for each species, then decreasing in the additional logs for each tree. The average for each log number was calculated and plotted for velocities measured using the HM200 and the ST 300. Figures 14 and 15 show the log velocity relationship between log order for both species with each piece of equipment. This is consistent with other reported research results from around the world. The butt log, while may be of high quality, is also affected by issues such as ground level decay that extends into the log, mechanical damage from felling operations, and previous logging damage. In larger and older trees like those measured during this project, the second log is usually of high quality. As the third and following logs are cut, there are more knots, defects, branches and other damage present affecting wood quality.

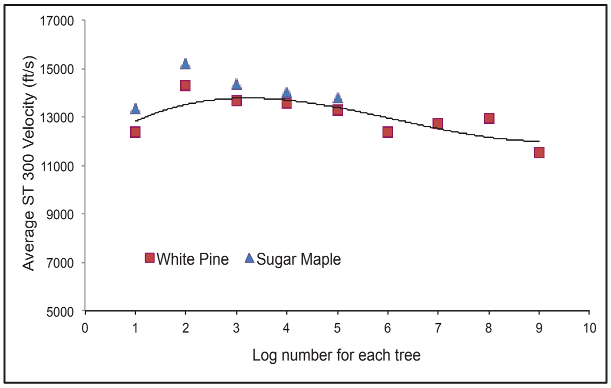

Figure 14—Mean log velocity as determined with the ST300 for each of the log numbers for all white pine and sugar maple trees evaluated in this study. Note: 1 ft/s = 0.305 m/s.

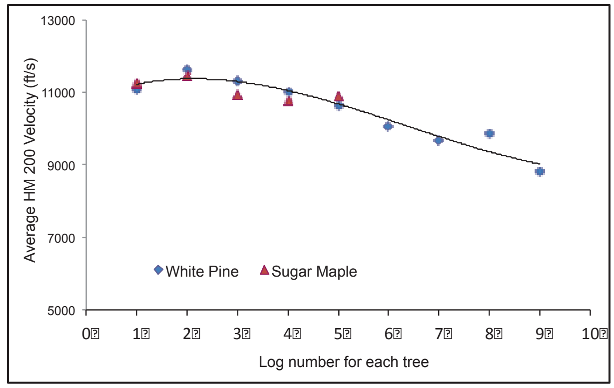

Figure 15—Mean log velocity as determined with the HM200 for each of the log numbers for all white pine and sugar maple trees evaluated in this study. Note: 1 ft/s = 0.305 m/s.

Radial velocity assessment

Further, one goal of the project was to assess the variability in radial or transverse stress wave velocity of standing trees at dbh, and compare that to the visual deterioration and decay present in trees. This tool is extremely effective in determining internal decay and deterioration. In a previous section, Figures 7 and 8 show the radial velocity measurements for all of the white pine and sugar maple trees. This information was converted into the inverse of velocity, as microseconds/ft of travel time is an effective and practical measurement for interpretation for field foresters and staff. Table 10 provides a summary of the mean, maximum, and minimum values for each species. Since two measurements were taken at 90 degrees to each other, the values are an average of those values.

Table 10—Radial stress wave times (microseconds/ft) for each species as determined at diameter breast height using the Fakopp microsecond timer.

Species	Radial Stress Wave Velocity Statistics (microseconds/ft)			
	Number of Trees	Mean	Maximum	Minimum
White Pine	28	307.0	416.3	234.2
Sugar Maple	51	212.4	398.7	150.4

A clear visual difference in wood quality was obvious through inspection of the harvested logs and can be assessed using radial acoustic velocity. This information can be especially valuable for forest management decisions, as the Fakopp can be used while trees are still standing to determine trees with large internal decay pockets that may not be visible from the outside. An assessment of the data showed that the stress wave times greater than 359 microseconds/ft contain deterioration in white pine. An assessment of the data showed that stress wave times greater than 300 microseconds/ft contain significant damage or deterioration for sugar maple.

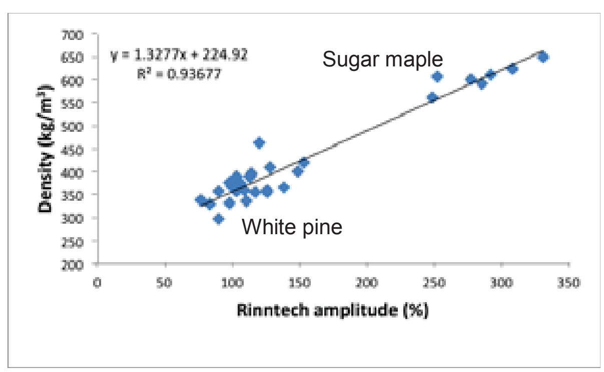

Figure 16—Resistance drilling measures as a function of green density.

Green density resistance drill relationship

The resistance microdrilling technique showed potential to predict green density for both species assessed in this project, a meaningful tool for potentially determining estimates of biomass energy mass, or carbon credits. Figure 16 shows the positive relationship between resistance drill amplitude and green density for a RINNTECH resistance microdrill. The figure shows the white pine and the sugar maple combined onto each chart. The lower density numbers are white pine and the higher density numbers are sugar maple. This information could improve the potential of forest managers to understand biomass estimates of their forest growing stock based on green density assessment.

Conclusions

The project activities resulted in a comprehensive assessment of the acoustic properties for two important wood species for the Menominee Nation, white pine and sugar maple. This assessment showed a natural variation in acoustic velocity that could be determined in standing trees using a fibre-gen ST300 and in logs using a fibre-gen HM 200. The variation in acoustic velocity can be used to sort trees and logs into quality grades than can be used to direct the material into appropriate product classifications. High velocity trees and logs showed a higher yield with less defect material (as determined through a visual log scaling) than those with lower velocity. Specifically, those logs with the highest acoustic velocities show the least average defect %. For sugar maple, the defect % was 1.2% for HM 200 velocities over 11,000 ft/s and 1.4% for ST 300 velocities over 14,000 ft/s. For white pine, the defect % was 1.8% for HM 200 velocities over 11,000 ft/s and 1.8% for ST 300 velocities over 14,000 ft/s. However, the use of visual log scaling was determined not to provide enough specific information to sort the logs into more specific grades. While it is not practical to conduct an intensive mill yield study of all sawn lumber, it may be possible to conduct a limited study of 5-10 logs each (high, medium and low velocity,) with the goal of providing improved measures of yield based on acoustic velocity.

A strong relationship between radial stress wave velocity and cross-section quality was shown for both white pine and sugar maple using the Fakopp microsecond timer, which can be used during forest management. It was shown that for a threshold setting for the Fakopp Microsecond Timer of greater than 300 microseconds/ft for sugar maple and 359 microseconds/ft for white pine was effective in identifying significant levels of internal decay in standing trees.

Finally, resistance microdrilling of the radial cross section showed an excellent relationship between the mean resistance and the measured green density of the tree. This could importantly be used to accurately predict weight measures of the stand for use in potential carbon credits or biomass estimation. Two commercial resistance drills were evaluated, with a predictive model of Green Density = (1.3277*Mean Resistance) + 224.92 for the RINNTECH Resistograph and Green Density = (8.6659*Mean Resistance) + 238.59 for the IML F350.

This project created a new partnership between the College of Menominee Nation's Sustainable Development Institute, the University of Minnesota Duluth's Natural Resources Research Institute and Menominee Tribal Enterprises. While the current project focused on acoustic measures at or after harvest, new projects could focus on other important forestry, secondary wood products, new product development or other economic opportunities.

Acknowledgments

The USDA NIFA Tribal Grants Research Program provided support for this project. Menominee Tribal Enterprises provided excellent cooperation. Menominee Tribal Enterprises is committed to excellence in the sustainable management of their forest, and the manufacturing of our lumber and forest products providing a consistently superior product while serving the needs of their forest, employees, wood products customers, tribal community, and future generations.

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Report

FPL–GTR–226

Proceedings
18th International Nondestructive Testing and Evaluation of Wood Symposium

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Abstract

The 18th International Nondestructive Testing and Evaluation of Wood Symposium was hosted by the USDA Forest Service's Forest Products Laboratory (FPL) in Madison, Wisconsin, on September 24–27, 2013. This Symposium was a forum for those involved in nondestructive testing and evaluation (NDT/NDE) of wood and brought together many NDT/NDE users, suppliers, international researchers, representatives from various government agencies, and other groups to share research results, products, and technology for evaluating a wide range of wood products, including standing trees, logs, lumber, and wood structures. Networking among participants encouraged international collaborative efforts and fostered the implementation of NDT/NDE technologies around the world. The technical content of the 18th Symposium is captured in this proceedings.

Keywords: International Nondestructive Testing and Evaluation of Wood Symposium, nondestructive testing, nondestructive evaluation, wood, wood products

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Contents

Session 1. Industrial Applications of NDT Technologies

Session 2. Nondestructive Evaluation and Hazard Assessment of Urban Trees

Session 3. Nondestructive Evaluation of Standing Timber

Session 4. Nondestructive Evaluation of Logs

Session 5. Condition Assessment of Historic Wood Structures—Experience from Around the Globe

Session 6. Nondestructive Evaluation of Composite Materials—Nanocellulosic Films to Glued Laminated Timber

Session 7. Nondestructive Evaluation of Structural Materials I— New Techniques and Approaches

Session 8. Nondestructive Evaluation of Structural Materials II— Enhancements to Traditional Methods and New Applications

Session 9. Material Characterization I—Acoustic-Based Techniques

Session 10. Material Characterization II—Near Infrared, Neutron Imaging, and Other Techniques

Session 11. Structural Condition Assessment I—NDT Fundamentals and Assessment Methods

Session 12. Structural Condition Assessment II—New Techniques and Field Experiences

Session 13. Poster Session