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Examination of the Arborsonic Decay Detector for Detecting Bacterial Wetwood in Red Oaks

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ABSTRACT: *The Arbor-sonic Decay Detector (ADD; Fujikura Europe Limited, Wiltshire, England) was used to measure the time it took an ultrasound wave to cross 280 diameters in red oak trees with varying degrees of bacterial wetwood or heartwood decay. Linear regressions derived from the ADD readings of trees in Mississippi and South Carolina with wetwood and heartwood decay yielded significantly different lines for some combinations and locations. The results of this study suggest that the ADD cannot yet be used to detect wetwood in oak trees with enough certainty to be of practical use to a forester or land manager. However, regression lines describing ADD readings of trees with wetwood at both study sites were located between those of healthy trees and decayed trees suggesting some, albeit limited, ability to differentiate wetwood trees. The use of ultrasound to detect bacterial wetwood in red oaks may be improved by designing a system that allows measurement of signal amplitude and evaluation of waveform patterns. The ability to successfully detect trees with heartwood decay was better, especially for trees with advanced decay. South. J. Appl. For. 24(1):6–10.*

In 1990, the value of hardwood lumber at point of production in the eastern United States was more than $3.5 billion (Murdoch 1992). Nearly 25% of hardwood sawtimber in eastern forests is of the red oak species group. Over the last 20 yr, red oak has become the most commonly used hardwood in the production of furniture, kitchen cabinets, and millwork. Bacterial wetwood and associated problems with color, drying, and machining significantly reduce the overall quality and value of red oak lumber and veneer (Ward 1982). Wetwood in oaks became more common in mills in the South during the 1980s, as increases in price and demand led to increased harvesting on poorer sites, the better sites having already been harvested or removed from timber production. The manager of one hardwood sawmill in Mississippi estimates that about 50% of the bottomland oaks processed in his mill are affected by wetwood.

Bacterial wetwood is a disease condition of living trees which develops from infection by anaerobic bacteria(Hartley et al. 1961). It has been estimated that losses due to bacterial wetwood in oak trees are in excess of 500 x 10^6 bf (nominal 1.2 x 10^6 m^3) per year at an annual value of $25 million (Ross et al. 1995). Bacteria affect the strength of wood in standing trees, causing weak bonding between the cells resulting in tangential separation along the rings, known as "shake," and radial separation along the rays, known as "honeycombing" (Ward and Pong 1980). These weakened zones often go undetected prior to wood processing and are revealed by defects following drying (Ward and Groom 1983). The effects of wetwood on dried lumber can be mitigated by using longer, cooler drying schedules (Verkasalo et al. 1993). Any system capable of detecting wetwood in standing trees has significant commercial value because wetwood-affected trees could be identified before harvest and valued accordingly. Furthermore, it may be possible to minimize future losses by manipulating site, stand, or tree factors found to be conducive to wetwood formation.

Bacteria that are associated with wetwood produce acetic acid and additional fatty acids that have a characteristic rancid, vinegar-like odor (Schink and Ward 1984). This odor, detected by sniffing increment cores, log ends, or milled

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lumber from freshly cut trees, is the only reliable criterion for discerning bacterial wetwood outside the laboratory. This can be a problem, as different individuals vary in their ability to detect the odors. Increment coring, which is inconvenient and invasive, is the only way to detect bacterial wetwood in standing trees while in the field. This method has the added drawback of the difficulty of coring larger trees.

Ultrasonics is a technique that uses ultrasound to detect anomalies in the test material. Ultrasound is a collective term for all sound waves in excess of 20,000 Hz, and above the range of human hearing. A number of devices have been designed to measure knots, decay, or other anomalies in wood (Sandoz and Lorin 1996, Niemz and Kucera 1997, Bauer et al. 1991, Shade et al. 1990, Wilcox 1988, Anderson et al. 1997). Waid and Woodman (1957) successfully detected flaws and knots in wood using ultrasonics. Greig and Pratt (1974) proposed that ultrasonics could be used to detect decay, but the instrumentation was not yet available. McCracken and Vann (1983) developed a system to detect and measure heartwood decay in standing trees using ultrasound.

The predecessor of the Arborsonic Decay Detector (ADD) was the Ultrasonic Decay Detector introduced in 1984 by NTT, the major telecommunications carrier in Japan. It was originally developed to detect decay in the 6.8 million wooden transmission poles in service of the carrier at that time. The instrument used ultrasonics not only to detect, but also to evaluate the extent of decay in the poles in service. The instrument was soon adapted to detect decay in living trees (Wade 1996). This improved instrument, the Arborsonic Decay Detector, was commercially released in the early 1990s.

The theory supporting the application of this instrument is that ultrasound travels fastest in solid materials; in sound wood, the signal travels at a velocity of approximately 2,000 m/sec via the cell walls. The time required for this sound to travel between transducers placed on opposite sides of a tree is in the range of hundreds of microseconds. If the cell wall structure is not intact, or is decayed, it takes longer to travel through the nearest path of sound wood. Ever increasing amounts of decay correspond to longer time intervals for the sound to pass between the two transducers. An ultrasound wave propagation time, and its corresponding tree diameter, are used to determine whether a tree is healthy, severely decayed, or has incipient decay.

In the case of bacterial wetwood, the only significant change in cell wall structure is the degradation of pit membranes (Verkasalo et al. 1993). The results presented here represent our progress in determining if this relatively minor change in cell wall structure will decrease sufficiently the speed of ultrasound, as measured by the ADD, to detect wetwood in standing trees. There have been recent reports of other means of detecting bacterial wetwood in oak. Pettersen et al. (1993) showed that ion mobility spectrometric analysis could detect bacterial wetwood using small wood slivers taken from infected northern red oaks (*Quercus rubra* L.). Impact-induced stress waves were used to detect wetwood in 84% of infected red oak boards, but less than 50% of infected white oak (Q. *alba* L.) boards (Ross et al. 1994).

The Arborsonic Decay Detector was used to detect butterfly stain (a form of bacterial wetwood) in Chilean tepa (*Laureliopsis philippiana* [Looser] Schodde) (Tainter et al. 1999). In that case, linear regression lines derived from the stained and healthy populations were significantly different, but were close enough together that it would be difficult to detect with certainty if a given tepa tree had, or did not have, wetwood. In that study, though, the presence of butterfly stain was a function of tree diameter, and the ADD readings were used to create a probability table that could be used in conjunction with tree diameter to predict the likelihood of the tree having butterfly stain.

The results of these studies led us to apply this new technology to the detection of bacterial wetwood, a costly source of reduction in product value in standing red oaks. We believe this is the first application of ultrasound detection of bacterial wetwood in live red oak trees.

Materials and Methods

Mississippi

Two sampling sites containing healthy, heartwood-decayed, and wetwood trees were selected in poorly drained, slack-water areas in Sharkey and Issaquena counties, Mississippi. In some instances, trees with heartwood decay also had wetwood infections. Trees were categorized as wetwood-infected or healthy, based on the odor of exposed wood, or of an increment core removed from the bole at 1.4 m above the ground. The tree species selected were willow oak (Q. *phellos* L.) and nuttall oak (Q. *nuttallii* E.J. Palmer). A total of 193 live trees, or freshly cut tree sections, were measured. Twenty-two trees had wetwood, 46 trees were healthy, and 125 tree ‘sections were decayed. Ultrasound readings were taken on tree sections immediately after felling and bucking so that any difference in readings between a live standing tree and a tree section was minimized. Thirty-five severely decayed tree sections were eliminated from the final data set because the ultrasound wave does not propagate through a void. Sites ranged in elevation from 7.5 to 10.5 m above sea level. Soils at both sites were typical Sharkey heavy clays, strongly acidic to neutral, with slopes ranging from 0.5 to 2%. Red oaks and sweetgum (*Liquidumbur styraciflua* L.) dominated the overstories.

South Carolina

One hundred and fifty-three trees were selected in the Clemson Experimental Forest in Pickens County, South Carolina. The intensity of wetwood infection in each tree was categorized as being severe, moderate, or minor based on the odor of an increment core removed from the bole at 1.4 m above the ground. Healthy trees were used as controls, and decayed trees were sampled for comparison purposes. The species selected for Arborsonic analysis of wetwood were: northern red oak, southern red oak (Q. *falcata* Michx.), black oak (*Q. velutina* Lam.), and scarlet oak (Q. *coccineu* Münchh.). Thirty-one trees were eventually deleted for various reasons. The trees were located on four sites which contained mixed stands at altitudes ranging from 258-282 m above sea level. The first (SI = 87 for white oak = 74 yr) and third (SI = 94 for white oak = 74 yr) sites were of good quality. Soil at site 1 was a Tallapoosa loam with an average slope of 21%; at site 3, soil was a Pacolet fine sandy loam with 15-40 % slopes. Stands on both sites consisted of predominantly cove hardwood poles. The second (SI = 59 for scarlet oak = 74 yr) and fourth (SI = 65 for scarlet oak = 41 yr) sites were of poor quality. Soils of both sites were Madison sandy loams, with average slopes of 10–12%. Site 4 was extremely rocky.

At each location, the diameter of each sample tree was measured at the height where readings were taken. Round bark plugs (4.5 cm diam) were removed, using a wad punch, to expose the xylem at the height selected and at points 180” apart from each other. Transducers (transmitter and receiver) were pressed simultaneously against the xylem on opposing points of each tree to generate the ultrasound wave across each diameter. Linear regressions through the origin were generated using the Arborsonic propagation time readings as the dependent variable and diameter at the measurement height (usually at 1.4 m above ground) as the independent variable. Analysis of variance was used to further analyze propagation times in relation to their respective stem diameters (time per unit of distance).

Results

Regression Analysis

Regression lines relating ultrasound propagation times to bole diameters for healthy, wetwood-infected, and heartwood-decayed sample trees in Mississippi are graphed in Figure 1. The slopes of the lines of heartwood-decayed trees differ from those for wetwood trees ($P = 0.0001$) and healthy trees ($P = 0.0001$). There is no difference between the slopes of lines for wetwood-infected and healthy trees ($P = 0.0607$), although the regression lines are close to being significantly different. When heartwood-decayed trees are included with wetwood trees, there is a significant ($P = 0.0001$) difference between the slopes of regression lines of this combined group and healthy trees. When healthy trees are deleted from the analysis, the slopes of regression lines between trees with heartwood decay and wetwood trees are significantly different ($P = 0.0001$).

There is no significant difference between any of the regression lines relating ultrasound propagation times to bole diameters for healthy, wetwood-infected, and heartwood-decayed trees in South Carolina (Figure 2). However, when heartwood-decayed trees are combined with wetwood trees, there is a significant difference ($P = 0.0241$) between that combined group and the healthy trees. When the healthy trees are deleted, and the heartwood-decayed trees are compared with wetwood trees, there is no significant difference ($P = 0.1105$) between the regression lines. When heartwood-decayed trees are deleted from the analysis, the wetwood and healthy regression lines are close to being significantly different ($P = 0.05$ 19).

Analysis of Variance

Performing analysis of variance on the data, in the form of propagation times divided by their respective bole diameters (µsec/cm), provided better definition of the linear relationships (Table 1). For South Carolina trees, the time per unit of distance values increased from 4.93 µsec/cm for minor wetwood infections, to 5.26 µsec/cm for moderate infections, to 5.32 µsec/cm for severe infections, corresponding to the wetwood-associated odor. The values for minor and interme-

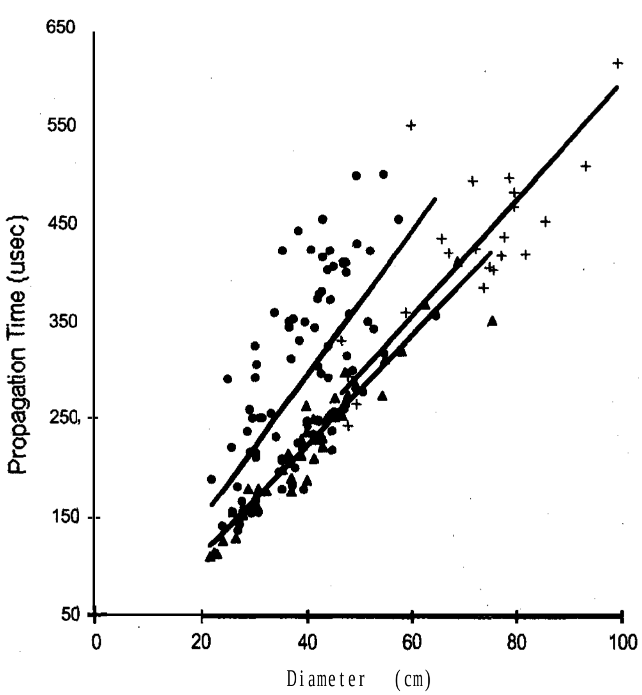

Figure 1. Graph of linear regression lines of Arborsonic Decay Detector readings for trees in Mississippi that were healthy (A), had bacterial wetwood (+), or had decayed heartwood (•).

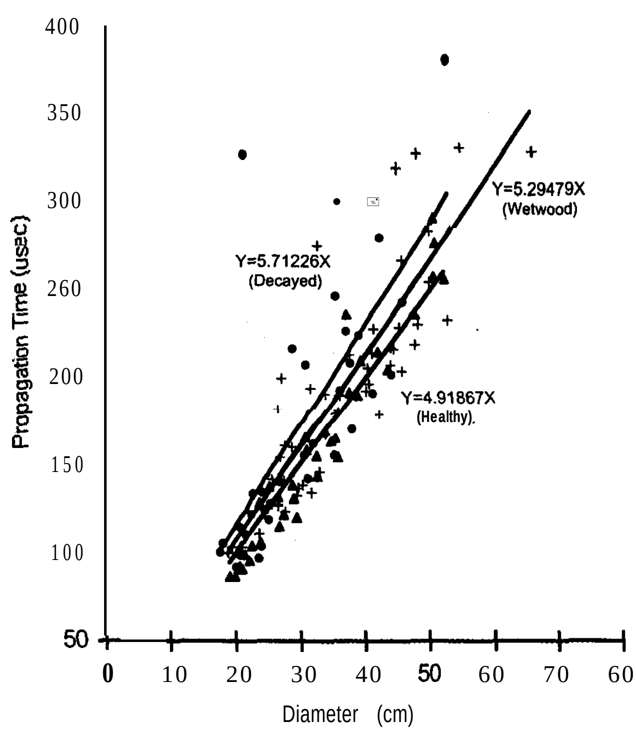

Figure 2. Graph of linear regression lines for Arborsonic Decay Detector readings for trees in South Carolina that were healthy (▲), had bacterial wetwood (+), or had decayed heartwood (•).

Table 1. Arborsonic Decay Detector readings by health status for red oaks in South Carolina and Mississippi.

	South Carolina				Mississippi	
Health status	No.	Time per unit of distance (μsec/cm)	No.	Time per unit of distance (μsec/cm)	No.	Time per unit of distance (μsec/cm)
Healthy	36	4.78 a*	36	4.78 a	91	5.58 a
Minor wetwood	14	4.93 a,b				
Intermediate wetwood	24	5.26 a,b	51	5.18† b	22	5.97† a
Severe wetwood	13	5.32 b				
Heartwood decay	35	5.39 b	35	5.39 b	45	7.36 b

* Means with the same letter in any column are not significantly different at a = 0.05.
† Average value of the time per unit of distance of minor, intermediate, and severe wetwood.

diate wetwood infections did not differ from those of healthy trees. There was no difference in value between heartwood-decayed trees and any of the wetwood-infected trees. However, time per unit distance values were different between healthy trees and heartwood-decayed trees and between healthy trees and trees with severe wetwood infections. This result is supported by the same outcome following a reanalysis of the data with all the wetwood levels combined (5.18 μsec/cm).

The mean value of propagation time per unit of distance for wetwood-infected trees in Mississippi was 5.97 μsec/cm, which did not differ from that of healthy trees (5.58 μsec/cm), but did differ from that of heartwood-decayed trees (7.36 μsec/cm).

It is apparent from Figures 1 and 2, and from Table 1, that propagation times were greater in Mississippi trees of all sizes compared to those of South Carolina trees. This difference may be explained in part by Mississippi trees having larger average dbh's (MS = 44.2 cm; SC = 33.4 cm) and probably having greater water contents, based on their respective soil types and environments, than the trees in South Carolina.

Discussion

To our knowledge, this is the first report examining the use of ultrasound to detect bacterial wetwood in live red oak stems. However, the results of this study suggest that the Arborsonic Decay Detector cannot yet be used to detect wetwood in oak trees with enough certainty to be of practical use to a forester or land manager. There are two possible explanations for this. The first is that the amount of cell wall degradation resulting from a bacterial infection in oak heartwood is insufficient to produce propagation readings (the speed of ultrasound as measured by the ADD) that differ enough to separate them from those of healthy wood. Presently, it may be possible to separate a population of wetwood trees from healthy trees but not individual trees with any degree of certainty. The second explanation concerns the ADD itself. The electronics are preset so that the propagation time in microseconds is displayed when the return signal reaching the receiver attains a certain amplitude. Independent research of ultrasound movement through wood indicates that signal amplitude rather than propagation time (i.e., velocity) is the appropriate variable to measure (Daniel Schmoldt, USDA Forest Service, Blacksburg, Virginia; pers. comm., May 3, 1999). The next step in this research will be to devise an ultrasound system that does not limit amplitude detection and that displays the actual wave forms produced from each test tree. This will allow us to correlate wave form patterns to heartwood structural integrity and health.

The relative positions of the regression lines representing healthy, wetwood-infected, and heartwood-decayed trees agree with what is known biologically about the condition of the heartwood of each tree type. However, based on the close proximity of these regression lines, it would seem difficult to separate individual trees of the three groups based solely on an Arborsonic reading. It is a credit to the sensitivity of the Arborsonic Decay Detector that it was able to define a trend in the relative positions of the three groups that makes sense from a disease perspective. That is, the regression lines describing wetwood oaks in Mississippi and South Carolina fell between the lines, for their respective regions, describing healthy and heartwood-decayed trees. In both instances, heartwood-decayed oaks yielded greater propagation times than wetwood-infected oaks, which in turn, had greater propagation times than those of healthy trees.

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