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Editorial

Recent Advances in Nondestructive Evaluation of Wood: In-Forest Wood Quality Assessments

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Keywords: forest; forest management; genetic improvement; nondestructive testing and evaluation; silviculture; standing trees; wood and fiber properties; wood quality; wood utilization

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Citation: Wang, X. Recent Advances in Nondestructive Evaluation of Wood: In-Forest Wood Quality Assessments. *Forests* **2021**, *12*, 949. https://doi.org/10.3390/f12070949

Received: 13 July 2021
Accepted: 16 July 2021
Published: 19 July 2021

Efficient wood production and utilization requires knowing the wood quality attributes of forest resources relevant to various end uses, prescribing appropriate silvicultural treatments that positively influence wood quality, and then, at the time of harvesting, sorting and allocating standing timbers to the most appropriate markets [1–3]. The field of forestry has many widely accepted field tools, sampling procedures, and models for gathering and summarizing data and making projections of growth, yield, and tree size; however, counterparts for wood quality assessment have lagged behind [3]. One of the reasons for this lag has been a lack of simple field tools permitting rapid collection of wood quality data from trees in a stand or sample plot.

The traditional method for evaluating wood quality in standing trees is to extract core samples from living trees using an increment borer, analyzing trees' growth trends based on inspection of the ring patterns, and measuring basic wood properties (density and stiffness) in a laboratory [4–6]. This procedure has been used by foresters around the world for many years for defining wood quality of forest resources. The main disadvantages of this method are as follows: first, it is time consuming and labor intensive, which often prevents its use because of the high cost involved; and second, the tree is wounded in the coring process even though it has been practiced as a "nondestructive" sampling procedure. To achieve rapid, reliable, and economical wood quality assessment in trees, forest managers and landowners are interested in implementing more robust nondestructive testing technologies in field operations. Nondestructive is a relative term, because damage is done whenever the protective covering of bark is compromised; the term is used in comparison with sampling methods that require the felling of trees.

Since the 1990s, there has been a steady increase in the development of tools for nondestructive assessment of wood quality in trees prior to harvesting. One significant development has been the SilviScan™ system specifically designed for characterizing many wood and fiber properties by taking core samples from trees and then conducting scanning and post analysis in the laboratory [7,8]. This instrument was developed by Dr. Robert Evans and his team in CSIRO, Australia to meet the requirements of plantation assessment and breeding programs. It involves several different measurement principles, including microscopic image analysis (tracheid and fiber diameters, vessel size and position, ring boundary position, ring orientation), X-ray densitometry (density profile, fiber tilt, ring boundary position), and X-ray diffractometry (microfibril angle (MFA), tracheid and fiber 3D orientation, cellulose crystallite width). It can generate a series of high-resolution wood property data from the same wood sample, including wood density, stiffness, microfibril angle, and tracheid properties such as tracheid diameter, coarseness, and cell wall thickness. All SilviScan™ data can be related to individual annual rings so that detailed "tree property maps" can be developed, allowing quantification of the effects of site, silvicultural treatment, or genotype. Currently there are three SilviScan™ systems in operation, one in the University of Melbourne, Australia; one in Innventia, Stockholm, Sweden; and one in FP Innovations, Vancouver, Canada. These three systems are now being used for a range of basic and applied research and commercial programs, providing test data to researchers around the world. These three systems together are capable of measuring 10,000 samples per year. The main advantage of SilviScan™ is that it has the ability to nondestructively assess a large number of trees and produce high resolution wood property profiles from pith to bark and along the tree height. The drawback is that it is a laboratory instrument with a complicated scanning process and relatively high cost.

Near infrared (NIR) spectroscopy is another laboratory technique that can be used to assess the wood quality of standing trees. Similar to SilviScan™, it requires taking core samples or wood chips from trees and then conducting scanning in the laboratory. Near-infrared is the region of the electromagnetic spectrum immediately after the visible region with the wavelength range of 780–2500 nm. NIR spectroscopy can measure the chemical composition of a material very rapidly, with minimum sample preparation. The technique was originally developed for use in biomedical applications. It has also been thoroughly investigated for use in the forest products industry, and it is particularly well-suited to quality control and process monitoring in pulp production [9]. Many studies have been performed to explore the potential of using NIR spectroscopy to characterize wood and fiber properties, specifically linking the wood chemistry to a range of properties, such as tracheid length, density, microfibril angle, and physical and mechanical properties [9,10]. One of the most successful applications of NIR spectroscopy is in the estimation of genetic parameters, particularly those related to pulp production [10]. However, there are some challenges in implementation. For example, calibration requires very extensive work, and it must be maintained and updated. There are also issues related to calibration accuracy and applicability in harsh environmental conditions outside of the laboratory.

Although taking pith-to-bark core samples enables the radial patterns of wood property variation to be understood, such an approach does not capture the circumferential variation that exists in internal wood properties. In addition, the sample collection and preparation costs may also make it impractical to take core samples from multiple heights up the stem of a tree, thus making it difficult to capture the longitudinal variation. To address some of these challenges, Scion—the New Zealand Forest Research Institute Limited, has developed a new semi-automated platform, the DiscBot, for the rapid and cost-effective assessment of wood properties on cross-sectional discs [10,11]. With the DiscBot, a disc is systematically moved under each of five measurement stations to collect data on disc size and shape, spiral grain angle, density, wood chemistry and microfibril angle. Data are collected at high resolution to give two-dimensional wood property maps for the sample. By scanning multiple discs within a single stem, the DiscBot can produce intra-stem wood property maps that provide a more complete picture of the full extent of variation that exists. These data and subsequent simulations provide greater insights into the full impacts of silvicultural practices, environment, and genetics on wood quality of the forest resources.

Another example is the development and commercialization of standing tree acoustic tools for assessing wood stiffness in trees [12–15]. The concept of using acoustic wave velocity as an effective measure of wood quality has been widely recognized in the forest products industry [1,14,16,17]. A resonance-based acoustic method, with a single sensor gauged with the material end, has been successfully used to grade structural timber, logs, poles, and wood-based composite materials (such as laminated veneer lumber and glued laminated timber) [18–20]. However, the resonance-based acoustic tool cannot be used on standing trees because it requires two end-cut surfaces for compressional waves to reverberate between. To measure acoustic velocity on standing trees, a time-of-flight (TOF) acoustic wave technique was developed to gauge two sensor probes with a tree trunk by inserting the probes into the sapwood [21–25]. In tree acoustic measurement, an impact impulse is introduced by a hammer impact on the start probe and TOF readings can be obtained by analyzing the receiving signals of the start and stop sensor probes [21,23,25,26]. The TOF acoustic method has been validated through various field and laboratory experiments.

Hand-held standing tree acoustic tools have been commercialized and are currently being used by many research organizations and forest companies around the world, providing a means for silviculturists, forest managers, and planners to predict the stiffness potential of trees and stands prior to harvest, which enables management, planning, harvesting, and wood processing to be carried out in a way that maximizes extracted value from forests.

The latest development on acoustic wave technology is the automated acoustic optimization system integrated into the processor head of a harvesting machine, allowing the processor head to acoustically test a stem and obtain its stiffness prior to making a log length cutting decision [15]. The system allows wood producers to cut logs according to the measured stiffness, match logs to their requirements, and therefore extract more value from the trees. This automated acoustic optimization system has gone through experimental trials in UK, Australia, New Zealand, and the U.S. and it has shown improved precision over the head-held tool—ST300. While ready for operational application, the system still needs the harvest head manufacturers to adopt the technology and fully integrate it into their harvest head design.

Resistance drilling is another method that has been extensively studied for its use in assessing wood quality of standing trees. The resistance drilling tool is an electronic micro-drill system that measures the relative resistance profile as a thin drill bit is driven into wood. The technique operates on the principle that drilling resistance is directly related to the density of the material being tested [27]. A resistance drilling tool consists of a power drill unit, a thin spade-type drill bit, and an electronic device that can be connected to a computer or a portable printer. As the needle drill bit cuts into the wood in a linear path, the drilling resistance is measured by recording the power consumption. The trace of change in drilling resistance is recorded as a digital representation display. This method was originally designed to characterize the radial density variation within a tree. However, resistance drilling tools have mostly been used for urban tree decay detection and wood structure inspection [28–32]. Recent improvements in resistance drilling instruments have prompted research efforts to evaluate the potential of using resistance drilling to estimate the wood density of standing trees, particularly in tree genetic improvement programs. One of the challenges in assessing wood density of trees using a resistance drilling tool is the effect of friction. Studies have indicated that as the needle drill bit cuts into wood, the wood chips can build up inside the cutting channel and cause friction on the needle shaft, which leads to an increase in drilling resistance [33,34]. New research has offered potential solutions to improve the accuracy of resistance measurement by developing friction models and using the models to remove the shaft friction from the original resistance profiles [35,36]. More research is needed to characterize the friction levels for different tree species.

The research and development of nondestructive evaluation technologies for assessing wood quality of standing trees is still ongoing. Recent technology advances have brought the operational assessment of wood and fiber properties of standing trees into resource evaluation, harvesting operation, forest management, and tree genetic improvement. Significant values are associated with wood and fiber quality in wood supply chain for production of structural lumber, engineered wood products (such as glulam, LVL and CLT), and pulping and paper. Rapid and nondestructive measurements on trees allow this value to be captured through better decision-making, allocation of resources to highest value users, and application of best processing methods.

This Special Issue "Recent Advances in Nondestructive Evaluation of Wood: In-Forest Wood Quality Assessments" calls for research papers on wood quality assessments in standing trees using emerging nondestructive and precision-based technologies and wood quality modeling with a focus on forest resource evaluation and wood utilization. These include SilviScan™, near infrared, DiscBot, acoustic waves, resistance drilling, as well as other novel concepts and methods. We also invite original papers and reviews that address how these technologies and the knowledge obtained from them can support the development of the next generation of forests, e.g., through tree breeding and silviculture.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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