Comparison of SilviScan and optical imaging measurements of tracheid dimensions and wood density

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Abstract
SilviScan uses X-ray transmission measurements along with optical imaging to profile tracheid dimensions and wood density in specially prepared cores. These measurements are useful for predicting the properties of pulp and paper generated from the wood. SilviScan measurements are resolution-limited by the width of the X-ray beam, which was 50 µm in the present study. Trees with growth rings smaller than 200 µm have latewood regions too small to measure without sampling adjacent earlywood, producing erroneous latewood measurements. For these suppressed-growth trees, we developed an all-optical imaging approach called Ring Profiler to contrast with SilviScan. Ring Profiler uses higher magnification than SilviScan, allowing direct measurement of tracheid wall thicknesses. Ring Profiler showed that SilviScan overestimated latewood tracheid radial diameters by as much as 100% in growth rings under 200-µm width. It also showed that SilviScan underestimated density of suppressed-growth latewood by 15-20%. Use of higher magnification limits Ring Profiler's measurements to fewer tracheids than SilviScan's (3% as many in the present study). Ring Profiler lacks the ability of SilviScan to measure microfibral angle by means of X-ray diffraction, and density measurement by Ring Profiler is indirect. Otherwise, all dimensional information provided by SilviScan can be generated at higher resolution using widely available optical imaging technology.

Introduction
SilviScan technology is the recognized leader in characterizing tracheid properties of trees.1 Most softwood trees studied using SilviScan have obvious commercial value for dimension lumber or pulp and paper. Design parameters for SilviScan are therefore suited for measuring fast-growing, thick-walled tracheids typical of plantation trees. In contrast with plantation growth, the U.S. Forest Service has an interest in optimizing the commercial value of small-diameter trees in the natural forests of the Pacific Northwest.2 The overabundance of these trees is a major contributor to the incidence and extent of catastrophic wildfires. Thinning operations to reduce this hazard are expensive. Therefore, it is important to find additional value for these trees beyond their use as biofuels. Owing to the low juvenile wood content associated with their age, exceeding 100 years in some cases, their use as dimension lumber and pulp wood is an attractive option. To explore this option, we had a number of suppressed-growth specimens measured by SilviScan for density, tracheid diameter, tracheid wall thickness, and microfibral angle.2

While SilviScan is capable of quickly measuring a sample with good statistical significance, the spatial resolution of 50 µm (SilviScan II) coupled with line-of-sight measurements through curved growth rings makes it unsuitable for measurements of suppressed-growth trees with annual ring widths less than several hundred microns. Severe averaging of morphological properties in the radial direction may lead to misinterpretation of results. For example, one tree experienced suppressed-growth conditions resulting in an annual growth ring of 160-µm width, containing only 8 tracheid layers in the radial direction (Figure 1). The latewood growth layer containing two or three tracheids (20 µm radially) is small compared to the 50-µm resolution of SilviScan. This leads to individual density measurements based on X-rays that have sampled both earlywood and latewood fibers. The resulting density profile points to a high degree of uniformity between earlywood and latewood that may not exist. In addition, the SilviScan approach of calculating wall thickness from measured density and diameter may not work well for the tracheids of suppressed-growth trees. These are often irregular in shape and much thicker in the tangential direction than in the radial direction, contrary to the assumption of isotropy used in SilviScan's calculation.

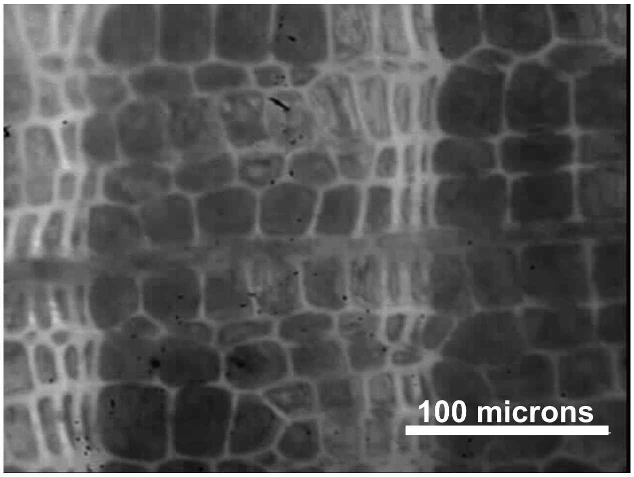

Figure 1. Highly suppressed growth in a Douglas-fir sample.

Ring Profiler

To examine the limits of SilviScan in our application, we developed an optical imaging technique called Ring Profiler (Figure 2).3 The imaging geometry is similar to that used by SilviScan to support its X-ray measurements, but with higher magnification. A field-of-view of approximately 300 μm radial by 233 μm tangential provides a pixel resolution of about 0.6 μm. This is sufficient for direct measurement of average wall thickness for a group of fibers representing earlywood or latewood within a growth ring, an advantage over SilviScan. We also have the flexibility to measure only earlywood or only latewood at any one time. Since SilviScan is automated, it will always have occasions where the 50-μm measurement window includes both earlywood and latewood. The tradeoff is in the field of view. Our example with Ring Profiler only measures 3% of the total number of tracheids scanned by SilviScan. The comparison between Ring Profiler and SilviScan is limited to the first earlywood and last latewood of each growing season tested.

The various methods of measurements by Ring Profiler are suggested in Figure 3. A rectangle highlights a region of interest (ROI) of either earlywood or (as in Figure 3) latewood. The radial and tangential size of the ROI is known from calibration. Several lines are shown within the ROI that cut across the walls of adjacent tracheids. Multiple lines like these are used in the measurement of average tracheid double-wall thickness (assuming the thickness of the middle lamella is inconsequential). Software extracts a profile of luminance values along each line. Pixels where the gray level is higher than that of a suitable running average gray level are designated as wall material.

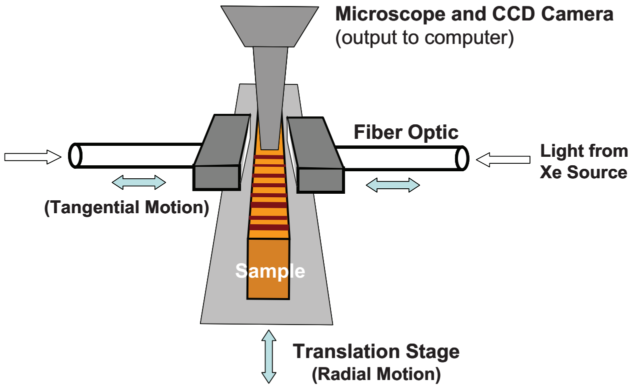

Figure 2. Schematic diagram of Ring Profiler.

Adjacent pixels of wall material are accumulated to determine the double-wall thickness. Lines are either radial or tangential to capture the different thickness in each direction. By comparison, SilviScan wall thicknesses are calculated from a formula that assumes isotropic wall thickness values.

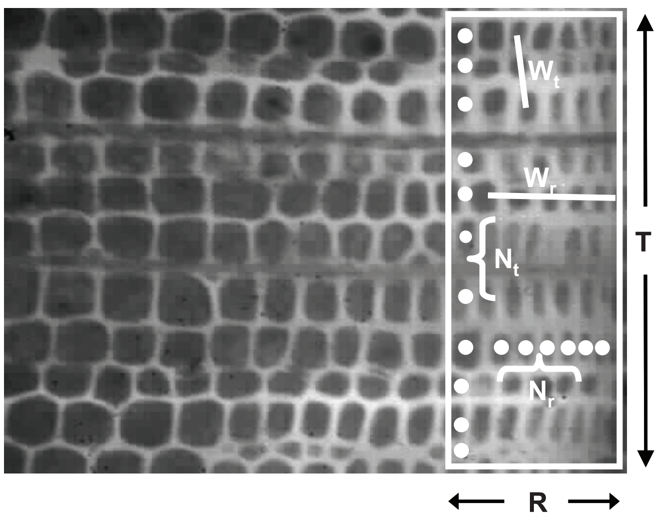

Figure 3. Methods of measurement of average tracheid wall thickness and diameter in a single band of earlywood or (as shown) latewood.

The same gray-level profiles can be used to determine tracheid diameters in the Ring Profiler method. We have also chosen to count the average numbers of radial and tangential tracheids in the ROI (shown as dots in Figure 4) and compute the radial and tangential diameters as the ratio of calibrated ROI dimensions to the corresponding count of tracheids. Average wood density can be calculated from tracheid dimensions or by thresholding the ROI and determining the percentage coverage of wall material. Percentage coverage times the density of cellulose (nominally 1500 kg/m^3) provides the wood density, though proper determination of the threshold value is an issue with this approach.

Results

Figures 4 and 5 show the major results of the comparison between SilviScan and Ring Profiler on a single sample of suppressed-growth Douglas fir.

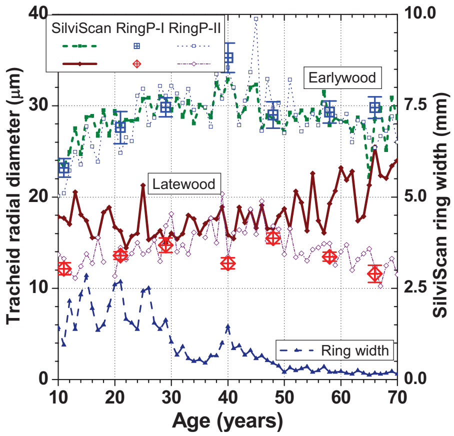

Figure 4. Tracheid radial diameter trend

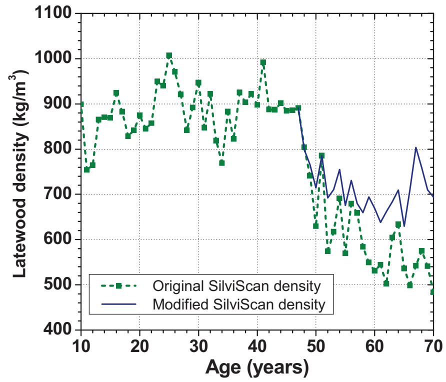

Figure 5. Latewood density trend

In the suppressed-growth years between 50 and 70, SilviScan considerably overestimates latewood tracheid radial diameter, and it underestimates latewood density. Since earlywood density remains relatively constant over the life of the tree, the dramatically decreased latewood density in later years as measured by SilviScan suggests greater uniformity between earlywood and latewood tracheids in the suppressed-growth period. If generally true, this could translate into improved uniformity of pulps made using suppressed-growth fibers.4 However, the latewood density decrease is only about half as big when measured by Ring Profiler as when measured by SilviScan.

Summary

These results demonstrate the need to monitor SilviScan results carefully when annual growth ring widths approach 200 μm or less, and SilviScan spatial resolution is 50 μm. Recently, SilviScan III has demonstrated a spatial resolution of 25 μm, which should eliminate some of the concerns. However, the SilviScan calculation of wall thickness can be a disadvantage at any resolution when the tracheids have unequal wall thickness in the radial and tangential directions, as was the case with the present sample.

References

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