RING PROFILER: A NEW METHOD FOR ESTIMATING TREE-RING DENSITY FOR IMPROVED ESTIMATES OF CARBON STORAGE

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Abstract.—Methods for estimating present and future carbon storage in trees and forests rely on measurements or estimates of tree volume or volume growth multiplied by specific gravity. Wood density can vary by tree ring and height in a tree. If data on density by tree ring could be obtained and linked to tree size and stand characteristics, it would be possible to more accurately predict changes in density and weight of tree biomass with projected changes in tree size and stand characteristics. Ring Profiler is a patented method for characterizing the structure of softwood tracheids and their changes from one tree ring to another over time. Measurements can be converted to density and can be multiplied by volume to estimate total weight and weight of carbon by ring. A sample displaying pith-to-bark ring structure is prepared from a radial core and scanned beneath a microscope as images are taken. Despite the sample's thickness (up to 6mm) it is possible to image it with light transmitted from below using a single light-emitting diode (LED) for illumination. Near-infrared radiation (NIR) from the LED is captured by tracheid walls and travels efficiently to the viewing surface, much as light travels through an optical fiber. NIR captured by lumens tends to be absorbed by particulate matter introduced during sample preparation. The result is a high-contrast image in which tracheid walls are bright, lumens are dark and the interface is sharp. Images containing approximately 400 tracheids each are processed by ImageJ, public software available from the National Institutes of Health (NIH). Measurements include the distribution of radial and tangential diameters and wall thicknesses, from which local density can be estimated and applied to improved estimates of carbon storage. Over time, measurements from Ring Profiler can increase our understanding of tree response to stress.

INTRODUCTION

Forests have been a strong carbon sink in the United States in recent decades. Forest policy makers and forest managers have a keen interest in monitoring and projecting how forest carbon stocks will change and learning how alternate management practices can influence carbon accumulation.

Current methods to estimate weight of total biomass or weight of growth in biomass rely in large part on estimates of wood volume in trees and estimates of average density of trees by species. Wood density can vary by tree ring (age) and height in a tree. The density associated with volume growth can change as the tree ages and can be influenced by stand and site conditions. The weight increase associated with a volume increase will depend on the changing value of density.

To what degree is wood density in a tree ring affected by tree characteristics, stand characteristics, and site characteristics? If data on density by tree ring

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could be obtained and linked to tree size and stand characteristics, it would be possible to more accurately predict changes in density and weight of tree biomass with projected change in tree size and stand characteristics.

With ongoing joint Forest Service and university efforts to revise tree biomass equations, information will be collected on tree volume and wood weight by tree part. With the collection of cross section samples for trees of varying sizes, species, and stand conditions there is an opportunity to collect density for some subsamples by tree ring (age or radius from the center). Modeling this link could allow for more accurate estimates of tree density associated with a given volume or with given volume changes under certain species, stand, and site conditions.

More detailed models could make it possible to answer additional questions about managing for carbon accumulation. Is it possible that forest treatment recommendations to increase carbon weight may differ from treatment recommendations to enhance tree volume? To what degree is slower volume growth in a denser stand offset by higher density in slower growing rings? How does this tradeoff differ by forest type, stand conditions, or site conditions?

The gold standard for measurement of tree-ring density from cores is the SilviScan™ instrument developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Melbourne, Australia (Evans 1994). Using robotic control of optical microscopy, X-ray densitometry, and X-ray diffraction, a complete picture is presented of density, tracheid structure, and microfibril angle over the life of the tree. At present, SilviScan™ is not an instrument for purchase but rather a service. The response time for results may be long for FIA requirements.

At the other extreme is the Haglof Tree Core Reader (Haglof Sweden AB, Langsele, Sweden). This field-worthy device accepts a standard core and provides a 6x magnifier to measure the narrowest growth rings. Though providing much less information than SilviScan™, and no information archiving, it has advantages of lower cost, no core preparation, and rapid field response.

Ring Profiler is intended to fill a niche midway between that of SilviScan™ and the Haglof device (Vahey et al. 2007). Like SilviScan™, it requires a processed core for measurement and produces archived results in a computer-based instrument. Like SilviScan™, it has an optical microscopic component for measuring tracheid structure. Unlike SilviScan™, it avoids the need for an X-ray component by producing a density measurement based on a near-infrared image of tracheid cross-sections. It lacks SilviScan™'s measurement of microfibril angle, but this information is not needed for FIA applications. In final implementation, it would be an instrument for sale rather than a service, allowing the owner-user control of turn-around time.

RING PROFILER CONCEPT

The Ring-Profiler concept is illustrated by Figure 1, showing an LED illuminating a portion of a radially cut sample prepared with the growth direction parallel to the light beam. Both exit and entry surfaces are sanded to a 1200 grit finish and polished with paper. A microscope objective collects transmitted light from the sample and images it on a charge-coupled device (CCD) camera array. Figure 2 shows a more rugged implementation of the optics, along with a representative camera image. Light travels through and along tracheid walls which show up as bright, while the lumens filled with debris from the sanding operation show up as dark. The field-of-view in the radial direction is 0.7 mm. After the image is generated, a scanning mechanism moves the sample 0.7 mm so that the next image aligns with the first. The process continues until the entire radial length is examined, or at least a portion of interest nearest the bark. This may take a matter of minutes.

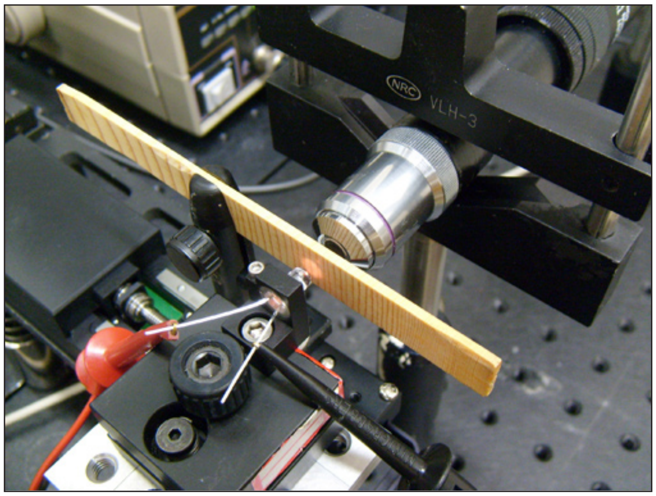

Figure 1.—The Ring Profiler concept.

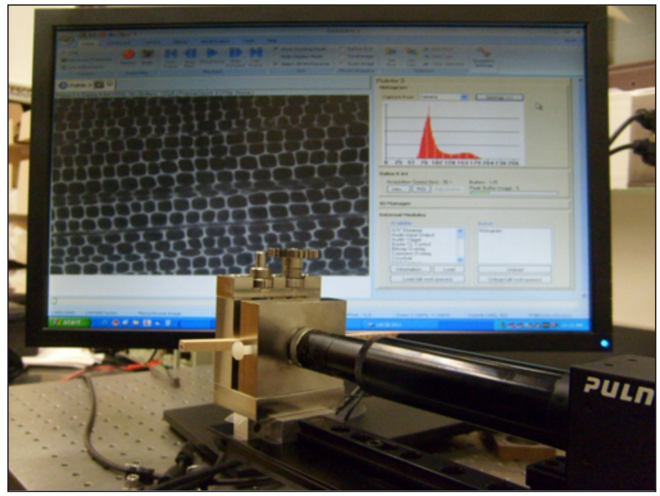

Figure 2.—A current version of Ring Profiler with example image.

The 0.7 mm field of view (FOV) was chosen with suppressed growth in mind. There might be three complete suppressed growth rings captured within this FOV, while for normal growth only a partial growth ring is captured. Image processing must be flexible enough to deal appropriately with each situation. Our focus to date has been on suppressed and intermediate growth, such as shown in Figure 3. A single latewood (LW) band near the center of the image is flanked on the right by the last earlywood (LEW) from the same growth year, and on the left by the earliest earlywood (EEW) from the next growth year.

Image Processing

By blurring the image and thresholding, we created masks for the three distinct bands of the image. The masks allowed us to optimally digitize portions of the original image. For example, Figure 3b shows processed LW, LEW and EEW bands containing lumens and rays as all black, and other material, mostly cell walls, as all white. By taking the dark area density to be 0 kg/m^3 and the white area density to be 1500 kg/m^3, the commonly accepted density of cellulose, we estimated the overall densities of the LW,

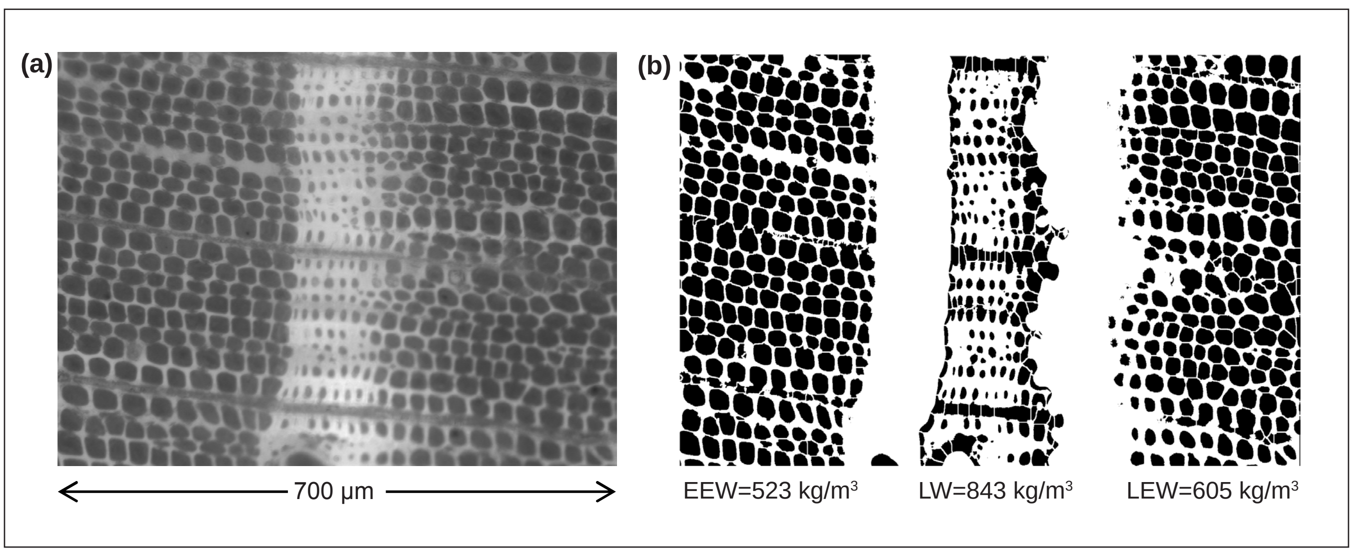

Figure 3.—(a) Latewood (LW)- centered image showing early earlywood growth of the next year (EEW, left) and last earlywood growth of the current year (LEW, right); (b) Binary images of the three sections, showing calculated densities.

LEW and EEW bands of the original image. An added benefit is that we can piece together the annual growth of the tree from the radial dimensions of the bands. This allows the calculation of accumulated mass.

Comparison with SilviScan™

This information may be sufficient for FIA applications. However, further processing of the lumen images of Figure 3b leads to measurements of the radial and tangential diameters and cell-wall thickness, such as are available from SilviScan™. The main point of differentiation from SilviScan™, with regard to measurement capability, is that the SilviScan™ measures density using X-rays and calculates cell wall thickness from density and tracheid diameters. Ring Profiler measures wall thicknesses and tracheid diameters and calculates density. The SilviScan™ approach allows for measurements of more tracheids, producing greater statistical accuracy of results. Finally, SilviScan™ X-ray technology is applied to the measurement of microfibril angle as well as density.

Both SilviScan™ and Ring Profiler require sample preparation from wood cores. This results in the greatest time delay between gathering the core and learning results. There are three SilviScan™ units to serve the world's needs, so there is an additional delay in shipping samples and waiting for prior customers to be serviced. At a targeted cost of ~$20,000, Ring Profiler will be within purchasing range of most testing laboratories, and should become much more widely distributed than SilviScan™. Future marketing directions for SilviScan™ are unknown; however, Ring Profiler has obtained patent protection in the United States (Vahey et al. 2011).

RING PROFILER AND FIA

In the near term, Ring Profiler could be a stationary lab instrument to process and measure cores provided by FIA. Information would be delivered in rough proximity to other FIA information for the same lands to inform management decisions. The information appears comparable to that which would nominally be obtained when the lands are revisited in later years. Suppose a course of remediation prompted by revisiting a forest in year 10 could be prompted by use of Ring Profiler in year 0. This would result in double the expanded growth in biomass in year 20. A quick calculation suggests that if the unmanaged forest grew 25 percent in 20 years, the forest remediated in year 10 would grow 27 percent in 20 years, and the forest remediated in year 0, based in part on Ring Profiler, would grow 29 percent in 20 years. This calculation assumes that remediation improves the content of normal-growth trees from 70 to 90 percent. More careful determination of these "back-of-envelope" numbers provides a starting point for discussion about the relevance of Ring Profiler to FIA.

RING PROFILER IN THE WOODS

In the longer term, Ring Profiler could be qualified for use in the woods. The essential imaging hardware weighs in the vicinity of 2kg, and much has already been accomplished with respect to merging the light source, camera, and sample holder into a stable, precision mechanical unit. Required computing power is commensurate with modern laptops, which adds additional weight and battery power requirements. However, the downloading of images to remote computers by cell or satellite phone is an active area of interest in many fields.

The greatest challenge appears to be producing an acceptable sample from the green core. This is known to be an area of active interest to law enforcement charged with detection of contraband trees, so work by others toward this end may be to the benefit of Ring Profiler.

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