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Dendrochronologia 27 (2009) 159–172
DENDROCHRONOLOGIA
www.elsevier.de/dendro

ORIGINAL ARTICLE

The use of precision dendrometers in research on daily stem size and wood property variation: A review

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Abstract

Dendrometers are instruments which are used to measure the diameters of trees. This review considers the use of dendrometers with high spatial and temporal precision in past and present research, the value of which is increasingly being realised. Various insights into tree growth and physiology can be obtained using high-resolution dendrometers, including the assessment of stem daily water status and the understanding of short-term growth responses to changing environmental conditions. This kind of data is useful for irrigation scheduling, assessing site quality, and developing models of the main drivers of tree growth at sub-diurnal resolution. A third, more novel application is the potential these instruments provide as a ‘‘template’’ that relates temporal measurement of growth to spatial measurements of wood properties. Accordingly, this kind of ‘‘re-scaled’’ data is useful in linking environmental conditions which prevailed as the wood formed to varying wood properties along a pith-to-bark wood profile of the sort generated by systems like CSIRO’s SilviScan™. This can provide valuable insights into how tree ring structure and radially varying wood properties represent past climates. The development of dendrometers, their use in these three main areas, and a systematic approach to growth-wood property rescaling is discussed in this review.
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Keywords: Dendrometer; Stem diameter growth; Wood property variation; Data management; Daily stem size variation

Introduction

A dendrometer is an instrument used to measure the diameter of the stems of trees. It is possible to define two broad categories of dendrometer: those that contact the stem and those that do not (Clark et al., 2000). Instruments which fall into the latter category include such devices as optical forks and prisms. This review is concerned only with dendrometers of the former kind that have high spatial and temporal precision, and with the data which can be generated using such instruments. The value of this data to commercial forestry is becoming better recognized (McLaughlin and Downing, 1995) and high-precision data have been used in a number of recent studies for various purposes and has led to a variety of applications. These include the assessment of stem water status, the understanding of short-term growth responses to changing environmental conditions and the generation of templates that relate temporal measurements of growth and climate to spatial measurements of wood properties (Zweifel et al., 2000; Zweifel and Häsler, 2001; Wimmer et al., 2002; Deslauriers et al., 2003). This last application is particularly useful as an approach in dendrochronology, to better understand climate/wood property

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doi:10.1016/j.dendro.2009.06.008

relationships, particularly in species where it is difficult to ascertain when segments of wood were formed. These applications and the history of the development of precision dendrometers are dealt with in this review, as well as an approach to managing and manipulating the sort of high-resolution data which can be generated. The review approaches the subject by summarising dendrometer development over the last century, by providing an overview of dendrometer applications in various research projects and finally by exploring an approach to managing the intensive data provided by these instruments.

Dendrometer development

High-resolution dendrometer data was already being used in the 19th century, in research looking at stem growth responses in multiple tree species under various weather conditions (Friedrichs, 1897). In the first quarter of the 20th century, MacDougal (1924) conducted an extensive study using high-resolution dendrometers, and identified that reversible changes in plant stem diameter occurred regularly in all species that he studied, even the cactus *Carnegiea*. He found that patterns of diurnal changes in stem radius were somewhat characteristic of a species, and broadly showed that hardwoods exhibited the smallest amplitudes, coniferous trees larger amplitudes, while succulent species had the largest amplitudes. Designs for high-resolution dendrometers were already being published in the 1930s and 1940s (Reineke, 1932; Daubenmire, 1945). Numerous problems have been associated with these precision dendrometers, including unreliability with loss of data and errors from artefacts unrelated to the actual stem growth. Since the early 1970s, however, improvements in technology have removed earlier limitations (LaPoint and Van Cleve, 1971).

Types of high-resolution dendrometers

Breitsprecher and Hughes (1975) classified high-resolution dendrometers into three classes: radial, diametral (both of which may also be called "point-type") or circumferential (which may also be called "band-type"), classes which have been used by other authors (Neher, 1993; Sevanto, 2003). Dendrometers of these three sorts measure changes in stem size in a single radius, across the diameter of the stem and around the circumference of the stem at a particular height, respectively. Band dendrometers, which are of the third type (circumferential) have been widely used in forest research, and have been designed to measure at a wide range of resolutions. Diametral diameters are suited to measuring diameter in small trees, but were initially developed, and are often used, for measuring diameter change in fruit.

The resolution of a dendrometer can be considered in terms of two parameters: time and space. For example, a dendrometer might measure very small changes in stem diameter (high spatial resolution), but measurements might be taken at long intervals (low temporal resolution).

"High spatial – low temporal" dendrometers

Instruments of this type are typically band dendrometers designed to be read manually using vernier measurement scales or similar. If read very frequently, they can theoretically be used to detect small changes in stem size. Since they require, however, that an operator read this scale periodically, the temporal and spatial resolution of the instrument is reduced. Non-recording dendrometers have a number of disadvantages (Fritts, 1976):

- the need to be read visually at a selected time;
- if diurnal changes in stem size are large, readings may need to be taken in the early morning when stem size is at a maximum;
- since two readings are needed to calculate a stem size change, any error causing an over-measurement for one period will be accompanied by an under-measurement for the following period.

Reineke (1932) designed a precision dial dendrometer of the point-type (measuring a single radius) in 1932, later modified by Daubenmire (1945). Daubenmire (1945) listed a number of disadvantages of Reineke's (1932) dendrometer, including the objection that a machinist's assistance would be needed and that errors were incurred from friction mounted parts. In a later paper, Reineke (1948) addressed some of the shortcomings that Daubenmire (1945) had described. Hall (1944) designed and tested a vernier band dendrometer, the limitations of which were discussed by Young (1952), who showed how variable rates of radial growth are around a stem at a particular height. On this note, Bormann and Kozlowski (1962) found that measurement by a point dendrometer at two opposite points of a stem approached the value measured by a single band. Despite the relatively low frequency of measurement recording, systems of this kind are very useful, and still find application in current research around the world (e.g. Knott, 2004). However, in general, band dendrometers have been shown to have a tendency to underestimate growth, or not measure any growth at all, for a period after installation as tree growth takes up initial slack in the bands (Bower and Blocker, 1966; Fuller et al., 1988; Keeland and Sharitz, 1993).

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