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Using X-ray CT based tree-ring width data for tree growth trend analysis

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ABSTRACT

Changes in the environment influence the growth of tree species in Europe. Understanding the drivers of these growth changes is important to predict further growth and adapt forest management. To disentangle the different drivers of growth changes, it is common practice to apply mixed modeling techniques to tree-ring width series. Mixed modeling requires precise, replicated and well cross-dated tree-ring width series. The goal of this study was to compare a recently developed ring width measuring method based on X-ray Computed Tomography images (CT scan) with the standard LINTAB measuring method and to examine whether the same growth trends are detected with both methods using common beech (*Fagus sylvatica*) and sessile oak trees (*Quercus petraea*) as a case study. Although the CT scan method has a lower resolution than LINTAB measurements, it is of interest since it measures wood density in addition to ring width and it is less laborious in comparison to standard ring width measuring methods. No significant differences in ring width were found between the two measuring methods. The small non-significant difference between the two methods could largely be explained by the drying of cores needed for CT scanning. The same growth trends were detected with both methods: for common beech and sessile oak in Southern Belgium. These findings suggest that ring widths measured on CT scan images can be used as input for long-term modeling of tree growth changes for the targeted tree species.

1. Introduction

Tree growth has been changing in European forests over the last decades (Becker et al., 1994; Bergès et al., 2000; Dittmar et al., 2003; Piovesan et al., 2008; Charru et al., 2010; Kint et al., 2012; Latte et al., 2015). Climate change, increased carbon dioxide and ozone concentration, and increased nitrogen deposition have been identified as drivers of these growth changes (Matyssek et al., 2010; Bontemps et al., 2011; Babst et al., 2013; Reyer et al., 2013). Understanding how tree growth changes over time is essential to adapt forest management to future predicted climate change (Lindner et al., 2010). This forest management adaptation is important since forests deliver important ecosystem services such as wood production and carbon sequestration (Thorsen et al., 2014).

Tree-ring series are true archives of the past, storing information on tree growth change drivers which are acting at different time scales. Inter-annual fluctuations in growth may be related to yearly variations in temperature or precipitation, while on longer time scales environmental change and tree aging may influence tree growth. Understanding the drivers of past growth changes will help to predict possible growth changes in the future. By applying a mixed modeling strategy to tree-ring width (TRW) series, the relative importance of these different drivers of growth change can be disentangled (Martínez-Vilalta et al., 2008; Kint et al., 2012; Aertsen et al., 2014). Analyzing tree growth trends requires accurate measurement of TRW, which is an essential condition in this and other fields of dendrochronology (Grissino-Mayer, 1997). Also replication is important for dendrochronology: by increasing the number of samples, possible anthropogenic (e.g. management) and non-

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Table 1
Location and characterization of the four forest sites where trees were cored.

Site	Coordinates	Elevation (m.a.s.l.)	Slope (°)	Orientation	Beech trees	Oak trees
Marche-en-Famenne	50°27′N 5°6′E	400	5	South-east	2	9
Libin	50°6′N 5°1′E	360	5	North	10	8
Nassogne	50°6′N 5°3′E	260–300	0	–	12	8
Couvin	50°2′N 4°44′E	300	5	East	3	6

anthropogenic (e.g. climate change) signals stored in tree-rings are enhanced, and errors due to missing rings or measurement errors are reduced (Fritts, 1976; Grissino-Mayer, 1997). Another premise of dendrochronology is cross-dating; i.e. by comparing growth variation within and among trees in a particular tree population the correct dating of TRW series is assured (Fritts, 1976). Black et al. (2016) showed that cross-dating is important to retain low- and high-frequency variability in TRW series. The abovementioned dendrochronological principles, i.e. accuracy, replication and cross-dating of the TRW measurements, determine the validity and the explanatory power of TRW series (Fritts, 1976; Maxwell et al., 2011), and the method used to measure TRW will influence these. Dendrochronology requires TRW measuring methods that are accurate and fast in order to obtain high numbers of precise TRW measurements.

Currently, several methods exist to measure TRW. These methods differ in resolution, degree of sample preparation, work load and cost, all of which directly or indirectly influence the accuracy, replication and cross-dating of the TRW series. The decision on which TRW measuring method will be used is mostly based on practical arguments, such as: experience, visibility of tree-ring boundaries and availability of measuring devices. Little research exists that compares accuracy of different TRW measuring methods (Maxwell et al., 2011; Arenas-Castro et al., 2015). To our knowledge, there are no studies available that evaluate the effect of the applied TRW measuring method on the outcome of TRW data based analysis, such as growth change modeling.

In addition to conventional TRW measurements with LINTAB (Speer, 2010) or Velmex, a recently developed method by Van den Bulcke et al. (2014) uses 3D X-ray CT scan images (hereafter called CT scan) to measure TRW based on micro-density profiles (De Ridder et al., 2010). 3D X-ray images of increment cores are produced by the CT scanner from which wood density profiles can be extracted. Maximum core length and resolution are determined by the amount of processed cores in one scan, as well as the physical limitations of the system (see, Dierick et al., 2014). Ring boundaries can be detected semi-automatically based on the density profile by setting a threshold in density. Furthermore, given the 3D nature of the images, a correction for structure direction by correcting ring and grain angle is applied. Conventional cross-dating procedures, as described above, are used to ensure correctly dated TRW series and in addition, density-based pattern matching can be applied to detect errors in TRW series (De Mil et al., 2016).

Measuring TRW with the CT scanner has the advantage that TRWs are measured semi-automatically resulting in less laborious work in comparison to LINTAB TRW measurements (Maes et al., in prep.). Note that semi-automated ring detection is also possible with Windendro and Co-recorder on flatbed scans of tree cores. Besides, CT scan images can be stored allowing re-measurement. In addition to TRW also density is measured with the CT scanner, although samples need to be dried which might influence the TRW measurements, due to shrinking. In this paper we will investigate if measuring TRW with the CT scanner (at a resolution of 110 μm) can increase the replication without impeding precision or cross-dating accuracy of measurements. We will compare two ways of measuring TRW. (i) Method 1: conventional method, tree-rings measured with the LINTAB system with a measuring accuracy of 10 μm; (ii) Method 2: tree-rings measured on CT scan images with a resolution of 110 μm using semi-automatic detection of ring borders based on wood density profiles.

In a first step, we will look if the two TRW measuring methods agree closely. This includes quantifying the effect of drying the cores prior to scanning, which is required if in addition to TRW correct density estimates are of interest. In a second step, the effect of TRW measuring method on growth trend modeling is evaluated. We examine whether the same long term growth trends are detected using data from the two TRW measuring methods.

2. Materials and methods

2.1. Tree-ring data

54 and 62 cores from beech (*Fagus sylvatica*) and oak trees (*Quercus petraea*) respectively, were collected in the winter of 2014 with a 5 mm increment corer (Suunto) at 1 m above ground (58 trees in total, 2 cores per tree). Cored trees were (co)dominant and growing in even-aged stands. Trees were located in four forest sites in the Ardennes region in the South of Belgium (Table 1), more particularly in mature stands on well-drained brown acidic soil (WRB: Dystric Cambisol). Elevation ranges from 260 to 400 m above sea level (m.a.s.l.) and slope ranges from 0 to 5 °.

Collected tree cores were stored in paper straws to dry. The steps followed for measuring TRW on CT scan images and LINTAB are visualized in Fig. 1.

The cores were first scanned with the X-ray CT scanner (NanoWood CT facility, Ghent University) at a resolution of 110 μm. This resolution was sufficient for the tree species in this study (see also De Mil et al., 2016). For other tree species with smaller rings resolution can be adjusted (see a.o. Van den Bulcke et al., 2014, 2009). Prior to scanning, cores were put in a custom-made cardboard holder (in one holder 33 cores of 60 cm fit, when scanning at 110 μm) and oven-dried for 24 h at 103 ± 1 °C. Nanowood (Dierick et al., 2014) is a multi-resolution system built at the Ghent University Centre for X-ray Tomography (UGCT) and is controlled by a generic LabView interface. After scanning, reconstruction was performed with the Octopus Reconstruction software package (Vlassenbroeck et al., 2007), licensed via InsideMatters (www.insidematters.be). Next, the X-ray CT toolchain was used to indicate tree-rings (De Mil et al., 2016). A correction for grain and tilt angle was applied to the digital cores. Density profiles were used to automatically indicate tree-ring boundaries. For beech maximum density values were used as tree-ring boundaries. For oak minimum density values were used, as wood density did not increase until the end of the growing season (Fig. 2). Falsely indicated rings or not indicated rings were removed or added by inspecting the CT scan images and during the cross-dating process.

After scanning the cores, visibility of tree-rings was increased by microtoming the surface to be able to measure TRW with LINTAB