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Age estimation of different tree species using a special kind of an electrically recording resistance drill

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ABSTRACT

The determination of tree age is an important issue for urban green planning, forestry and dendrology; finding non-destructive and quasi-non-destructive methods for this purpose is of great theoretical and practical importance. The resistance drilling method is quasi-non-destructive because the average diameter of an opening that remains after drilling does not exceed 3 mm. Do electrically recording resistance drills allow precise assessment of tree age? The aim of this study is to assess the accuracy of determining the number of tree rings based on an examination of this special kind of drilling resistance profiles for three tree species, the pine *Pinus sylvestris* L., the oak *Quercus robur* L., and the birch *Betula pendula* ROTH. In 2015 and 2016, 15 pine trees, 15 oak trees, and 15 birch trees were randomly selected. For each studied tree, a measurement was conducted using the electrically recording resistance drill IML-Resi E400 with a flat-tipped 1.5/3 mm steel needle (research sample), and an increment core was taken (reference sample). The drill used was not a real Resistograph®. The analysis of the E400-profiles underestimated the number of tree rings; the mean bias error (MBE) values were –6.5, –2.5, and –6.0 years for pine, oak, and birch, respectively. The proportion of investigated trees with less than five years difference between the research and reference samples varied from 38.4 (birch) to 66.7 (oak) percent. The accuracy of tree age determination was lowest for birch and highest for oak. The binomial generalised linear model (GLM) revealed that the most accurate tree age assessments were obtained from tree rings wider than 2 mm. The measurements clearly showed that the electrically recording resistance drill IML-Resi E400 enables a quick, although approximate, tree age assessment. Future research should concentrate on electronically regulating and recording drills, providing a higher spatial and signal resolution, and a stronger correlation to wood density.

1. Introduction

Tree age assessment is important for both the theory and practice of urban green planning, forestry and dendrology. The threshold for stress tolerance and growth changes as trees age; these thresholds significantly influence the variability in the morphological structure of trees, including their crown projection area and the extent of their root systems. Modelling the relationships between tree age and these elements is particularly important for urban green planning. Various models are employed in forecasting an optimal location for trees, taking into account the need for providing them with a suitable living space for their crowns and root systems (Iakovoglou et al., 2002; Larsen and Kristoffersen, 2002; Grabosky and Gilman, 2004; Brasch et al., 2009).

In practice, various methods are used when assessing wood structures (e.g., Nowak et al., 2016; Gao et al., 2017). Generally, the issue of the invasiveness of these methods have been considered destructive and can increase the risk of inducing pathogenic infections; this is an issue that has received scientific attention for several dozen years (e.g., Zielski and Krąpiec, 2004; Wessels et al., 2011). Non-destructive and quasi-non-destructive methods are categorised into two groups: global test methods (e.g., ultrasonic and stress wave techniques) and local test methods (e.g., resistance drilling method) (Niemz and Mannes, 2012; Nowak et al., 2016).

The resistance drilling method has been shown to be a suitable tool for estimating tree age when using electronically regulating and recording drills and measurement in high resolution (Rinn et al., 1996). The technical basics of this method area product of the results of the physics thesis that originally developed resistance drilling; a combined project started in 1986 that included the tree-ring lab of Hohenheim University and the Institute of Environmental Physics of Heidelberg

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University (1986–1988) (Rinn, 1989). The challenge was to develop a method for measuring wood density profiles because tree rings can be identified by changes in radial density profiles (Rinn, 1989, 2012). The detection of defects was a side-effect and was later used for practical application (Rinn, 1990; Isik and Li, 2003; Wang et al., 2003; Wang and Allison, 2008; Zhang et al., 2009; Rinn, 2016). The resistance drilling method is based on measuring the resistance of wood against a needle driven into the trunk at a controlled speed. Power consumption of the engine during drilling indicates the wood density and its resistance against the penetrating needle. The variability in resistance values is recorded in graphical form (resistograms) that illustrate the resistance amplitude. The resistance values are determined by local wood density. The main cyclic pattern is shaped by wood density of individual latewood and earlywood zones, and small peaks are connected by the intra-annual density structures (Rinn, 2014, 2016). Drill holes produced by the resistance drilling machines have much smaller diameters (3 mm) than those left by increment cores taken with an increment borer. There are three main groups of resistance drills: mechanical, electrical, and electronically recording (electronically regulating and recording). More than 80% of the resistance drills on the market are versions with mechanical recording, often powered by an ordinary battery-driven drill (Rinn, 2013, 2016).

The technical resolution of the resistance drills with a mechanical recording mechanism was not sufficient for a detailed assessment of density profiles (Rinn, 2015). Are resistance drills with electrical recording able to differentiate between latewood and earlywood? Do electrically recording resistance drills allow precise assessment of tree age? The aim of this study is to assess the accuracy of determining the number of tree rings based on the examination of drilling resistance profiles for three tree species, the pine *Pinus sylvestris* L., the oak *Quercus robur* L., and the birch *Betula pendula* ROTH. The selection of the tree species was based on their specific, unique wood structures in the transition zone between latewood and earlywood.

2. Materials and methods

2.1. Basics of resistance drills

In the early 1980s, two German engineers, W. Kamm and S. Voss, developed a drill that recorded the penetration resistance of a thin needle in wood. This achievement prompted a development that led to the first functional resistance drilling machine (Rinn in 1986), and the first series of portable resistance drills (Fein&Rinn: Densitomat 300 in 1987, Rinn&Teo: Densitomat 350 in 1989) (Rinn, 2013).

Resistance drills with mechanical recording were characterised by resonance effects of the recording spring mechanism, which led to erroneous readings from over-tuned profiles. These mechanically recorded profiles had been shown to be unreliable, systematically leading to inaccurate evaluations. The developers consequently switched to electrical and then Rinn started developing electronically regulating and recording resistance drills (details see Rinn, 2012, 2016). Until today, there have been more than 20 different kinds of resistance drills released on the market: Sibtec (DDD, DDD2000), GPA (XDG400, D400), TEREDO (1, 2, 3), IML (R1280/1410, M300/400/500, F300/400/500, E300/400/500, and B400), and Rinntech (R2350, R3450, R4450/S, R5450/S, R6500/PR/EA/ED/SC). Only a few of these resistance drills meet the technical conditions in terms of resolution and precision for the trademark Resistograph® (Rinn, 2013).

2.2. Study site, drilling resistance profile and increment core

The study area is located in the Tenczynek forest section of the Krzeszowice forest district, near Kraków. The investigations were carried out in fresh deciduous and fresh mixed-deciduous habitat types in mixed stands with pine, oak, and birch.

In 2015 and 2016, 45 sample trees were randomly selected from the Kraft's second class (Assmann, 1961) in one-story forest patches, or the upper canopy layer (> 2/3 top height; 100 according to IUFRO; Leibundgut, 1956) in patches with complex structure. In total, 15 pine trees, 15 oak trees, and 15 birch trees were sampled. The diameter at breast height (DBH) distributions in these stands were characterised by varying degrees of asymmetry with local maximums; modelling these DBH distributions usually requires the use of a mixture of probability density functions (e.g., Podlaski, 2011a, b). The sample trees were in good condition; they did not reveal any pathogenic symptoms (Szewczyk and Guz, 2012).

The most accurate tree age assessments are those based on counting the number of tree rings on the trunk cross-section. A tree ring is a layer of xylem cells formed within a single growing season, produced by meristematic cells of the cambium. Determination of tree age uses a phenomenon of periodic activity of the cambium. The variability in the tree ring structure determined by photoperiod and periodic growth inhibition of tissues, which is more pronounced in temperate zone trees, ensures a relatively accurate tree age determination. Some errors may occur due to the formation of additional tree rings within a single growing season caused by the loss of an assimilative apparatus and the necessity to replace it with a new one in the same year. Tree age assessment is usually performed by extracting samples from the trunk using an increment borer and analysing these samples.

A measurement was conducted for each sample tree, at a height of 1.3 m, using the electrically recording resistance drill IML-Resi E400 with a flat-tipped 1.5/3 mm steel needle (research sample). This drill is not a real Resistograph® (Rinn, 2013). Locations for sample extraction from each trunk were carefully selected. The drilling resistance measurements were taken at a universal drilling speed of 20 cm/min with maximum sensitivity of measurements. The plane of drilling was stabilised in two directions, parallel and perpendicular to the axis of drilling, to ensure that the needle was driven as centripetally as possible. The printouts produced by a mobile printer after every measurement were compared with the electronic images generated in the IML-E-Tools 2000 software.

From each sample tree, within 3 cm of the previously drilled hole, an increment core was taken using an increment borer (reference sample). Tree-ring widths were measured with a microscopic measuring instrument, with an accuracy of 0.01 mm, connected to a computer. The individual tree-ring width series were cross-dated. As quality criteria, the *t* value (Baillie and Pilcher, 1973) and the collinearity of increment, Gleichlaüfigkeit (Buras and Wilmking, 2015), were considered. Absent tree rings were found for two birch trees; therefore, 15 pine trees, 15 oak trees, and 13 birch trees were analysed.

An essential element of the analysis was a visual assessment aimed at the comparison of consistency of the boundaries between tree rings determined using the resistance drilling method with those identified precisely on increment cores. The boundaries between tree rings were determined based on an assumption that there is a considerable difference in density of latewood and earlywood; clearly distinctive peaks of curves were considered to represent the boundaries between particular tree rings (Fig. 1).

2.3. Statistical analyses

The accuracy of the tree age assessment based on the resistance drilling method for each investigated tree species was calculated using the mean bias error (MBE) and the mean absolute error (MAE):

$$\mathrm{MBE} = \frac{1}{n_\bullet}\sum_{i=1}^{n_\bullet}(l_{ri} - l_{ci}) \tag{1}$$

$$\mathrm{MAE} = \frac{1}{n_\bullet}\sum_{i=1}^{n_\bullet}|l_{ri} - l_{ci}| \tag{2}$$

where l_{ri} is the number of tree rings determined using the resistance