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Testing the accuracy of resistance drilling to assess tree growth rate and the relationship to past climatic conditions

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ABSTRACT

Assessing tree growth trends over time is a central but challenging aspect of urban forest management. The potential damage caused by invasive devices used in dendrochronological analysis is a common concern among urban foresters. Thus, the development of a less-invasive method for assessing tree growth rate faster that provides reliable results is clearly beneficial. In this study, resistance drilling (RD) profiles were compared with stem core assessments (Core) to estimate the growth rate of 78 trees of three species (*Quercus robur, Ulmus procera,* and *Platanus x acerofolia)*. All studied trees were core-sampled in 2013 and then resistance drilled in 2015 at a stem height of 1–1.3 m in both north (N) and west axes (W). The dependency and accuracy of paired annual ring series (CORE measurements and Resi reading) were tested using ANOVA and regression analysis. In addition, point and event year tests were determined to confirm the accuracy of the RD to assess growth trends at both population and tree level. Growth series from both methods were cross-dated to test the reliability of RD to relate historical tree growth to past climatic conditions. ANOVA analysis confirmed that average ring width values and age of 70 out of 78 trees were statistically similar for both methods and similar for both sampled stem axes. Within each tree, regression analysis indicated significant correlation between cored ring datasets and paired resistance drilled ring datasets (R^2 = 0.78–0.95, $p < 0.05$) across species. RD reliably detected pointer years at population level for *Q. robur* only. For all species, RD could not adequately detect event years at tree level. Regardless of species and drill axes, RD was less accurate in measuring ring width below 1 mm. For all species, RD yielded lower intercorrelation indices and greater number of “A” flagged segments as compared to CORE. Overall, RD can successfully estimate mean annual ring values to a comparable standard as conventional CORE analysis. However, the RD device used in this study did not detect the inter-annual growth pattern to the same standard as stem CORE analysis, RD should not be used to replace dendrochronology in climate-tree growth studies.

1. Introduction

In general terms, tree growth rates are critical inputs regarding site index assessment, long term monitoring health, population dynamics and stand yield prediction (Hu et al., 2018; Moser et al., 2017; Stephenson et al., 2014). In particular, measuring tree growth rate may 1) improve our assessment of the age structure of tree stands (Nikolova et al., 2011; Oldfield et al., 2015; Worbes et al., 2003;) improve our understanding of how different tree species grow in different sites (Cedro and Nowak, 2006; Rogers et al., 2014; Searle et al., 2012;) advance our understanding of how different species respond to climatic variability (Gillner et al., 2013; Ordóñez and Duinker, 2014;) help identify robust species that withstand extreme climatic events such as drought (Chen et al., 2010; Fahey et al., 2013; Sedmák et al., 2014); and, 5) assist our ability to forecast and assess threats such as pests, diseases and wood decay associated with aging trees (Neil and Wu, 2006; Orozco-Aguilar et al., 2018; Tubby and Webber, 2010).

Dendrochronology is the most used method to conduct growth-climate studies in urban, peri urban, plantations and natural forests worldwide (Dolanc et al., 2013; Gillner et al., 2014; Helama et al., 2012; Leal et al., 2015; Nitschke et al., 2017; Pretzsch et al., 2017; Rozendaal et al., 2010). Variation of tree annual increments is influenced by management practices (planting density, thinning, pruning, fertilization and irrigation regimes) as well as climate (changes in temperature, water availability and CO_2 concentration over time (Moser et al., 2016; Scharnweber et al., 2011; Searle et al., 2012; Stravinskienė et al., 2015). Several approaches, analytical tools and indices have been proposed to assess tree growth patterns as a natural

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response of climatic variability. Among these approaches, cross-dating is a standard procedure used to synchronize tree annual increments and date to their exact calendar years of formation, and to elucidate whether past climatic information can be linked to growth records (Bartens et al., 2012; Gillner et al., 2013). Pointer years (synonymous with event years and signal years) is another approach used to statistically understand the impact of extremes climatic events, such as frost and drought events on tree growth (Eilmann and Rigling, 2012; García-Suárez et al., 2009; Hartmann et al., 2015; Meir et al., 2015). Positive and negative pointer years are defined as remarkably wide, and narrow annual increment frequently detected within the same group of trees (Bunn, 2008; Lara et al., 2015; Salzer et al., 2009). A third approach is referred to as component of resilience which consist of a set of indices used to assess tree growth rate before, during, and after climatic events, such as hurricanes, fire, frost and extended drought (Castagneri et al., 2014; Fahey et al., 2013; Moser et al., 2017; Vogt et al., 2017; Volgusheva et al., 2011).

The potential damage of using invasive devices (stem cores and resistance drills) to enable dendrochronology analysis is a constant concern among urban foresters and tree growers (Baum and Schwarze, 2007; Gao et al., 2017; Wessels et al., 2011). However, literature regarding the effect of stem coring and resistance drilling on tree mortality and the development of decay in trees is both scarce and contrasting. Early research supported the argument that the coring holes and stem wounds may play a role in wood discoloration and decay infection (Helliwell, 2007; Laplamme, 1979; Schwarze and Heuser, 2006 Weber and Mattheck, 2005), yet recent research found no significant effect of coring on tree mortality and decay in undisturbed forest stands (van Mantgem and Stephenson, 2004; Wunder et al., 2013, 2011). Species growing in urban environments might be more sensitive to coring and resistance drilling, but the current lack of long-term evidence means that both approaches may cause wood damage but are unlikely to hasten tree breakage or mortality. Overall, the comparative effect of coring or drilling on wood decay infection of urban trees remains untested.

Dendrochronology research first requires coring trees twice (two axes are needed to cross date the samples), second obtained cores need mounting, sanding, and last, annual increment delimitation demands careful measurement under the microscope, which overall is a time-consuming process. Therefore, the development of an alternative method to assess growth rates of standing trees which is reliable as dendrochronology but more rapid will be of great benefit to urban foresters and researchers. Resistance drilling allows a rapid evaluation of wood properties in standing trees, presence of decay and cavities in poles and the assessment of wood density in both forest plantations and urban forests (Johnstone et al., 2007; Koeser et al., 2016; Luley et al., 2009; Oliveira et al., 2017; Orozco-Aguilar et al., 2018; Wang and Allison, 2008). For instance, Johnstone et al. (2011) and Isik and Li, 2003 successfully used resistance drilling to predict mean wood density values of *Eucalyptus globulus* and *Pinus taeda* plantation trees, respectively. Both studies suggested the usage of resistance drilling as a suitable and far more time and cost-effective way than core sampling and traditional dendrochronology to assess trends in growth of forest grown and urban trees. However, impartial tests to determine whether resistance drilling is as accurate or as reliable as dendrochronology to perform annual increments analysis and further climate-growth studies are limited.

To our knowledge, the first attempt to use resistance drilling for estimating growth rates of *Taiwania cryptomerioides* plantation trees was done by Wang et al. (2003). Later, Lukaszkiewicz et al. (2005) evaluated 50+ *Tilia cordata* street trees of variable size and developed a regression model describing trends in growth of trees whose age was known, but in many cases planting records are not available to support such approach. Lukaszkiewicz and colleagues found on-field limitations when using resistance drilling such as 1) drilling tangential to the ring structure, 2) internal decayed wood which affects the quality of the resistance drilling profiles for annual increment analysis and, 3) limited length of the boring bit which restricts its utilization in large/mature trees. In addition, Ukrainetz and O'Neill (2010) reported that resistograph readings are sensitivity to various environment and instrument factors. Contrary, Guller et al. (2012) revealed promising result of the usage of resistograph outputs for annual ring measurements of *Punis brutia.* The aim of this study was to assess whether resistance drilling can be used to reliably assess the growth rates and growth patterns of a sample population of urban trees. To this end the following research hypotheses were tested: 1) Tree growth rates estimated from stem core measurements are comparable to those from resistance drilling regardless of the tree species, 2) Tree growth rates estimated from stem core measurements are comparable to those from resistance drilling reading in the identification of pointer and event years and, 3) Tree growth series from stem core measurements and resistance drilling readings are similar in the assessment of climate-growth patterns across species.

2. Materials and methods

2.1. Study site

The research was carried out in the urban forest of the City of Melbourne, Australia (37°48′S, 144°57′E). The climate of Melbourne is temperate with an average annual rainfall of 656 mm with the wettest months being from September to December. The annual average temperature is about 19.7 °C ranging from a highest average in February (25.7 °C) and the lowest in July (13.4 °C) (www.bom.gov.au). This study sampled 100 urban trees from six parks and five streetscapes located across an elevation gradient between 12 and 49 m above sea level. Soil analyses (provided by the City of Melbourne) found that the six sampled parks (n = 32 soil samples) have predominantly loam-silt loam soils while streetscapes (n = 12 soil samples) have predominately sandy loam – loam soils. Soils under street-based trees had significantly ($P < 0.05$) more sand, less silt, less organic matter and higher pH than soils under park trees. Differences between specific parks and streets were also found for clay, sand, silt and pH; however, no differences were found in soils under different tree species across these sites (City of Melbourne, 2012; Nitschke et al., 2017).

2.2. Background silvics of the three species

The Melbourne's city council maintains ~70,000 trees in parks and streets with an average tree density of 26.5 ha^{-1} (± 18 ha^{-1}) and a canopy cover of 12.3% (3–20%). The five most common species are *Eucalyptus camaldulensis*, *Platanus x acerifolia*, *Ulmus* spp. and *Corymbia maculata* which account for 29% of the total tree population. More than 50% of the species are native to Australia and most exotic species originated from Europe, followed by North America and Asia (Dobbs et al., 2013). The tree population of Melbourne includes an important population of approximately 6500 European elms (*Ulmus procera, U.* × *hollandica, U. glabra*, and *U. minor*) that have never been affected by Dutch elm disease (*Ophiostoma* spp.) (Frank et al., 2006). These elms with plane tree (*P.* × *acerifolia*) account for many of the large street trees in Melbourne and contribute character to many parks (City of Melbourne, 2012).

The city's urban forest is undergoing unprecedented change and many trees are approaching the end of their lifespan due to a combination of factors, such as age, extended drought, extreme heat waves and water restrictions (City of Melbourne, 2012; May et al., 2013). The recent period of drought (1997–2009) and water restrictions triggered an irreversible decline for many trees, particularly planes trees, *Elms* spp. and *Populus* spp (May et al., 2013). In addition, a concomitant infestation of elm leaf beetle (*Pyrrhalta luteola*) may have contributed to the decline in tree health within this genus. A useful life expectancy (ULE) assessment undertaken on 35 0000 street and park trees