Terrestrial laser scanning reveals consistent dependencies between mean wood density and tree crown architecture

V. Kankare[1], N. Saarinen[1], J. Pyörälä[2], T. Yrttimaa[1], S. Huuskonen[3], J. Hynynen[3], M. Vastaranta[1]

[1]School of Forest Sciences, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland
Email: ville.kankare@uef.fi, ninni.saarinen@uef.fi, tuomas.yrttimaa@uef.fi, mikko.vastaranta@uef.fi

[2]Department of Forest Sciences, University of Helsinki, P.O. Box 27, 00014 University of Helsinki, Finland
Email: jiri.pyorala@helsinki.fi

[3]Natural Resources Institute Finland, Latokartanonkaari 9, 00790 Helsinki, Finland
Email: saija.huuskonen@luke.fi, jari.hynynen@luke.fi

1. Introduction

Wood density is an important quality characteristic determining the suitability of raw material for a specific end use. In addition, the interest in wood density has considerably increased in recent years due to its importance in estimating forest biomass and carbon storage (Clough et al. 2017, Nam et al. 2018). Wood density of a tree species is widely expressed as a value from basic wood-density tables existing in scientific literature. However, it is known to be a site-specific parameter that can significantly vary within and between trees due to each individual tree adapting to its growing environment (Saranpää 2003). This has created a need to obtain wood density information over varying tree communities but there has not been a viable technological or methodological solution to characterize tree architecture (especially crown characteristics) sufficiently. Recently, the methodological development of terrestrial laser scanning (TLS) has reached a point where characterization of tree crown and branch properties is possible (e.g. Pyörälä et al. 2019). Therefore, the aim of this study was to evaluate the relationship between crown characteristics (shape and size) and wood density variation of Scots pine (*Pinus sylvestris* L.) trees in three different study sites. The main research questions were: (1) Are the dependencies between tree crown architecture and mean wood density consistent between different study sites? (2) What are the most influential crown characteristics explaining the wood density variation?

2. Data and Methods

The three study sites consist of even-aged (approximately 50 years) Scots pine dominated forests that are maintained by Natural Resources Institute Finland (detailed description in Saarinen et al. 2020). During the establishment, six different thinnings were conducted in addition to a control (i.e. no treatment). Treatments included three thinning types (thinning from below, above and systematic thinning) with two different thinning intensities (moderate and intensive). Wood density samples were collected using increment borer at fixed stem height of 1.3 m in March-April 2019 from 135 trees. Sample trees were selected based on the diameter distribution to represent different tree and stand characteristics. Bored samples were then analyzed with X-ray microdensitometry (Peltola et al. 2007) and following attributes

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were calculated: ring basal area weighted mean values for wood density (WD_g) and mean ring width (RW_{mean}).

TLS data was collected with Trimble TX5 3D laser scanner (Trimble Navigation Limited, USA) with multiple scan setup to achieve best possible point coverage (see details Saarinen et al. 2020). The descriptive crown characteristics were derived from the point cloud data using algorithms originally developed by Yrttimaa et al. (2019, 2020) and Pyörälä et al. (2018). Derived characteristics included: crown height ($Crown_H$), area ($Crown_A$), volume ($Crown_V$), width ($Crown_W$), length ($Crown_L$), mean branch diameter ($Branch_D$), and mean whorl-to-whorl distance ($Whorl_D$).

The relationship between the crown characteristics, WD_g and RW_{mean} in the tree study sites were first investigated based on Pearson's correlation matrices. Then, a linear mixed effects model (LME) in package nlme (Pinheiro et al. 2016) of the R-software (R Core Team, 2019) was fitted and the analysis of variance was applied in testing the statistical significance of each crown attribute.

3. Results

Analysis showed that no strong (i.e. > 0.6) or statistically significant (p-value < 0.05) correlations between WD_g and crown characteristics were found in the three study sites. The highest correlation was found for $Branch_D$ (0.24). However, when evaluating correlations within thinning treatment wise, slightly higher correlations were visible. The highest correlations were found between $Crown_H$ (0.53) and BranchD (-0.53) from intensive thinning from below and control plots, respectively but overall the correlations were low. In contrast, when evaluating the correlations between crown characteristics and RW_{mean}, strong (i.e. > 0.6) and statistically significant (p-value < 0.05) correlations were observed for $Crown_A$, $Crown_V$ and $Crown_W$. Observed correlations were at similar levels between different study sites. The highest correlation (0.67) was observed between $Crown_V$ and RW_{mean}.

LME modelling showed that none of the crown characteristics had a statistically significant (p-values > 0.05) effect on WD_g in any of the tree study sites. In contrast, LME modelling showed that almost all of the crown characteristics had statistically significant effects (p-values < 0.05) on RW_{mean}. Only exceptions were BranchD and WhorlD.

4. Discussion and conclusion

Results showed that the dependencies between crown characteristics and WD_g and RW_{mean} within the three study sites are consistent. Even though no strong correlations or statistical significant effects were observed between WD_g and evaluated TLS derived crown characteristics, the resulting correlations were similar between the study sites. Similar results have been reported previously and for example Jaakkola et al. (2005) concluded that intensive thinning is required to have considerable effect on WD_g. Results showed that the short timeframe since the establishment (approximately 15 years) affected more on crown characteristics than on wood density attributes. This indicates that the overall change in crown characteristic is faster compared to wood density attributes.

However, results showed that the crown characteristics tended to have a more significant effect and higher correlations on RW_{mean} than WD_g. The most influential characteristics were $Crown_W$, $Crown_A$ and $Crown_V$. These characteristics also had a statistically significant effect on RW_{mean} based on LME modelling. This result supports the fact that the increasing size of the tree crown causes trees to allocate their growth to stem size to increase the structural carrying capacity. Therefore, the future research should focus on evaluating the development (i.e. growth) of crown characteristic in relation to mean density variation.

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