Terrestrial Laser Scanning Reveal Connection Between Changes in Tree Stem Dimensions and Crown Structure

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1. Introduction

Tree growth is a physio-ecological phenomena of high interest among researchers across disciplines. It is known that the growth of trees is affected by the availability of growth resources such as temperature, nutrients, water and sunlight as well as competition between trees (e.g. Tomé and Burkhart 1989; Ericsson et al. 1996). With limited growth resources, a tree aims to reach its living crown upwards for enhanced lighting conditions before allocating growth to its supporting structures (Oliver and Larson 1996). Therefore the allometric relationship between primary and secondary growth of trees has been considered as an indicator of trees' adaptation to the environment (King et al. 2006; Bartholomé et al. 2013).

Observing changes in tree characteristics has conventionally required either retrospective measurements of destructively sampled trees or modeling (Weiskittel et al. 2011; Kershaw et al. 2016). The use of close-range sensing techniques such as terrestrial laser scanning (TLS) have today enabled non-destructive approaches to reconstruct the three-dimensional (3D) structure of trees and tree communities in space and time (e.g. Dassot et al. 2011; Liang et al. 2016). Prior studies have shown that the characteristics of both stem (e.g. Liang et al. 2013; Olofsson and Holmgren 2016; Saarinen et al. 2017) and crown (e.g. Henning and Radke 2006; Seidel et al. 2011, 2015; Metz et al. 2014) can be characterized using point cloud-based methods. Changes in the structure of trees and tree communities can then be analysed when the point cloud acquisition campaign is repeated to cover a few years monitoring period (e.g. Luoma et al. 2019, 2021; Yrttimaa et al. 2020a).

This study aims at improving the understanding of tree allometry in general and the relationship between tree stem and crown dynamics in particular using bitemporal TLS point clouds. As presented in prior studies (e.g. Seidel et al. 2015; Pretzsch 2021), tree growth is seemingly affected by stem and crown structure that can be accessed using point cloud-based methods. The objective of this study was thus to investigate how tree crown structure and its dynamics reflect changes in stem characteristics. We hypothesize that the growth of attributes characterizing tree stem dimensions (i.e., basal area and stem volume) is related to the attributes characterizing tree crown structure and its changes (i.e., projection area, perimeter, surface area, volume, length, center of mass). The findings of this study are assumed to be beneficial in justifying upscaling applications where detailed ground-sampled information from the target tree characteristics of interest is generalized at the entire forest landscape level by making use of the allometric relationship between the target characteristics and features obtained from airborne remote sensing techniques.

2. Materials and methods

The experimental design of this study consists of 37 circular sample plots (r = 11 m) and 1280 trees and is located in Evo, southern Finland (61°19.6′ N 25°10.8′ E). The study site encompasses diverse southern boreal forest structures including both managed and single-layered as well as unmanaged and multi-layered forests. A multi-scan TLS campaign was first carried out in the spring/summer of 2014 (T1) and repeated in the autumn of 2019 (T2) to capture at least a five-year monitoring period in between the observations (for more details, see Yrttimaa et al. 2020a). A point cloud classification procedure presented in Yrttimaa et al. (2020b) was applied to detect trees and to separate points

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originating from tree stem (i.e. stem points) from points originating from branches and foliage (i.e., non-stem points). The stem points and a point cloud processing method developed in Yrttimaa et al. (2019) were used to derive stem attributes such as basal area and stem volume at T1 and T2. Attributes characterizing crown structure were obtained by enveloping the non-stem points with a 2D/3D-convex hull object for which a set of features, such as projection area, perimeter, surface area, volume, length, and center of mass, were derived. Changes in the examined stem and crown attributes were computed by subtracting the T1-attributes from the T2-attributes (see Figure 1). Correlation coefficient (r) was utilized in assessing the relationship between the stem and crown attributes.

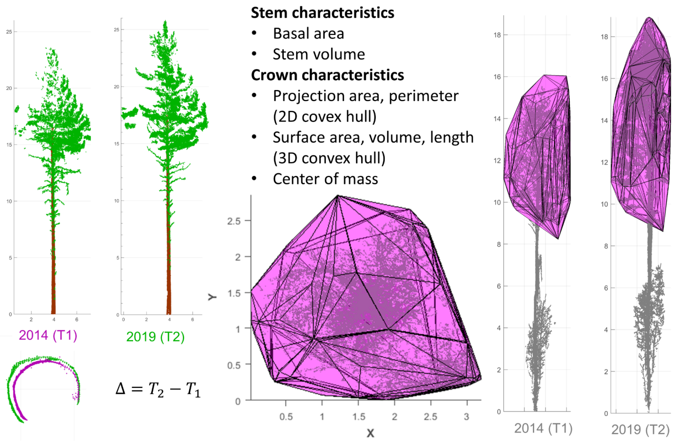

Figure 1. Illustration of the tree characteristics derived from the classified point clouds.

3. Results and discussion

A total of 736 trees could be detected from the point clouds at both time points with their stem and crown characteristics derived using the point cloud-based methods. Investigations of the relationships between stem growth and crown dynamics revealed that basal area increment and stem volume increment were best correlated with attributes characterizing the crown dimensions at T1 and T2. Correlation coefficient of 0.37-0.46 was obtained depending on the crown attribute in question (see Table 1). The relationship was noticed to be stronger (r = 0.65-0.77) for trees in managed sample plots with sparse and even canopy structure. This finding is in line with that reported by Seidel et al. (2015) that the physical dimensions of a tree crown are closely related with radial tree growth. However, seemingly lower correlations were recorded between stem growth and changes in the crown characteristics (Table 1). Changes in the center of mass of the crown as well as crown length were the most correlating crown characteristics with r = 0.17-0.23. This can be explained by the fact that, in general, tree growth is affected by competition between trees that can be captured through the structural status of a tree crown (Metz et al. 2013; Seidel et al. 2015). Here, the monitoring period covered a relatively short period of time with respect to the lifespan of trees in boreal forests. As per the general knowledge, a tree prioritizes reaching its living crown upwards for enhanced lighting conditions before allocating growth to its supporting structures (Oliver and Larson 1996). Thus, changed growing conditions first affect the dynamics of crown structure with stem growth following with a delay. More prediction power for estimating stem growth through the structure of tree crown is assumed to be gained by taking neighbourhood competition into account (see e.g. Metz et al. 2013).

Table 1. Correlation coefficient (r) indicating the relationship between increments in stem dimensions (basal area and volume) and crown characteristics derived at T1/T2 and their change (in parenthesis).

Crown characteristics	Basal area increment	Stem volume increment
Projection area	0.45 (0.05)	0.38 (0.10)
Perimeter	0.46 (0.04)	0.37 (0.09)
Surface area	0.46 (0.11)	0.40 (0.25)
Volume	0.45 (0.06)	0.42 (0.25)
Center of mass	0.40 (0.19)	0.36 (0.23)
Length	0.33 (0.17)	0.30 (0.23)

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References

Bartholomé J, Salmon F, Vigneron P, Bouvet JM, Plomion C, Gion JM. 2013. Plasticity of primary and secondary growth dynamics in Eucalyptus hybrids: a quantitative genetics and QTL mapping perspective. *BMC plant biology, 13(1), 1-14.*

Dassot M, Constant T, Fournier M. 2011. The use of terrestrial LiDAR technology in forest science: application fields, benefits and challenges. *Annals of forest science, 68(5), pp.959-974.*

Ericsson T, Rytter, L, Vapaavuori E. 1996. Physiology of carbon allocation in trees. *Biomass and Bioenergy, 11(2-3), 115-127.*

Henning JG, Radtke PJ. 2006. Ground-based laser imaging for assessing three-dimensional forest canopy structure. *Photogrammetric Engineering & Remote Sensing, 72(12), 1349-1358.*

Kershaw Jr, JA, Ducey MJ, Beers TW, Husch B. 2016. Forest mensuration. *John Wiley & Sons.*

King DA, Davies SJ, Noor NSM. 2006. Growth and mortality are related to adult tree size in a Malaysian mixed dipterocarp forest. *Forest Ecology and Management, 223(1-3), 152-158.*

Liang X, Kankare V, Yu X, Hyyppä J, Holopainen M. 2013. Automated stem curve measurement using terrestrial laser scanning. *IEEE Transactions on Geoscience and Remote Sensing, 52(3), 1739-1748.*

Liang X, Kankare V, Hyyppä J, Wang Y, Kukko A, Haggrén H, Yu X, Kaartinen H, Jaakkola A, Guan F, Holopainen M, Vastaranta M. 2016. Terrestrial laser scanning in forest inventories. *ISPRS Journal of Photogrammetry and Remote Sensing, 115, 63-77.*

Luoma V, Saarinen N, Kankare V, Tanhuanpää T, Kaartinen H, Kukko A, Holopainen M, Hyyppä J, Vastaranta M. 2019. Examining Changes in Stem Taper and Volume Growth with Two-Date 3D Point Clouds. *Forests 10 (5), 382.*

Luoma V, Yrttimaa T, Kankare V, Saarinen N, Pyörälä J, Kukko A, Kaartinen H, Hyyppä J, Holopainen M, Vastaranta M 2021. Revealing Changes in the Stem Form and Volume Allocation in Diverse Boreal Forests Using Two-Date Terrestrial Laser Scanning. *Manuscript submitted in publication.*

Metz J, Seidel D, Schall P, Scheffer D, Schulze ED, Ammer C. 2013. Crown modeling by terrestrial laser scanning as an approach to assess the effect of aboveground intra-and interspecific competition on tree growth. *Forest Ecology and Management, 310, 275-288.*

Oliver CD, Larson BC. 1996. Forest stand dynamics: updated edition. *John Wiley and sons.*

Olofsson K, Holmgren J. 2016. Single tree stem profile detection using terrestrial laser scanner data, flatness saliency features and curvature properties. *Forests, 7(9), p.207.*

Saarinen N, Kankare V, Vastaranta M, Luoma V, Pyörälä J, Tanhuanpää T, Liang X, Kaartinen H, Kukko A, Jaakkola A, Yu X, Holopainen M, Hyyppä, J. 2017. Feasibility of Terrestrial laser scanning for collecting stem volume information from single trees. *ISPRS Journal of Photogrammetry and Remote Sensing, 123, 140-158.*

Seidel D, Leuschner C, Müller A, Krause B. 2011. Crown plasticity in mixed forests—quantifying asymmetry as a measure of competition using terrestrial laser scanning. *Forest Ecology and Management, 261(11), 2123-2132.*

Seidel D, Schall P, Gille M, Ammer C. 2015. Relationship between tree growth and physical dimensions of Fagus sylvatica crowns assessed from terrestrial laser scanning. *iForest-Biogeosciences and Forestry, 8(6), 735.*

Tomé M, Burkhart HE. 1989. Distance-dependent competition measures for predicting growth of individual trees. *Forest Science, 35(3), 816-831.*

Weiskittel AR, Hann DW, Kershaw Jr JA, Vanclay JK. 2011. Forest growth and yield modeling. *John Wiley & Sons.*

Yrttimaa T, Saarinen N, Kankare V, Liang X, Hyyppä J, Holopainen M, Vastaranta M. 2019. Investigating the feasibility of multi-scan terrestrial laser scanning to characterize tree communities in southern boreal forests. *Remote Sensing, 11(12), 1423.*

Yrttimaa T, Luoma V, Saarinen N, Kankare V, Junttila S, Holopainen M, Hyyppä J, Vastaranta, M. 2020a. Structural Changes in Boreal Forests Can Be Quantified Using Terrestrial Laser Scanning. *Remote Sensing, 12(17), 2672.*

Yrttimaa T, Saarinen N, Kankare V, Hynynen J, Huuskonen S, Holopainen M, Hyyppä J., Vastaranta, M. 2020b. Performance of terrestrial laser scanning to characterize managed Scots pine (Pinus sylvestris L.) stands is dependent on forest structural variation. *ISPRS Journal of Photogrammetry and Remote Sensing, 168, 277-287.*