Quantifying Tree Crown Plasticity with TLS Data for Improved Individual-tree Growth Models

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1. Introduction

Given certain site conditions, growth of individual trees and consequent spatiotemporal dynamics of forest stands depend principally on inter-tree competition for light as well as other potentially limiting resources (Caplat et al. 2008, Kolobov and Frisman 2016). Various models have been developed to predict tree growth, but most of them are relatively simplistic: trees are conceptualized as vertically oriented and stationary objects defined primarily by their stem diameter, and competition between them is determined as a result of tree sizes and stand-level characteristics. These models are applicable for providing reasonably accurate estimates of tree growth over various conditions, but too naïve to cover the whole range of actual variation.

To narrow down the gap between the model outputs and the underlying complex determinants of tree growth, both spatial and structural parameters have been added to the models. Spatially explicit models have been developed to improve competition assessment by using the locations of single trees, which conventionally are measured as x,y coordinates of the breast height or the tree base. While the spatially explicit dependencies and related causalities can improve our understanding of forest structure, the use of actual tree locations instead of distance-independent approaches had seemed to add little additional value when predicting tree growth and mortality, even in structurally complex forests (Kuehne et al. 2019). In terms of structural characteristics, the primary focus has been on the crown, given that aboveground interactions between trees are mediated by the size, shape, and relative position of their crown elements (Davies and Pommerening 2008). Inclusion of crown dimensions has been mostly limited to simple and easily measurable parameters such as height of the crown base or living crown ratio, which can be considered as indicators of the past competition experienced by the tree (e.g. Hasenauer et al. 2006).

The approaches described so far are however not taking full advantage of all the crown-related structural parameters. Crown radius, area or volume are important characteristics in terms of the photosynthetic capacity of a tree, to either substitute or complement the crown length. Furthermore, tree crowns are characterized by a high degree of plasticity which is affected by microscale competition on the available resources (Davies and Pommerening 2008), and trees have potential to lean towards less contested spaces as a result of phototrophism (Strigul et al. 2008). These dynamics may be a partial reason for the low performance of spatially explicit models, which base only on stem coordinates (García 2014a). Lee & Garcia (2016), for example, found that accounting for tree plasticity reduced the importance of the stand spatial structure in a tree growth model for mixed-species stands.

The practical complication with crown-related structural parameters has been the inability to extract them by conventional field measurement tools, but modern technologies such as terrestrial laser scanning (TLS) enable capturing this information from standing trees in their natural environment (Seidel et al. 2011, Krůček et al. 2019). In our study, we take advantage of TLS data collected from various locations in Finland, reflecting a range of site conditions in boreal forests. We focus on Scots pines (*Pinus sylvestris* L.) and Norway Spruces (*Picea abies* (L.) Karst.) in pure and mixed stands by measuring various advanced crown-related parameters. We link this information to the location and characteristics of the neighbouring trees, intending to quantify the effects of inter-individual competition and consequent plasticity of the tree crowns in 3D space. Finally, we aim at estimating models to predict the extracted crown parameters with subsequent potential to improve individual tree growth models.

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2. Data and Methods

TLS data applied in this study was acquired in 2017–18 as a part of large plot-wise data collection plan. Of altogether over 250 plots with manual tree measurements (r = 9.00 m), 12 pine-dominated and 12 spruce-dominated stands were selected for this study (Figure 1). These plots represented mature forests with different site characteristics and tree densities, located in southern and middle Finland where competition on light was expected to be limiting tree growth, and were visually assessed as feasible for the extraction of individual tree clouds. The selected 24 plots had 255 manually measured tally trees, which had been determined using a relascope-based sampling strategy. The tally trees included 128 Scots pines, 103 Norway spruces and 24 trees of other species, which had diameters at breast height (DBH) between 73 and 425 mm and tree heights between 5.7 and 29.1 m, respectively.

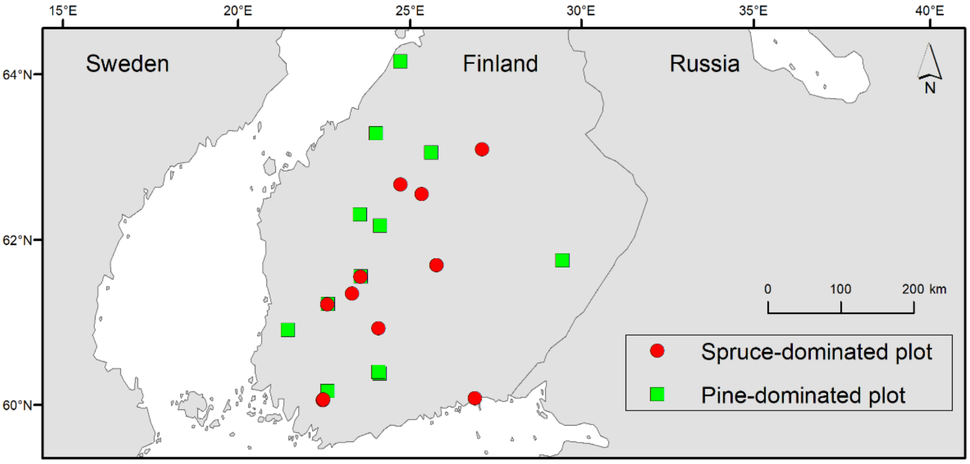

Figure 1: Location of the study plots. Some of the plots are closely located, and therefore overlapping on the applied map scale. Background map: © EuroGeographics for the administrative boundaries.

Each plot was scanned using Leica P40 terrestrial laser scanner from 4-5 stations. Distinct scans were then co-registered and processed through automated analyses to locate the trees. First, a digital terrain model was created to indicate the ground level, and thereafter the trees were detected based on point concentrations organized as near-vertical planes. Breast height coordinates and diameters were predicted using a further developed version of slice-based circle fitting method as presented by Pitkänen et al. (2019), and stem directions were estimated using the lowest part of the stem. TLS points of all the tally trees were semi-automatically extracted from the plot-wise clouds by first assigning connected point clusters in the vicinity of the tree to the candidate single-tree cloud, and then manually cleaning the remaining parts of the neighbouring trees. All the plots also included a number of other trees without field measurements. They were not extracted as individual TLS point clouds due to the high workload of data processing but recognized as competitor trees in the analyses based on their location and DBH.

All the crown parts of the tally trees were then extracted, and their extents were modelled using 3-D convex hulls. They were then calculated crown base height (from the tree base), crown height, width, volume, and surface area. Various indices regarding to the crown shape and symmetricity were calculated as well, and coordinates of the crown centroid and treetop (i.e. the highest TLS point) were extracted to measure their potential shift from the breast height coordinates. Further, competition between the trees was assessed using size ratios of the various earlier calculated features, weighted by subject-to-competitor distances (Pommerening and Maleki 2014). Then, all the crown-related parameters were correlated to tree, stand and competition characteristics with a generalized linear mixed modelling (GLMM) framework to identify the dependencies and potential drivers of these features.

Further, we considered the crown extent as the tree assimilation zone as defined in Garcia (2014a, 2014b), and assumed similar dynamics to also occur underground for the root system. Using the package *siplab* (Garcia, 2014b) of R Statistical software (R Core Team, 2021), species-specific functions for predicting the centroid of the assimilation zone (i.e of the crown) were fitted. A default uniform resource spatial distribution was used, and then the parameters of the influence function, allotment and resource efficiency were fitted to the observed data.

3. Results and Discussion

The GLMM models will reveal the significance of the stand characteristics, spatial arrangement of the trees and competition between the individuals for the observed crown characteristics and their plasticity. Further, the assimilation zone, predicted using the *siplab* framework, will provide a starting point for enhancing individual tree growth models. Part of the associated outcomes, however, will be further elaborated in the forthcoming studies.

4. Conclusions

TLS technology can provide important eco-physiological information on trees and forests, which is based on non-destructive point cloud measurements at a millimetre level accuracy. This study applies TLS-derived information to identify species-specific drivers and dynamics related to resource competition, which is reflected by the morphological plasticity of trees. Further, preliminary simulation of assimilation zones is expected to have linkages with growth modelling of individual trees, therefore providing potential for further research according to the key findings.

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