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Report on forest growth analysis

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1 Introduction

The purpose of this study is to test whether tree growth can be modelled based on multitemporal observations of LiDAR scans of forest stands. The growth models would be useful for growth simulation tasks in a logging planner application. Timing of logging and thinning operations could be planned more accurately with good models for simulating future growth of forest stands.

1.1 Material and Methods

This study will compare three different methods to estimate the annual growth of the forest stands in the study area. The first method (Method I) is based on the calculation of the dominant height (H_{dom}) of a stand with a model developed by Kotivuori et al. (2016) [3]. The second method (Method II) uses PreFor Oy's individual tree detection (ITD) inventory models based on point clouds. The model estimates dominant height as the mean height of the 100 largest trees by diameter at breast height (DBH or $d_{1.3}$) per hectare. Breast height is defined as 1.3 m above ground. The third method (Method III) is similar to the second but uses field reference measurements of tree DBH as input data.

1.1.1 Study Area

The study area is located in Evo in southern Finland and consists of nine test plots with varying and in places partially overlapping geometries. The origins of the locations and geometries of the plots are unknown. For the purpose of this study, the plots have been labeled A to I as shown in the figure below. The plots vary in sizes between 0.28 and 0.38 hectares.

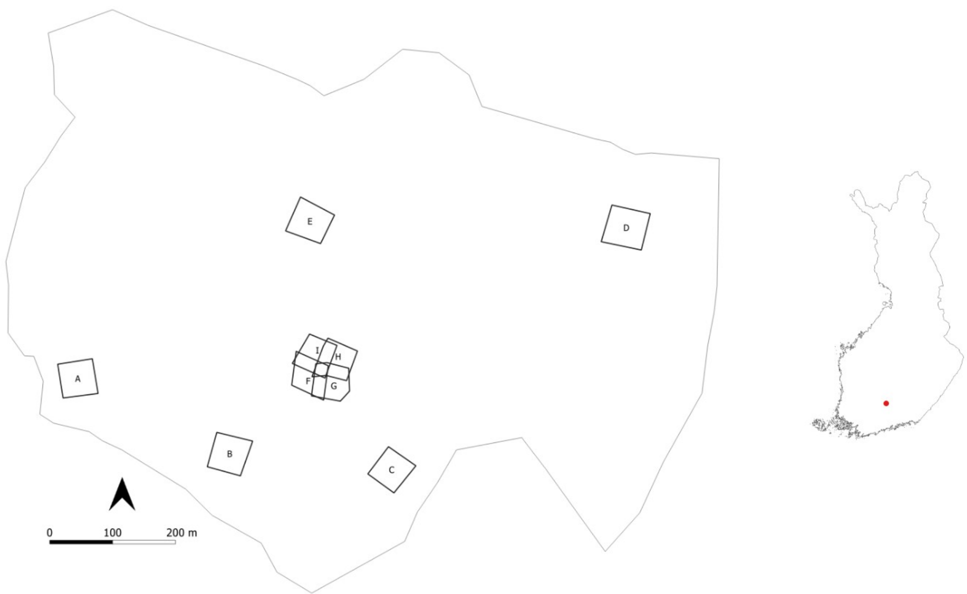

Figure 1: The nine plots labeled A to I are located in a forest property in Evo, Finland.

1.1.2 LiDAR Data

The test area has been LiDAR scanned by PreFor on two occasions, 10 May 2023 and 14 October 2025. Thus, there are three growing seasons between the scans. The scans produce point clouds that are used for individual tree detection and species classification with PreFor's proprietary models. The DBH of trees is estimated with models that take tree species, height, and crown width as input.

1.1.3 Method I: Estimation of Dominant Height from Point Clouds

This area-based method is based on a model for estimating dominant height (H_{dom}) of a forest stand from point clouds [3]. The equation of the nationwide (Finland) model is

$$H_{dom} = 3.1475 + 0.9855 \times h95_F$$

where $h95_F$ is the 95th height percentile of the first return points in the point cloud. The H_{dom} is calculated individually for each plot. As this is an area-based model, it does not distinguish between tree species.

1.1.4 Method II: Estimation of Dominant Height from ITD Inventory

This method is based on PreFor's forest inventory which is based on a set of individual tree detection (ITD) models developed by the company. The models detect, localize and classify trees by species from point clouds. In ITD applications, the dominant height is determined as the mean height of the 100 trees with the largest DBH per hectare [2]. For example, H_{dom} for a plot with a size of 0.28 hectare would be calculated as the mean of the 28 trees with the largest DBH.

1.1.5 Method III: Field Reference Measurements of DBH

The DBH of all trees with a value greater than or equal to 70 mm in plots B to I were manually measured in 2023 and 2025. Manual field measurements were not collected for plot A. The terrain and a large number of trees made it too difficult and time consuming to individually measure each tree in plot A. Plot A was also dominated more by spruce (*Picea abies*) and birch (*Betula spp.*), and for the purposes of this study, it was decided to focus on stands dominated by pine (*Pinus sylvestris*). In total 1950 trees were manually measured.

The height of the measured trees is estimated with a reverse DBH to height model developed by Kalliovirta and Tokola (2005) [1] that estimates the height of the trees based on DBH. The Kalliovirta and Tokola models have specific values for parameters depending on the geographical area of Finland and the tree species.

The measurements of this method can be regarded as ground truth and the performance of methods I and II can be assessed by comparing their results to this. The drawback with this method is the error that stems from the measurement with the caliper. Trees are rarely circular, but more often oval. In the Evo reference measurements it was observed that DBH can vary by up to 15% depending on the direction the caliper is placed on the trunk. Because of this fact, it is important to measure the trunks from two directions and use the mean of these measurements.

Figure 2: The diameter of all the trees with a $d_{1.3}$ greater than or equal to 70 mm were measured with a caliper. The trunks of pines (*Pinus sylvestris*) are often not round but oval. The measured diameter is the mean of the largest and smallest diameter measured from different directions on the trunk at 1.3 m height.

1.2 Results

Tables 1 and 2 show the results of the dominant height measurements with the three methods used in this study.

Plot	Method I		Method II		Method III	
	2023	2025	2023	2025	2023	2025
A	24.00	24.33	21.53	23.42	-	-
B	20.62	20.99	18.74	20.07	17.97	19.21
C	22.54	23.41	20.92	22.66	20.53	22.05
D	26.86	27.17	25.33	26.04	25.28	25.87
E	26.40	26.79	25.33	25.79	24.71	25.76
F	27.48	27.65	25.81	26.53	25.72	26.51
G	26.82	27.25	25.37	26.12	25.61	26.32
H	26.92	27.02	25.43	26.01	25.60	26.24
I	26.53	26.86	25.29	25.63	24.55	25.62

Table 1: Observed dominant heights (H_{dom}) in meters of the plots at 2023 and 2025.

Plot	Method I	Method II	Method III
A	0.11	0.63	-
B	0.12	0.44	0.41
C	0.29	0.58	0.51
D	0.11	0.24	0.20
E	0.13	0.16	0.35
F	0.06	0.24	0.26
G	0.14	0.25	0.24
H	0.03	0.19	0.21
I	0.11	0.11	0.36

Table 2: Observed mean annual growth of dominant heights (H_{dom}) in meters over the three year period of the dominant canopy layer in nine test plots in Evo, Finland.

1.3 Discussion

The results clearly show that we can measure the growth of forest stands with multitemporal observations based on LiDAR scans. The estimation of growth varies quite significantly depending on the method used. Method I, which simply measures the height of the forest canopy surface, clearly underestimates growth. The method is problematic because it does not distinguish between tree species. The composition of species of a stand affects the competition for nutrients, water, and light, which in turn affects the growth of individual trees. This fact alone probably does not explain the rather large difference in observed annual growth between methods I and II. The more probable explanation is that individual tree detection is always more accurate than an area-based approach to measuring the dominant height.

Based only on these measurements, it is impossible to develop new tree growth models. That would require significantly more observations of stands of different ages because trees grow at different annual rates depending on age. Vuokila and Väliaho (1980) [5] and Oikarinen (1983) [4], in their articles on developing growth models for cultivated coniferous and birch forest stands respectively, discuss in detail the laborious methods on developing growth models. It requires an extensive amount of field reference data from stands at different stages of development.

The use of LiDAR and airborne laser scanning (ALS) will make field data collection faster and more cost-effective. With multitemporal observations of the dominant heights of the stands, it is possible to predict future growth with the help of available growth models.

Vuokila and Väliaho (1980) [5] and Oikarinen (1983) [4] have developed site index (H_{100}) curves for the tree species they studied. The site index estimates the fertility of the area in which the stand is growing. The index H_{100} tells what dominant height a stand reaches at the biological age of 100 years. It has been shown that the more fertile an area is, the higher the trees grow. These curves also predict the growth rate of the dominant height at different ages. A set of observations of the dominant height at different years can be used by fitting them to the set of site index curves. In this way, the H_{100} site index can be found and future growth can be predicted with the site index curve.

These site index curves are highly localized and usually give good results only when used in the areas they have been developed for. Using this method for predicting future growth of forest stands would require site index curves that have been developed for the areas of interest.

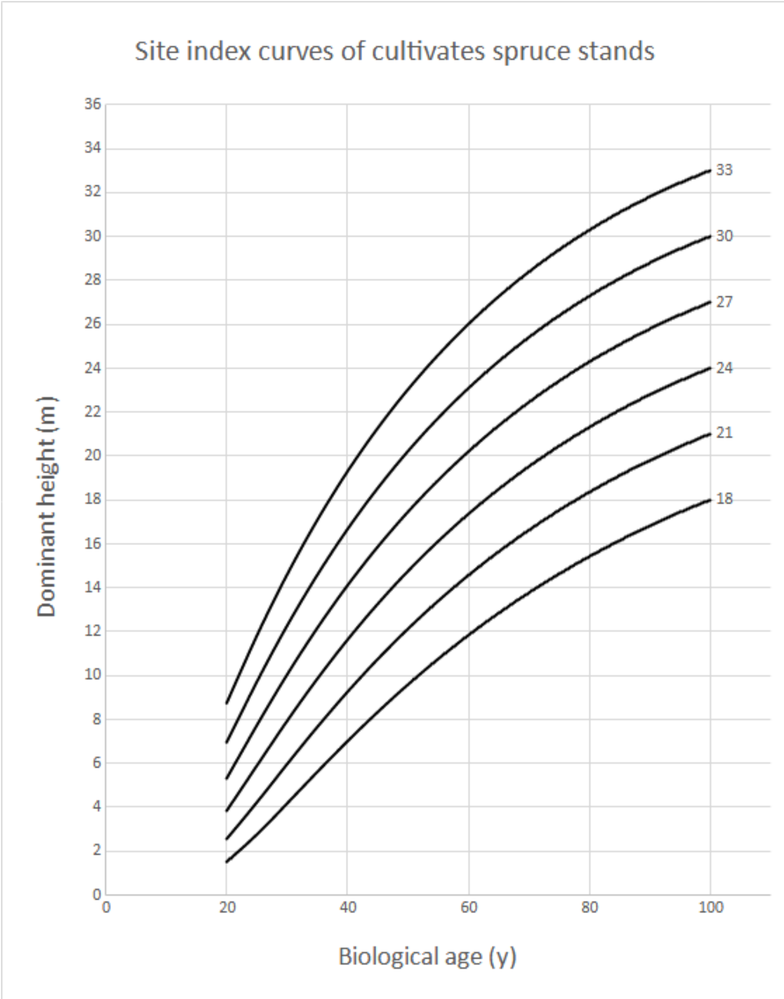

Figure 3: An example of site index (H_{100}) curves for cultivated spruce stands in southern Finland, developed by Vuokila and Väliaho (1980) [5].

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