NATION-WIDE MAPPING OF TREE GROWTH USING REPEATED AIRBORNE LASER SCANNING

Jörgen Wallerman, Kenneth Nyström, Mats Nilsson, Peder Axensten, Mikael Egberth, Jonas Jonzén, Emma Sandström, Johan E.S. Fransson, and Håkan Olsson

Swedish University of Agricultural Sciences
Department of Forest Resource Management
SE-90183 Umeå, Sweden

ABSTRACT

In this study, mapping of tree growth was performed using data from the two nation-wide acquisitions of airborne laser scanning in Sweden. Following the successful first national acquisition performed in 2009 - 2015, a new, repeated, scanning is now launched and ongoing. The first scanning provided new, accurate (in accuracy as well as in spatial resolution) data about the forest and quickly found wide-spread use in the forest industry. It outperformed previous methods and provided a new standard of data capture for forest management planning. The addition of a second scanning provide information also about changes, where forest tree growth is of high interest in the industry. This study presents the first results from large-scale assessment of growth for basal area-weighted mean tree height ($H$) and mean stem volume ($V$), using the bi-temporal scannings and sample-plot data from the National Forest Inventory. Growth was most accurately assessed by the direct change metrics of the scannings, although the accuracies were moderate. The accuracy of forecasts, i.e. only utilizing the predicted forest state at the first scanning, were similar for $H$ but inferior for $V$, though.

Index Terms— Forestry, growth, airborne laser scanning, time-series.

1. INTRODUCTION

In the last decades, airborne laser scanning (ALS) has been successfully used for large area forest mapping in the Nordic countries [1]. In Sweden, Lantmäteriet (the Swedish National Land Survey) made a large-scale ALS mapping with national cover of Sweden in years 2009 to 2015. The primary aim of the scanning was to produce a new national elevation model with high accuracy, to aid scenario analyses of climate change induced effects. The acquired laser data were also made publicly available at low cost. This motivated the forest industry to make large area products using these laser data in combination with field reference plots. In addition, the Swedish Forest Agency and the Swedish University of Agricultural Sciences were commissioned by the government to do a nation-wide forest map using the ALS data from Lantmäteriet [2]. These maps were produced using the area-based method [3, 4] with sample plot data from the Swedish National Forest Inventory (NFI) [5], and are freely available from the home page of the Swedish Forest Agency, as raster data bases under the name “Skogliga grunddata”, version 1.0. These maps have found wide-spread use in the forestry sector for management planning, environmental monitoring, and at authorities like, e.g., the County Boards and the Swedish Forest Agency.

The benefits provided by the first national ALS raised sufficient interest in the society and the private sector to jointly provide fundings for continuously repeated ALS campaigns. Thus, a second scan of Sweden was initiated in year 2018. This effort aims to cover 75% of the land area when, at the rate given by the current annual fundings, finished after eight years of production [6]. The new acquisition is used to provide an updated version (version 2.0) of ”Skogliga grunddata”, which currently (January 2020) covers about 40 000 km$^2$ of the country. In addition, the availability of ALS data from a repeated scanning provides new possibilities, such as large-scale mapping of forest changes, site index (e.g., [7, 8, 9]) and forest tree growth, of which the latter is the main focus of this study. Accurate assessment of growth is influenced by several factors, such as the point-densities in the scannings and length of time between the acquisitions. Using ALS data on the order of 10 points/m$^2$ and growth periods ranging from 1.5 to 4 years, great potential of the technique in boreal forest has been shown, producing plot-level (625 - 1,600 m$^2$) estimates of growth in terms of mean tree height with 0.15 m standard error and 8.39 m$^3$/ha standard error for mean stem volume [10]. Evaluating several methods, using the densely scanned data to individual tree detection did not clearly outperform the potentially less data demanding methods using differencing of the canopy height model (CHM) and the standard area-based metrics ([10]). Less dense ALS data early showed only marginal potential [11], though, using data of
Using higher density ALS data, up to 3 points/m², studies of gap detection and growth of a 5-years period in mixed boreal forest (Quebec, Canada) obtained positive results - estimates "consistent with expected height growth" [12]. Assessment of forest growth from the two national scannings in Sweden is an important new possibility for improved forest management planning, and is in strong demand from the forest industry. Furthermore, since the repetition rate of the national scannings currently is about seven years, there is also a need for models to fore-cast the forest state in existing raster maps from "Skogliga grunddata" in the absence of a new scanning.

This paper presents the first results of estimating forest growth from the two national ALS acquisitions performed by Lantmäteriet in Sweden, using the ALS data available in the southern, most productive, part of Sweden, and corresponding measured growth in repeatedly sampled plots surveyed by the NFI. The goal of this paper is to develop and evaluate models predicting growth of basal area-weighted mean tree height ($H$) and mean stem volume per hectare ($V$), directly applicable to the two ALS acquisitions of national cover in Sweden. This, assuming a prior detection of other causes of changes than growth, such as forest harvesting and damages.

2. DATA

The data produced by the two studied ALS acquisitions are most suitable for analyses using the area-based method [11, 4], due to the moderate scanning densities. The ALS data were obtained from the finished and ongoing production of "Skogliga grunddata", i.e. point-cloud data filtered for side-overlap in adjacent flight paths and obvious errors. Height above ground level of each point were assessed using the terrain model derived from the first acquisition of ALS data. At each location of a permanent plot, the ALS data from each scanning were summarized using a standard, large set of metrics. In these calculations were height and density metrics determined using only points higher than 1.5 m above ground level. The southern area was scanned during rather similar circumstances, i.e. each scanning was made

Three different approaches to assess forest tree growth were evaluated; inference of tree growth using the difference of two separately fitted state models (Eq. 1), modelling growth directly from the two acquisitions of ALS metrics (Eq. 2), and predict growth using allometric models and the
where $Y_t$ is the target forest variable, $m_t$ is the vector of ALS metrics, at time $t = (1, 2)$.

Following the production of the national raster maps of forest variables ("Skogliga grunddata"), similar multiple linear regression models were developed and compared using the root mean squared error (RMSE) of the estimated growth for the period between scannings.

4. RESULTS

Naturally, the survey data does not match the ALS data acquisitions in time. In between, forest damages as well as harvesting operations may occur. Such damages and harvesting operations are registered within the NFI survey protocol, although it is a subjective assessment prone to errors. Here, the permanent and repeatedly surveyed NFI plots were used. Thus, at each plot, the survey time was selected to match the ALS acquisition as close as possible, with regard to the recorded damages and treatments. Furthermore, the surveyed annual growth were used to correct the surveyed states for the differences in time between each survey and the time of scanning.

Modelling the forest states at each time of scanning (following Eq. 1) resulted in linear regression models of basal area-weighted mean tree height ($H$), inferred only from the 95:th height percentiles of ALS points ($P_{95}$), showing adjusted $R^2$ values of 95% for the first scanning and 88% for the second. Mean stem volume ($V$) were modeled using non-linear regression from $P_{95}$ and the percentage of ALS first returns from the tree canopy ($D$), and provided adj. $R^2$ values of 78% for each scanning. Following Eq. (2), growth of $H$ was modelled by the direct change in $P_{95}$ from each scanning acquisition, resulting in an adj. $R^2$ value of 38%. Growth of $V$ was modelled with an adj. $R^2$ value of 30%, from the changes of $P_{95}$ and $D$ between scannings, but also by $P_{95}$ and $D$ from the first scanning, providing adaptation to the forest development state. Following Eq. 3 and the Richardson growth model approach [13], non-linear simultaneous regression was applied to develop a model forecasting the predicted states of $H$ (adj. $R^2$ value of 88%) and $V$ (adj. $R^2$ value of 96%), from a given state and temperature sum. Residual errors of each approach and variable are presented in Table 4.

Assessing growth from two independent estimates (Eq. 1) was almost as accurate as utilization of specifically designed models of growth (Eq. 2). Fore-casting (Eq. 3) was as accurate for $H$, but not for $V$. In general, the accuracies were low,
especially for $V$. The data are not ideal for growth assessment, though. In fact, surveys and scannings are very seldom carried out simultaneously. Unknown damages and thinnings may occur in between, and the surveyed growth does not represent the time-span of the scannings. There is also lack of positioning accuracy of sample plots, as no high-precision GPS errors of $V$ obtained here, compared to $H$, as $V$ was modeled by canopy height metrics in combination with density metrics but $H$ only from the former. Canopy density is probably less spatially autocorrelated compared to canopy height, thus more affected by GPS errors.

### Table 1. Accuracy of predicted growth of basal area-weighted mean tree height ($H$) and mean stem volume ($V$) using the modelling equations 1 - 3.

<table>
<thead>
<tr>
<th>Eq.</th>
<th>Variable</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>$H$</td>
<td>2.6 $[m]$</td>
</tr>
<tr>
<td>(1)</td>
<td>$V$</td>
<td>59 $[m^3ha^{-1}]$</td>
</tr>
<tr>
<td>(2)</td>
<td>$H$</td>
<td>2.1 $[m]$</td>
</tr>
<tr>
<td>(2)</td>
<td>$V$</td>
<td>55 $[m^3ha^{-1}]$</td>
</tr>
<tr>
<td>(3)</td>
<td>$H$</td>
<td>2.0 $[m]$</td>
</tr>
<tr>
<td>(3)</td>
<td>$V$</td>
<td>162 $[m^3ha^{-1}]$</td>
</tr>
</tbody>
</table>

### 5. ACKNOWLEDGEMENTS

This work were financed within ”Skogliga grunddata” - a joint project of the Swedish University of Agricultural Sciences and the Swedish Forest Agency, as well as the research project MISTRA Digital Forest, and the National Forest Data Laboratory funded by VINNOVA.

### 6. REFERENCES


