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Calibration of nationwide airborne laser scanning based stem volume models

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ABSTRACT

In-situ field measurements of sample plots are a major cost component in airborne laser scanning (ALS) based forest inventories. Field measurements on new inventory areas can be reduced by utilizing existing stand attribute models from former inventory areas. We constructed a nationwide model for stem volume, and examined seven different calibration scenarios using 22 inventory areas distributed evenly throughout Finland. These scenarios can be divided into three main categories: 1) calibration with additional predictor variables, 2) calibration with 200 geographically nearest sample plots, and 3) calibration with MS-NFI (Multi-source National Forest Inventory of Finland) volume at the target inventory area. Calibration with degree days, precipitation, and proportion of birch resulted in the greatest decrease in error rate of stem volume predictions. The mean of the root mean square errors (RMSE) among the 22 inventory areas decreased from 28.6% to 25.9%, and the standard deviation of RMSEs from 4.3% to 3.9% using three additional predictor variables. Correspondingly, the mean and standard deviation of absolute values of mean differences (|MD|) decreased from 8.3% to 5.6% and from 5.6% to 4.4%, respectively. All calibration scenarios decreased the error rate, especially the high |MDs| observed in the northern part of Finland. Calibration with sample plots from geographically nearest inventory areas was useful when there were sample plots that offered a good representation of the target area. MS-NFI based calibration was also a reasonable option if loggings and other inconsistencies between datasets could be detected and accounted for.

1. Introduction

Forest inventories have traditionally relied on field measurements, but field data collection is expensive. As a result, remote sensing applications have become an essential component of many practical inventories. Nevertheless, the sample plot measurements required to support these remote sensing based inventories still constitute the largest cost component in practical inventories (Maltamo and Packalen, 2014). The use of airborne laser scanning (ALS) in remote sensing assisted sampling inventories (e.g. Ståhl et al., 2016) has emerged as a promising option to further reduce inventory costs on very large areas; it may also enable the number of field samples required to be reduced. It is also possible to construct models that utilize data collected from very large areas (e.g. Hadi et al., 2016; Kotivuori et al., 2016), and to calibrate them to better represent local forest structure.

Forest inventories based on ALS data and the area based approach (ABA) have been applied widely during the last 15 years (Næsset, 2014; Vauhkonen et al., 2014). Kotivuori et al. (2016) utilized ALS and field sample plots acquired originally for nine forest inventory areas to construct nationwide models for stem volume, above-ground biomass and dominant height. They showed that using the nationwide models, it was possible to obtain good predictions across Finland for volume and biomass: the plot level root mean square error (RMSE) values ranged from 22% to 34%, with a mean of 28%. However, large mean difference (MD) values (−14% to 19%, absolute mean 9%) could occur at the inventory area level (calculated from plot level figures). Corresponding RMSEs for the regional models ranged from 20% to 27%, with a mean of 24%. Kotivuori et al. (2016) highlighted that the MD of the nationwide volume and biomass models can be considerably reduced with calibration based on only 20 field plots (MD −3% to 4%, absolute mean 2%). However, they did not examine whether existing, publicly available datasets can be used to calibrate the predictions at the inventory area level.

The utilization of ALS datasets from geographically separate inventory areas has been studied by Næsset et al. (2005), Breidenbach et al. (2008) and Suvanto and Maltamo (2010). Næsset et al. (2005) tested three different estimation methods (OLS = ordinary least squares, SUR = seemingly unrelated regression, and PLS = partial least

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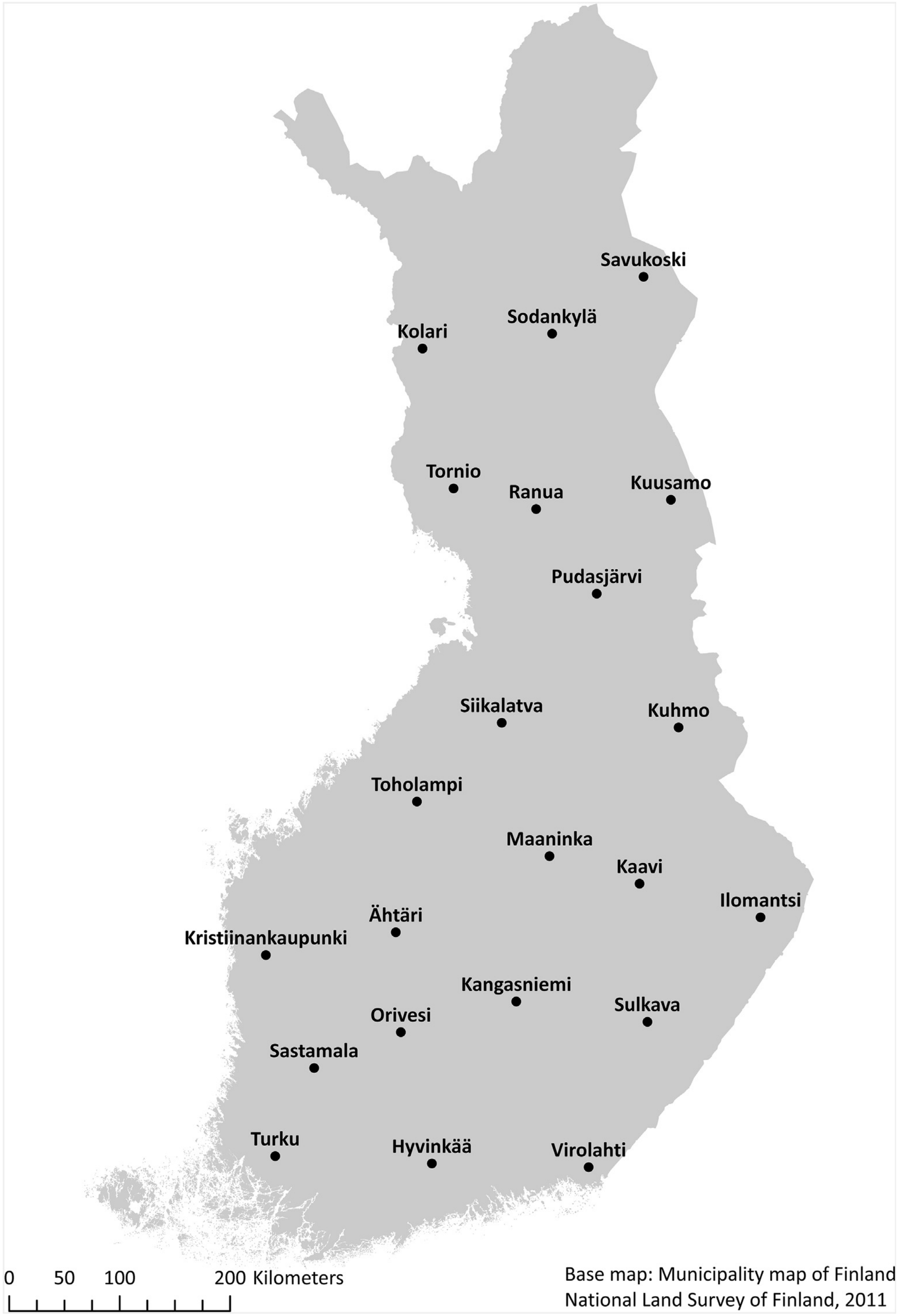

Fig. 1. Locations of the inventory areas.

squares). Breidenbach et al. (2008) looked at mixed-effect models, and Suvanto and Maltamo (2010) weighted OLS estimation in general stem volume prediction. In each of these studies, sample plots from two separate inventory areas were utilized. In addition, Næsset and Gobakken (2008) used multiple regression analysis and up to ten separate areas for the prediction of above-ground biomass across regions.

The above-mentioned studies concluded that when using the same ALS based models, the volume and biomass predictions of separate geographical areas are usually affected by changes in forest structure and the use of different ALS devices. However, dominant height is only marginally affected by variations in different ALS datasets, and therefore it can be predicted with a low error rate even without in-situ field measurements (Kotivuori et al., 2016; Gopalakrishnan et al., 2015). Gopalakrishnan et al. (2015) used altogether 76 separate inventory areas around the southeastern US, where the R^2 of the dominant height model in the training dataset was 0.74 and the absolute root mean square error was 3 m. In turn, Kotivuori et al. (2016) reported a 7% mean RMSE and a 2% mean |MD| (absolute value of relative mean differences) at the inventory area level (from plot level figures).

In Sweden, Nilsson et al. (2017) used NFI sample plots and national ALS data in nationwide forest attribute mapping. They used an approach where pre-selected regression model forms were refitted for