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Classification of forest land attributes using multi-source remotely sensed data

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ABSTRACT

The aim of the study was to (1) examine the classification of forest land using airborne laser scanning (ALS) data, satellite images and sample plots of the Finnish National Forest Inventory (NFI) as training data and to (2) identify best performing metrics for classifying forest land attributes. Six different schemes of forest land classification were studied: land use/land cover (LU/LC) classification using both national classes and FAO (Food and Agricultural Organization of the United Nations) classes, main type, site type, peat land type and drainage status. Special interest was to test different ALS-based surface metrics in classification of forest land attributes. Field data consisted of 828 NFI plots collected in 2008–2012 in southern Finland and remotely sensed data was from summer 2010. Multinomial logistic regression was used as the classification method. Classification of LU/LC classes were highly accurate (kappa-values 0.90 and 0.91) but also the classification of site type, peat land type and drainage status succeeded moderately well (kappa-values 0.51, 0.69 and 0.52). ALS-based surface metrics were found to be the most important predictor variables in classification of LU/LC class, main type and drainage status. In best classification models of forest site types both spectral metrics from satellite data and point cloud metrics from ALS were used. In turn, in the classification of peat land types ALS point cloud metrics played the most important role. Results indicated that the prediction of site type and forest land category could be incorporated into stand level forest management inventory system in Finland.

1. Introduction

Forest land and site type classifications are used at national and international levels to monitor the amount, quality and state of forests. In forestry, different classifications of forest land attributes are also important, as they form the basis for silvicultural operations. In Finland, forest land and site type information is collected in the National Forest Inventory (NFI) and in regional stand-wise forest inventories made for forest planning.

The traditional stand-wise inventory, based mainly on field work, has been recently replaced with an inventory method using airborne laser scanning (ALS), aerial images and field measurements (Maltamo and Packalen, 2014). ALS-based inventory is accurate, less time-consuming and less expensive than the traditional stand-wise field methods (e.g. Næsset, 2004; Packalén and Maltamo, 2007). In the area-based ALS approach metrics calculated from height, density and intensity distribution of ALS points are used to predict stand attributes at plot or substand level (Holmgren, 2004; Næsset, 2002). Even though the stand attributes (volume, basal area, mean height and mean diameter of growing stock) can be predicted with high accuracy, classification of forest land and site types has only been tested in a few studies (Holopainen et al., 2010; Vehmas et al., 2011).

ALS-based surface models have been found to be useful in many forestry applications. Despite this the potential of ALS-based surface metrics have not been extensively studied and e.g. in practical ALS-based forests inventories only ALS point cloud metrics are used. Surface metrics can be calculated, for example, from ALS-based terrain (DTM), surface (DSM) or canopy height (CHM) models. ALS-based DSM or CHM have been used in individual tree detection (Hyyppä and Inkinen, 1999), stand delineation (Koch et al., 2009) and evaluation of canopy cover and leaf area index (Korhonen et al., 2011), but also, e.g., in classification of forest types and estimation of forest attributes (Van Aardt et al., 2008,

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change detection (Vastaranta et al., 2012) or prediction of spatial pattern of trees and need for forest management operations (Pippuri et al., 2012). ALS-based DTM metrics have only been utilized in a few forest studies. One example is Racine et al. (2014), who predicted stand age using ALS-based DTM metrics (e.g. elevation, slope, aspect, catchment area, solar radiation and wetness index) and point cloud metrics as structure metrics. Korpela et al. (2009) also used ALS-based surface metrics in the classification of mire site types. Metrics calculated from different surfaces may also describe forest land attributes better than straightforward ALS point cloud metrics.

Most remote sensing-based forest classification studies have focused on the utilization of passive satellite images. There are also studies where forest land and different forest types have been discriminated using ALS data and some of these have utilized ALS-based surfaces, such as DTM, DSM, CHM and intensity rasters in classification (e.g. Antonarakis et al., 2008; Brennan and Webster, 2006; Charaniya et al., 2004). In some land use studies wetlands and swamp forest have also been mapped using remotely sensed data (e.g. Maxa and Bolstad, 2009; Sader et al., 1995; Townsend and Walsh, 2001). As far as we are aware, there are no ALS-based studies where mineral soils and peat lands have been separated from each other, but Dirksen (2013) discriminated swamp forests and non-paludified forests using ALS data.

ALS data has only been used to classify forest site type (understory vegetation-based) in a couple of studies. Vehmas et al. (2011) classified forest site types in mineral soils using ALS point cloud metrics and Korpela et al. (2009) classified, e.g., mire site types, mire habitats and nutrient status based on point cloud metrics and ALS-based DTM metrics. Recently, the potential of ALS data to identify herb-rich forests has also been studied (Vehmas et al., 2009). Worldwide, a more common method for site type classification is site index, which is based on the dominant height of growing stock at a certain age. For instance, Gatziolis (2007) estimated dominant height and site index using an individual-tree-based ALS method and Packalén et al. (2011) using an area-based method.

Forest land and site type information collected in NFI could be used as training data in practical ALS-based forest inventory. Earlier Hollaus et al. (2007), Maltamo et al. (2009) and Tuominen et al. (2014) successfully combined NFI plot data and ALS data for the estimation of growing stock attributes. Using comprehensive field data from NFI could increase the cost-effectiveness of ALS-based inventory, since separate field data would not need to be collected. In addition, the accuracy of the inventory could improve when forest land and site type classification is done by an NFI field expert.

In this study the following classification schemes are studied: land use/land cover (LU/LC) classification using both national (Finnish) classes and United Nations Food and Agriculture Organization (FAO) classes, main type, site type, peat land type and drainage status. In the NFI of Finland both national and FAO LU/LC classification is used to assess the amount of forest area. National LU/LC classification is based on the purpose of land use (productive forest, poorly productive forest, open land, other forestry land, agricultural land, built-up land, etc.) and site productivity. Thus, the national LU/LC classification system can be regarded as a two-phase system: first classification by land use in forestry land, agricultural land, and built-up land classes, and then by site productivity where the forestry land is divided into productive forest, poorly productive forest, open land, and other forestry land sub-categories. The FAO LU/LC classification, in turn, is based on land use and crown cover and height of trees in their maturity stage. FAO LU/LC classification is used in the assessment of global forest recourses (FAO, 2006).

In Finland forest land is classified into mineral soil or peat land (main site type) based on the composition of an organic layer of soil (peat or not) or proportion of peat land vegetation. Forest land is also classified into uniform forest site types based on site fertility and wood-producing capacity. Site classification uses Cajander's (1926) forest site type theory, which is based on understory vegetation. Mires constitute 28% of land cover in Finland (Korhonen et al., 2008) and are important habitats from the point of view of both forestry and biodiversity. They can be discriminated into dozens of peat land types (Laine and Vasander, 2008), but more general categorisation divides them into spruce- and pine-dominated and open peat lands. Peat lands are also often classified into corresponding site type classes with mineral soils. Forest land can also be classified based on drainage status, which describes the draining state of a forest stand. Draining status can be divided into undrained and drained (by ditches) mineral soils and peat lands.

The main aim of this study was to (1) examine the classification of forest land attributes using ALS-based data, satellite images and NFI plots as training data and to (2) identify best performing metrics for classifying forest land attributes. It was of special interest to test different ALS-based surface metrics in the classification of forest land attributes. The predicting power of common ALS point cloud metrics and spectral metrics of satellite images were also evaluated.

2. Materials and methods

2.1. Study area and field data

The study area (~6500 km^2) is located in Southern Finland (Fig. 1) and consists mainly forests, but also some lakes, fields and urban areas. Forests can be considered as typical managed boreal forests in Finland and are mainly dominated by coniferous species: Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.). Deciduous species are usually found as a minority in mixed forests. The study area includes both mineral soils and peat lands and forests with different site types and developing stages.

Field data of 828 plots in 164 clusters (9–12 plots per cluster) were collected in the 10th and 11th cycles of the National Forest Inventory during 2008–2012. In NFI, a forest stand is defined as a homogeneous parcel regarding site and growing stock variables and it should usually be at least 0.25 ha in size. Land use and site variables of forests are always collected for the forest stand, or the parcel of land use class, in which the centre point of the plot is located. Additional forest stands are described if any trees in additional stands are selected to be measured. In Southern Finland, tree selection was done by a Bitterlich relascope with a basal area factor of 2 and a maximum radius of 12.52 m for the plot of trees. The proportion of the centre point's stand within a circle with this maximum radius was recorded. In this study, we used plots that had only one forest stand or national LU/LC class within the 12.52 m radius.

Plots in lakes/rivers and plots where the height of vegetation was clearly different compared to laser-based canopy height were excluded (caused, e.g., by clear cuts between the field and ALS data collections). Reason for this was that we wanted to focus on classification of forest land attributes (waters are very easy to detect using satellite data) and changes in forest between field inventory and remote sensing data acquisition affects remote sensing metrics in an apparent manner. Therefore, it does not make sense to include sample that are clearly wrong.

Field data collected in NFI of Finland by experienced field workers can be expected to be very accurate evaluation of forest land attributes. The following classifications determined for each plot were used: national and FAO LU/LC class, main type, site type, peat land type and drainage status. Some of the classes only had a small number of observations, and therefore a few classes were merged. Despite this, the number of observations between different classes varied a lot. In the final classification schemes the national LU/LC classification included forestry land, agricultural