Ecological Indicators 85 (2018) 367–376

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Research paper

Predicting stem diameters and aboveground biomass of individual trees using remote sensing data

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ARTICLE INFO

Keywords:
Aboveground biomass
Diameter at breast height
Modelling
Individual tree crowns
Remote sensing
Airborne laser scanning
Hyperspectral imagery

ABSTRACT

Airborne laser scanner (ALS) data and hyperspectral (HS) data have become standard data sources in studies related to forest ecology and environmental mapping. Nowadays it is possible to have combined acquisitions of ALS and HS data, and also to have very high point density ALS data that allows us to study forests at individual tree level. In this paper, a study on the combination of HS and ALS data with models for diameter at breast height (DBH) and aboveground biomass (AGB) prediction at individual tree crown (ITC) level is presented. ALS data were used to delineate ITCs and to estimate height and crown diameter of each ITC, whereas HS data were used to identify the tree species. The proposed approach consists in developing DBH and AGB models using field data of an area and to apply these models to areas with similar characteristics. Two datasets were considered: the first dataset is located in boreal forests and it is composed by three separate study areas (Aurskog-Høland, Hadeland, and Våler); the second dataset is located in temperate forests and it is composed by two separate study areas (Val di Sella, and Pellizzano). Aurskog-Høland and Val di Sella study areas were used only to develop species-specific and non-species specific models for DBH and AGB in the two biomes, while the other study areas were used for validation at plot level with remote sensing data. Local models were also developed using field data and ALS and HS data, and they were compared to the ones developed on Aurskog-Høland and Val di Sella study areas. The results show that the proposed approach provides high accuracies in both biomes, even if problems related to underestimation exists. Predictions with a general non-species specific model developed on one study area did not differ significantly from predictions obtained by using local models

1. Introduction

The knowledge of stem diameters and aboveground biomass distribution is important for forestry and ecology studies (Slik et al., 2010). They can help in understanding forest dynamics as they are related to a wide variety of ecosystem processes and services, including gas exchange and climate mitigation, productivity, biodiversity, tree competition and succession, ecological niche and water interception. Traditional methods for assessing these attributes comprised field inventories and conventional remote sensing (i.e. aerial photography, bi-dimensional analysis of satellite images). However, in the recent years it has become possible to have airborne laser scanner (ALS) and hyperspectral (HS) data acquisitions over the same areas for ecological studies (Asner et al., 2017). ALS (Vierling et al., 2008) and HS (Asner et al., 2015) data are a very promising tool for studies related to forest ecology and environmental mapping. Until now ALS and HS data have been mainly used to estimate forest variables at plot or stand level (Luo et al., 2017). However, recent development in technology and costs have made it possible to have very high point density ALS data and very high spatial resolution HS data that allows us to study forests also at tree level (Coomes et al., 2017; Dalponte and Coomes, 2016). Indeed, from ALS data individual tree crown delineation methods (Zhen et al., 2016) provide means to determine) height and crown dimensions at tree level. Moreover, with HS data precise tree species classification is possible (Dalponte et al., 2012; Fassnacht et al., 2016). This opens up the possibility to have a higher spatial resolution in large area studies – a resolution that in the past only was possible through intensive field work.

In forest surveys carried out for forest management purposes, diameter at breast heights (DBH) and species are registered for all trees at each sample plot and tree height is measured for selected sample trees. Aboveground biomass (AGB) is predicted, for the surveyed trees using

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http://dx.doi.org/10.1016/j.ecolind.2017.10.066
Received 3 May 2017; Received in revised form 26 October 2017; Accepted 27 October 2017

allometric models. Such models rely primarily on DBH and tree height as inputs, and for many forest types and geographical regions they are species-specific and specific for geographic area (e.g. Corona, 2012; Marklund, 1988; Scrinzi et al., 2010). In particular DBH and species information play an important role as tree height is often predicted as a function of these attributes. As DBH cannot be directly measured with airborne remote sensing (ARS) data, it may be useful to develop new models based on tree characteristics directly (or almost directly) measurable from ARS data. Following this idea, Jucker et al. (2017) recently developed allometric models for predicting DBH and aboveground biomass based on height and crown diameter using a global dataset of more than a hundred thousand individual trees. The study of Jucker et al. (2017) did not involve remote sensing data as they focused exclusively on the development of the allometries. Moreover, the work by Jucker et al. (2017) entailed development of global and regional allometric models without considering species-specific information.

In the current study we wanted to advance the fundamental idea of Jucker et al. (2017) by introducing not only models for DBH and AGB prediction based on height and crown diameter but also to apply these models using information on species, height and crown diameter predicted using ALS and HS data. Thus, the objective of the study was to evaluate models for aboveground biomass prediction and their combination with ARS data for DBH and AGB predictions at ITC and plot level. The remotely sensed data considered were ALS and HS data. The specific objectives were to evaluate 1) models developed on field data versus models developed on remotely sensed data and 2) the use of species-specific models versus non-species specific models for the prediction of DBH and AGB for three main species groups typically found in inventories in northern Europe. Furthermore, we wanted to provide insight on the usefulness of local models and on the effect of the species information at ITC level on the prediction of DBH and AGB in boreal forests.

2. Datasets description

In this study we considered two datasets located in different biomes. The first dataset is located in boreal forests in Norway and it is composed of three separate study areas (Aurskog-Høland, Hadeland, and Våler). The second dataset is located in temperate forests in the Italian Alps and it is composed of two separate study areas (Val di Sella and Pellizzano). We considered two datasets located in different biomes and geographic regions in order to show the broad applicability of the proposed methodology. In order to not make the paper too long, in the main text we provide the description only of the boreal dataset, and the results on this dataset. The description and the results on the temperate dataset can be found in the Supplementary Materials.

The three areas of the boreal dataset are located in southeastern Norway (Fig. 1). The main species of the forests in the areas are Norway spruce (*Picea abies* (L.) H. Karst), Scots pine (*Pinus sylvestris* L.), and deciduous tree species, such as birch (*Betula spp.* L.) and aspen (*Populus tremula* L.). A summary of the field data of the boreal dataset are presented in Table 1. Aurskog-Høland study area was used to build up the DBH and AGB general models (thus only field data were used), while the Hadeland and Våler study areas were used to build up local models and to have a plot level validation using remote sensing data.

2.1. Aurskog- Høland study area

The Aurskog-Høland study area (890 km^2) is located in the municipality of Aurskog-Høland. The field data consisted of 36 circular sample plots of 1000 m^2 and four plots of 500 m^2. Within each sample plot, tree species, DBH, and tree coordinates were recorded for all trees with DBH > 5 cm. For 667 trees also height and crown diameters were measured. For more information about this study area, see (Breidenbach et al., 2010).

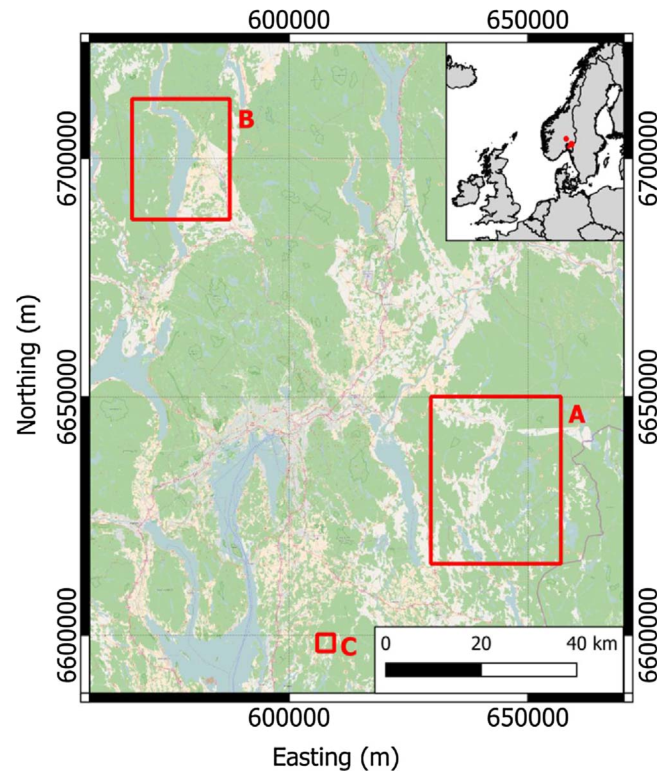

Fig. 1. Location of the three study areas: A) Aurskog-Høland, B) Hadeland; and C) Våler.

Table 1
Summary statistics of the field data for all datasets.

		Aurskog-Høland	Hadeland	Våler
Tree height (m)	Minimum	3.5	3.0	3.6
	Maximum	29.4	25.4	21.5
	Mean	14.4	11.8	9.0
DBH (cm)	Minimum	5.0	3.0	5.0
	Maximum	49.5	52.8	51.2
	Mean	18.6	13.2	13.2
Tree crown diameter (m)	Minimum	0.38	–	–
	Maximum	9.05	–	–
	Mean	3.40	–	–
Tree AGB (kg)	Minimum	4	2	2
	Maximum	1058	738	1233
	Mean	152	82	86
Plot AGB (Mg ha^{-1})	Minimum	–	19	20
	Maximum	–	217	431
	Mean	–	120	132
Species composition (%)	Broadleaves	19	23	23
	Pine	40	14	25
	Spruce	41	63	52

2.2. Hadeland study area

The Hadeland study area (about 1300 km^2) is located in the Hadeland district. The field data were collected on 13 circular sample plots of size 500 m^2 and 21 circular sample plots of size 1000 m^2. Within each sample plot, tree species, DBH, and tree coordinates were recorded for all trees with DBH > 3 cm. A total of 3970 trees were recorded.

The Hadeland area was fully covered by 105 airborne HS images collected on 21st and 22nd of August 2015 using the CASI sensor. The CASI sensor acquired data in 72 bands between 367 nm and 1045 nm with about 9.4 nm spectral resolution. The spatial resolution was 0.5 m. The flight altitude was around 1500 m and the images were acquired between 11:12 AM and 4:36 PM

ALS data were acquired the same days of the HS data using a Leica