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Assessing above-ground biomass of open-grown urban trees: A comparison between existing models and a volume-based approach

Topi Tanhuanpää[a,b,*], Ville Kankare[a], Heikki Setälä[b], Vesa Yli-Pelkonen[b], Mikko Vastaranta[a], Mikko T. Niemi[a], Juha Raisio[c], Markus Holopainen[a]

[a] University of Helsinki, Department of Forest Sciences, Finland
[b] University of Helsinki, Department of Environmental Sciences, Finland
[c] City of Helsinki, Public Works Department, Street and Park Division, Finland

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ABSTRACT

Assessment of the amount of carbon sequestered and the value of ecosystem services provided by urban trees requires reliable data. Predicting the proportions and allometric relationships of individual urban trees with models developed for trees in rural forests may result in significant errors in biomass calculations. To better understand the differences in biomass accumulation and allocation between urban and rural trees, two existing biomass models for silver birch (Betula pendula Roth) were tested for their performance in assessing the above-ground biomass (AGB) of 12 urban trees. In addition, the performance of a volume-based method utilizing accurate terrestrial laser scanning (TLS) data and stem density was evaluated in assessing urban tree AGB. Both tested models underestimated the total AGB of single trees, which was mainly due to a substantial underestimation of branch biomass. The volume-based method produced the most accurate estimates of stem biomass. The results suggest that biomass models originally based on sample trees from rural forests should not be used for urban, open-grown trees, and that volume-based methods utilizing TLS data are a promising alternative for non-destructive assessment of urban tree AGB.

1. Introduction

Trees and other green infrastructure provide the urban environment with various ecosystem services (Gómez-Baggethun and Barton, 2013), such as noise reduction (Bucur, 2006), storm water management (Valtanen et al., 2014), air pollutant removal (Setälä et al., 2013; Morani et al., 2011), and improvement of aesthetic beauty (Hauru et al., 2015). In recent years, applications such as iTree (iTree, 2015) have rendered it possible to evaluate tree-derived ecosystem services based on tree characteristics in an urbanized setting (see, e.g., Baró et al., 2014; Nowak et al., 2013). However, the majority of the studies addressing ecosystem services provided by urban trees are based on city- or regional-scale models, whereas local-scale empirical urban data is needed to estimate, e.g., the influence of roadside trees in ecosystem service provision (Pataki et al., 2013; Pataki et al., 2011). An ecosystem service related to this study is sequestering and storing of atmospheric carbon, through which urban trees both locally and globally affect the carbon cycle and thus the mitigation of climate change (Nowak and Crane, 2002). It has been estimated that the terrestrial biosphere, consisting mainly of forests, accounts for approximately 45% (1.4 Gt) of the global sequestration of atmospheric carbon annually (Schimel et al., 2001). Davies et al. (2011) showed that the contribution of urban forest to nationwide carbon storage can also be considerable, especially in countries with low overall forest coverage. Moreover, FAO classifies urban trees and forests as being part of a larger group encompassing trees outside rural forests (de Foresta et al., 2013). Following the FAO classification, Schnell et al. (2015) studied forest monitoring data from 11 countries on three continents and showed that on average over 10% of the countries' tree biomass actually accumulates outside rural forests. The figure mainly consists of urban forests as well as scattered and other non-forest trees on agricultural land. Still, urban tree-specific allometric models for biomass assessment are scarce and thus little is known how general models perform in an urban environment.

The traditional means for accurately assessing the aboveground biomass (AGB) of a tree is based on weighing the aboveground parts of the tree, quantifying the relative amounts of stem wood and branches, and defining the dry biomasses of both

* Corresponding author at: University of Helsinki, Department of Forest Sciences, P.O. Box 27 (Latokartanonkaari 7) FI-00014, Finland.
E-mail address: topi.tanhuanpaa@helsinki.fi (T. Tanhuanpää).

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components. Since the procedure is destructive, i.e., it requires cutting down the specimen, the aim of the procedure is most often to construct an allometric biomass model from a sample of trees. The model is then used to estimate the biomass for the local tree population. Various species-specific models have been proposed for assessing the biomass of single trees (see, e.g., Yoon et al., 2013; Ter-Mikaelian and Korzukhin, 1997). The use of these models is commonly based on easily obtainable measurements, like diameter at breast height (DBH) and tree height. The main shortcoming of model-based biomass assessments is that the target population should resemble the one used for creating the model. This is especially problematic in urban tree populations whose growth conditions and thus biomass allocation patterns can differ from the environment where the biomass models were created (see, Dahle et al., 2014; Poorter et al., 2012; Niemistö, 1995). Furthermore, the use of traditional biomass modelling procedures is rarely applicable in urban inventory projects simply due to the fact that destructive sampling is rarely an acceptable solution in the urban environment. Hence, alternative ways of acquiring field reference data for urban tree-specific biomass are sought.

During the last decade, various laser scanning (LS) methods enabling the use of precise three-dimensional (3D) information on, e.g., urban space and infrastructure have become an essential tool in urban mapping and planning (Kukko et al., 2012; Pu and Vosselman, 2009; Pfeifer et al., 2007). Terrestrial laser scanning (TLS) is a stationary method for collecting detailed 3D data. The scanner emits millions of laser pulses and records the back scattering echoes. Based on accurate range and angle measurements, the data are processed into point clouds that can be thought of as detailed 3D images of the scanned objects. In TLS, the scanner is typically mounted on a tripod at a height of approximately 2 m. The resulting point clouds enable detailed modelling of, e.g., building facades (e.g., Zhu et al., 2011; Haala et al., 2008) and tree stems (Liang et al., 2014; Holopainen et al., 2013). The point clouds can be used to model entire trees with high precision to the level of single branches, which enables accurate dimension and volume measurements of virtually any visible part of the tree (e.g., Raumonen et al., 2013; Maas et al., 2008). Utilization of TLS data in assessing AGB has been studied in both rural (Hauglin et al., 2013; He et al., 2013; Kankare et al., 2013; Yu et al., 2013) and urban surroundings (Vonderach et al., 2012) by enhancing and localizing the existing biomass models. Combining the TLS-derived volume estimates with species-specific basic densities of wood and bark paves the way for an alternative method of estimating tree AGB without having to cut down the tree (see, e.g., Yu et al., 2013; McHale et al., 2009). A non-destructive method would enable gathering of large tree-level reference datasets, e.g., for executing remote sensing-based biomass inventories or creating tree-specific biomass models. Such methods would be useful especially in the urban environment where adequate destructive sampling is not applicable.

The aims of this study were twofold. Firstly, we wanted to investigate the performance of two allometric biomass models (Repola, 2008; Muukkonen, 2007) for silver birch (*Betula pendula* Roth) under semi-open urban conditions on roadsides. We hypothesized that (I) models based on trees sampled from rural forests will provide biased biomass estimates in semi-open urban surroundings. The hypothesis was tested separately for stem, branches, and total AGB. Secondly, we wanted to explore the possibility of measuring tree-level reference AGB using TLS-based volume measurements and a priori knowledge about species-specific basic densities. Our second hypothesis was that (II) the TLS-based method outperforms the existing biomass models when estimating AGB for semi-open-grown urban trees.

2. Materials

The study area is located in the city of Helsinki, Finland (60°10′15″N, 024°56′15″E, Fig. 1). The area represents a typical urban growth environment for roadside trees. The grassy ground surface is bordered by paved surfaces on two sides. The area was built in the 1960s and the majority of the roadside trees also originate from that time. However, some damaged or dead trees have been replaced during the years. The trees used for the biomass estimation were 12 silver birches aged approximately from 20 to 55 years. The trees were cut down because of a construction project in August 2014, which allowed us to measure an accurate reference biomass for each tree.

Tree DBH and height were measured manually from the point clouds. The DBH was determined as a mean of two perpendicular measurements, whereas the tree height was determined from the highest laser hit in the point cloud. The DBH of the study trees

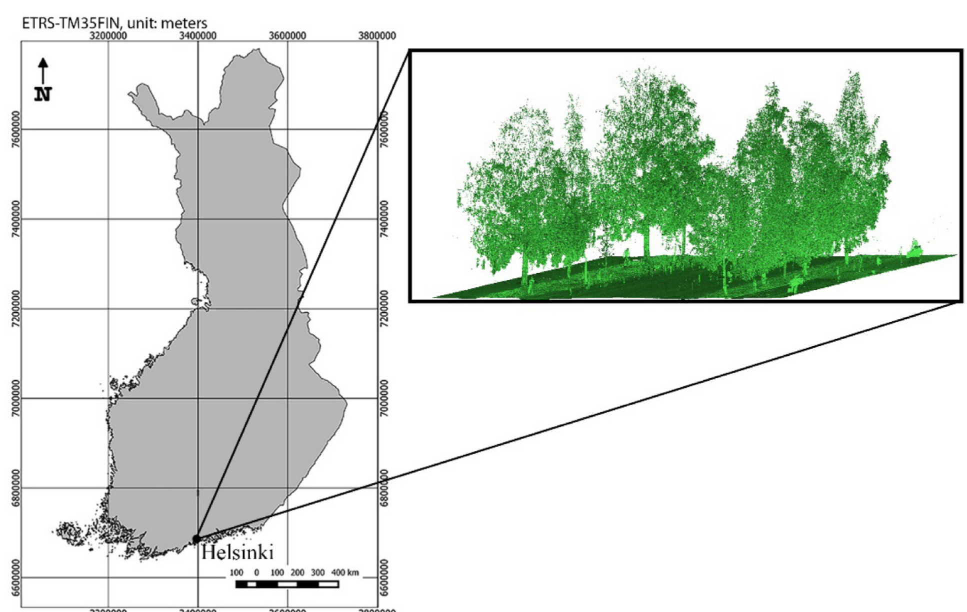

Fig. 1. Illustration of the study area in the city of Helsinki in southern Finland. In upper right a road section with standing roadside trees visualized as TLS point cloud.