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Estimating biomass of individual pine trees using airborne lidar

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Abstract

Airborne lidar (Light Detection And Ranging) is a proven technology that can be used to accurately assess aboveground forest biomass and bio-energy feedstocks. The overall goal of this study was to develop a method for assessing aboveground biomass and component biomass for individual trees using airborne lidar data in forest settings typical for loblolly pine stands (*Pinus taeda L.*) in the southeastern United States. More specific objectives included: (1) assessing the accuracy of estimating diameter at breast height (dbh) for individual pine trees using lidar-derived individual tree measurements, such as tree height and crown diameter, and (2) investigating the use of lidar-derived individual tree measurements with linear and nonlinear regression to estimate per tree aboveground biomass. In addition, the study presents a method for estimating the biomass of individual tree components, such as foliage, coarse roots, stem bark, and stem wood, as derived quantities from the aboveground biomass prediction. A lidar software application, TreeVaW, was used to extract forest inventory parameters at individual tree level from a lidar-derived canopy height model. Lidar-measured parameters at individual tree level, such as height and crown diameter, were used with regression models to estimate dbh, aboveground tree biomass, and tree-component biomass. Field measurements were collected for 45 loblolly pine trees over 0.1- and 0.01-acre plots. Linear regression models were able to explain 93% of the variability associated with individual tree biomass, 90% for dbh, and 79–80% for components biomass.

Keywords: Biomass; Lidar; dbh; Tree height; TreeVaW; Loblolly pine (*Pinus taeda L.*)

1. Introduction

Measurement of forest biomass provides an indication of carbon sequestration in trees and also an estimate of cellulosic material as a potential source of renewable energy. As with most forest measurements, field methods provide consistent means of assessing biomass, but usually at a high cost, and often involving destructive sampling on a limited geographic coverage.

Remote sensing methods can be integrated with field assessments of biomass to produce the information needed to estimate biomass and carbon in forests at a wide range of scales. Lidar, sometimes spelt LIDAR or LiDAR, is an acronym derived from Light Detection And Ranging. As with radar, initially spelt RADAR, which is seldom spelt out (Radio Detection and Ranging), lidar has already become a commonly used acronym, and therefore this paper will use the lower-case spelling throughout. Lidar systems are active remote sensing devices that measure the time of travel needed for a pulse of laser energy sent from the airborne system to reach the ground and reflect back to the sensor. The time measurement is converted into a distance measurement that is used to derive a precise three-dimensional characterization of reflecting ground surfaces, including forest vegetation. In areas with dense vegetation cover, lidar pulses will mainly reflect from the top and from within the vegetation canopy, with some laser pulses penetrating to the ground and therefore providing an accurate ground elevation. As opposed to optical remote sensing methods, airborne lidar has certain characteristics,

Abbreviations: CHM, canopy height model; dbh, diameter at breast height; DSM, digital surface model; GPS, global positioning system; lidar, Light Detection And Ranging; RMSE, root mean squared error; USDA, United States Department of Agriculture

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such as high sampling intensity, direct measurements of heights, precise geolocation, and automated processing, that make airborne laser systems useful for directly assessing vegetation characteristics and deriving forest biomass at multiple scales, from individual trees to regional extents. This study describes an application of small footprint, scanning lidar data.

Previous lidar studies, whether using waveform or discrete return lidar data, attempted to derive plot level or individual tree attributes, such as tree height and crown dimensions, and then use allometric relationships to estimate biomass, usually at plot or stand level. Early lidar biomass studies used profiling laser systems and related the area under the canopy profile to timber volume or biomass [1–4]. Forest stand characteristics were estimated using data from scanning lasers that provided lidar data with either full waveform digitization [5–10] or small-footprint, discrete-return systems [11–18]. All these studies demonstrate that lidar has become a proven technology for estimating forest biophysical parameters automatically and with relatively high accuracy, mainly at plot level [19], and stand level, e.g., [20]. Despite intense research efforts, operational applications of small-footprint lidar are not numerous, mainly because of the current high cost of lidar data. However, several European countries have initiated programs to use lidar for large-scale forest inventories, with Scandinavian researchers on the forefront [21].

Few studies have focused on individual tree level [22,23]. Although morphological computer vision algorithms have been used to identify automatically tree crown structures visible on lidar-derived three-dimensional canopy height models (CHM) and to measure tree height and crown diameter, results are usually reported at plot level [24,25] or stand level [26]. The main reason is the difficulty of validating results for individual trees, when an objective correspondence needs to be established between field- and lidar-measured individual trees. This difficulty arises due to uncertainties with individual tree mapping on the ground, related to global positioning system (GPS) locations, close canopy conditions, vertical tree position in the canopy, etc. As opposed to the studies mentioned above, the current study attempts to estimate individual tree biomass and to report results at the individual tree level.

In this study, biomass is defined in dry weight terms. Aboveground tree biomass refers to the weight of the tree portion that is found above the ground surface, when oven-dried until a constant weight is reached. Plot-level biomass estimates are normally expressed per unit area and are made by summing the biomass values for the individual trees on a plot, and then extrapolating to the land area for which the plot is representative. With remote sensing systems affording high resolution, including lidar, we consider that the individual tree approach has certain advantages: first, we expect to see an increased accuracy for deriving biomass estimates remotely, and second, when estimating biomass at larger scales, this approach offers the means of better understanding the sources of uncertainty and error with remote sensing estimates. These sources, which include variances associated with ground-based allometry, ground-based sampling, and regression errors, must be taken into account if realistic variances of remote sensing estimates are to be reported. Such variances are important for defining measurement intervals for monitoring purposes, and can be used as a ranking tool to assess the performance of scale-up approaches as well as estimation procedures for different canopy parameters. The need is clear for a consistent and rigorous statistical and methodological framework, operationally affordable with modern remote sensing means, such as lidar, for aboveground biomass and carbon estimation with application from local to regional and even larger extents.

2. Objective

The overall goal of this study was to develop a methodological framework for assessing aboveground biomass for individual trees using airborne lidar data in forest settings typical for the southeastern United States. Besides aboveground biomass, the study also reports results for other biophysical parameters of interest for forest inventory, such as diameter at breast height (dbh) and tree components biomass. More specific objectives included:

(1) assessing the accuracy of estimating dbh for individual trees using lidar-derived individual tree measurements, such as tree height and crown diameter, since dbh is the most reliable variable for biomass estimation; and
(2) investigating the use of lidar-derived individual tree measurements with linear and nonlinear regression to estimate individual tree aboveground biomass.

In addition, this study presents a method for assessing the accuracy of estimating individual tree component biomass, such as foliage, coarse roots, stem bark, and stem wood.

3. Materials and methods

3.1. Study site

The study area is located in the southern United States (30°42′N, 95°23′W), in the eastern half of Texas (Fig. 1), having approximately 48 km^2. The study area covered with scanning lidar includes pine plantations in various developmental stages, old growth pine stands in the Sam Houston National Forest, many of them with a natural pine stand structure, and upland and bottomland hardwoods. Much of the southern US is covered by forest types similar to the ones included in our intensive study areas, with similar forest types, productivity, and patterns of land use change. A mean elevation of 85 m, with a minimum of 62 m and a maximum of 105 m, and gentle slopes characterize the topography of the study area.