USING LIDAR AND COLOR INFRARED IMAGERY TO SUCCESSFULLY MEASURE STAND CHARACTERISTICS ON THE WILLIAM B. BANKHEAD NATIONAL FOREST, ALABAMA

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Abstract.—Light detection and ranging (Lidar) and color infrared imagery (CIR) were used to quantify forest structure and to distinguish deciduous from coniferous trees for selected stands on the William B. Bankhead National Forest in Alabama. Lidar bare ground and vegetation point clouds were used to determine tree heights and tree locations. Lidar accuracy was assessed by comparing Lidar-derived tree heights to field-measured tree heights. An independent t-test showed Lidar-derived coniferous tree heights were statistically the same as field-measured heights (p = 0.24). Likewise, the mean Lidar deciduous tree heights were statistically the same as the average field-measured tree heights (p = 0.10). The CIR photograph analysis detected groves of coniferous and deciduous trees. The overall classification accuracy of deciduous and coniferous vegetation in the CIR image was 95.59 percent. Our research demonstrates the ability of Lidar to correctly determine tree height and tree location in a mixed pine-hardwood forest. The results obtained from this study indicate that Lidar can assist ecologists and managers to make decisions that would be difficult to make if based solely on field measurements.

INTRODUCTION

Light detection and ranging (Lidar) is used to describe at an unprecedented level of detail the biophysical characteristics of woody vegetative communities. Recently, Lidar has proven to be of great assistance to ecologists and foresters by efficiently determining tree heights and other forest attributes (Lefsky and others 2002, Brandtberg and others 2003, Evans and others 2006). The use of Lidar systems in forestry has come about in part because of the need for faster, less expensive, and more accurate forest data collection (Blair and others 1999, Evans and others 2006, Koukoulas and Blackburn 2004). Lidar has the capability to provide forest measurements at fast rates, low costs, and high accuracies that cannot be obtained through field measurements (Anderson and others 2006a). In particular, Lidar can characterize forest ecosystems in more detail than typical remote sensing applications by determining stand structure, composition (when combined with other remote sensing methods), tree height, crown dimensions, leaf area index, basal area, and aboveground biomass (Lefsky and others 2002, Naesset and others 2004, Popescu and others 2003). Moreover, the ability of Lidar to remotely measure tree height and crown size for great expanses of forest is useful to further understand ecosystem structure and function (Blair and others 1999).

Specific research objectives of this study were to (1) test if Lidar can measure individual tree heights in the forest types of the William B. Bankhead National Forest (BNF) in Alabama; and (2) examine the capabilities of Lidar data in combination with infrared imagery to distinguish pines from hardwoods and identify tree locations for a mixed pine-hardwood stand in the BNF. We tested the difference between Lidar and ground-measured tree heights for both deciduous and coniferous trees in a forest on the mid-

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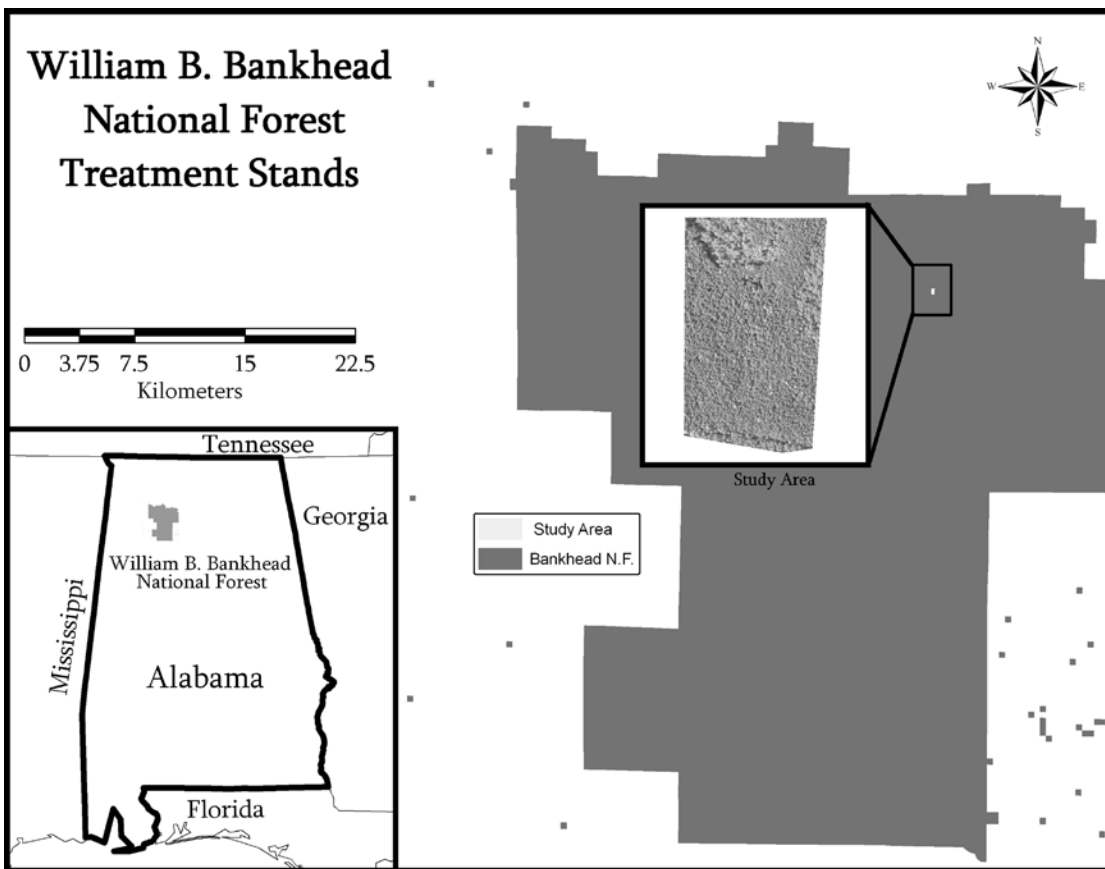
Figure 1.—The study area located in the BNF.

Cumberland Plateau that was not previously sampled with Lidar. Hudak and others (2002), Popescu and others (2004), and Anderson and others (2006b) have shown that Lidar can be used to measure tree height, location, and crown size in different forest types.

STUDY AREA

The study area (Fig. 1) is located on the northern third of the BNF in Lawrence County, AL. The BNF is within the Cumberland Plateau region of the southern Appalachian Mountains described as having gentle slopes and broad undulating uplands (Smalley 1982). The soils of this subregion are moderately deep, well drained, and permeable (fine-loamy, siliceous, semiactive, thermic Typic Hapludults). The stands are dominated by even-aged loblolly pine (*Pinus taeda* L.) with some Virginia pine (*P. virginiana* L.) volunteers, but management objectives are aimed at shifting the stands towards an upland hardwood dominated composition.

MATERIALS AND METHODS
Data

Lidar data were collected for selected BNF stands on July 2, 2005 with an Optech Airborne Laser Terrain Mapper 3100 instrument. This Lidar multi-return system, two returns, uses a scanning laser to measure the earth and vegetation below the aircraft by recording the start of the laser pulse and the return time of the laser to the system sensor. Because the flight elevation and exact location of the plane are recorded with a Real-Time Kinematic Global Positioning System and an Inertial Measurement Unit for each laser return, we can calculate the ground topography and the height of the vegetation by knowing the speed of light, angle of pulse, and the x, y, and z orientation of the airplane. The Lidar was acquired at an altitude of 910

Digital Surface Model

293.38 m
259.64 m

a.

Digital Terrian Model

312.91 m
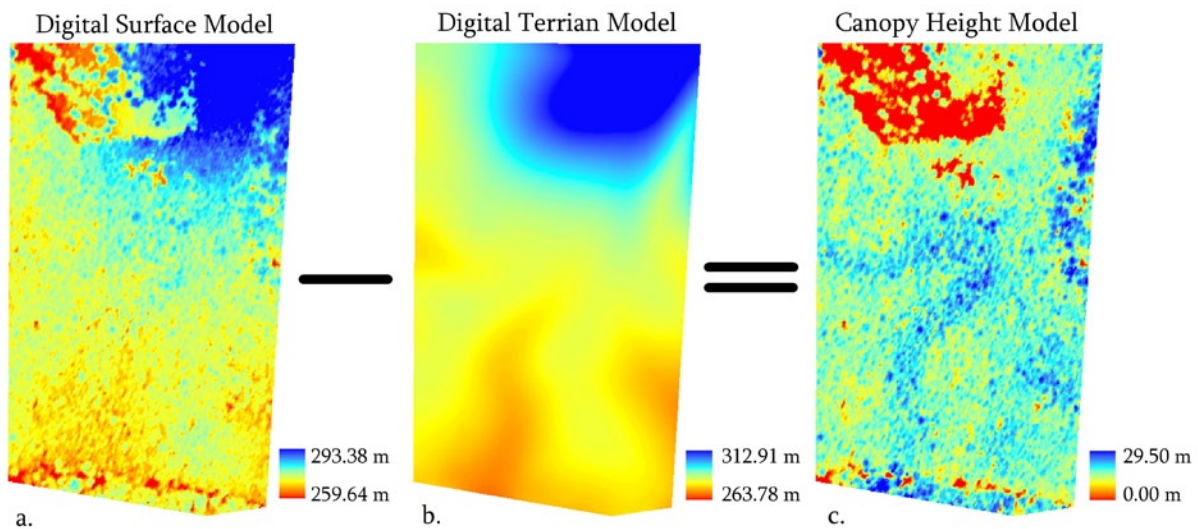263.78 m

b.

Canopy Height Model

29.50 m
0.00 m

c.

Figure 2.—Process to obtain the vegetation heights. The digital terrain model (b) was subtracted from the digital surface model (a) to produce the canopy height model (c).

m to achieve a footprint of 0.27 m with a point density of three postings per square meter. In addition to Lidar, digital CIR photographs were collected for the entire BNF on September 9, 2005. The CIR photographs were obtained at an altitude of 3290 m such that a photo scale of 1:21,600 was achieved with a spatial resolution of 0.50 m.

Interpolation

To determine tree heights and locations, it was necessary to classify the Lidar points into two different categories. The result of classifying the Lidar data were two sorted point clouds: bare earth returns, which represented the ground topography because the points were reflected by the ground, and first return, which depicted vegetation heights because they were reflected by vegetation. Once the vegetation and the bare earth point clouds were sorted based on elevation above an ellipsoid, both point clouds were used to create the interpolated terrain models (raster images) that allowed us to calculate tree heights.

The terrain models were interpolated using three different methods: Inverse Distance Weighted (IDW), Universal Kriging (UK), and Ordinary Kriging (OK). We tested the best interpolation method based on the amount of error between the predicted and the measured points for IDW, UK, and OK. A digital terrain model (DTM) was created from the bare earth and first returns such that each 0.5 m pixel represented the ground elevation. A digital surface model (DSM) was then developed to represent the above ground vegetation with a 0.5 m spatial resolution. Both the DSM and DTM images were interpolated using the OK method. The canopy height model (CHM) was produced by subtracting the DTM image from the DSM image to obtain the vegetation heights for the study area (Fig. 2). The resulting CHM raster image contained the vegetation heights that were used to obtain tree locations, heights, and crown dimensions in TreeVaW. TreeVaW© is a software application used to extract forest inventory parameters from Lidar data. The tree heights calculated in TreeVaW were compared to the field height measurements.

CIR Classification

The CIR study area image was classified by iteratively selecting representative groupings of deciduous and coniferous trees based on spectral differences. The deciduous class was dominated by the *Quercus*

species and the coniferous class was dominated by loblolly pine and Virginia pine. Supervised classification produced an image that identified the locations of deciduous and coniferous trees. The accuracy assessment of the CIR image calculated a consumer's accuracy, or the chance of correctly determining what is actually on the ground; producer's accuracy, the probability the map is correctly classified; commission error, the chance of including a pixel in a class when it should have been excluded; and omission error, the probability of excluding a pixel that should have been included in the class. The high overall accuracy obtained from the CIR image allowed us to separate the coniferous trees from the deciduous trees, so TreeVaW's tree height algorithm could model each category separately. The CIR image and the Lidar data were georeferenced using a Real-Time Kinematic Global Positioning System prior to analysis so both data sets were co-registered.

Tree Measurements

Field data were collected by using a ForestPro laser range finder (Laser Technology, Inc., Centennial, CO) to obtain 75 tree heights. The trees whose heights were collected were selected by establishing five plots in a systematic manner and measuring the 15 trees in each plot that were closest to plot center and had diameter at breast height (d.b.h.) over 1.5 inches. Among the measured trees were both overstory and midstory trees that would not be clearly visible in the Lidar. We excluded from the analysis by taking the average of the field-measured trees and omitting those that were less than an arbitrarily assigned height of 75 percent below the mean. The field-measured tree heights were considered to be the correct measurement, thus allowing the accuracy of the Lidar-derived tree heights to be assessed. We compared the field-measured tree height averages to the average Lidar derived tree heights using an independent t-test at an alpha level of 0.05 in SPSS ver. 11(SPSS Inc., Chicago, IL). We did not compare individual field-measured trees with individual measured trees located with the Lidar data.

TreeVaW was used to identify tree location and tree height. The TreeVaw algorithm is based on the local maximum filtering technique that uses a search window of variable size (Kini and Popescu 2002). The local maximum technique is typically used in multispectral imagery to find the greatest reflection point to denote the apex. In this study, however, the local maximum was used with the Lidar CHM data because the vegetation heights in the CHM are analogous to reflection pixels.

The TreeVaw algorithm reads the height value from each pixel in the CHM and calculates a window size to search for the local maximum. The variable window that is used to represent tree canopy can be either a circle or a square. The algorithm filters the image within a window shape and identifies the local maximum. After the location of each identified tree has been marked, the CHM is sampled at the local maximum to determine the height of each tree. TreeVaW avoids low vegetation by setting a minimum tree height to be used. For this study the minimum tree height was set to 3.00 m.

Two separate TreeVaw processes were run to identify coniferous and deciduous trees. The coniferous trees were set to a smaller crown width size (3.00-5.00 m) that was determined by measuring the crown width in the classified coniferous CIR image. For the deciduous trees we used a larger crown width (7.50-10.00 m) that was also determined by measuring the crowns in the area classified as deciduous.

The data were processed with ArcGIS (9.2) software (Environmental Systems Research Institute, Inc., Redlands, CA), ENVI (ITT Visual Information Solutions, Boulder, CO) remote sensing software, and Tree Variable Window (TreeVaw), an ENVI application (Kini and Popescu 2004).

Table 1.—Accuracy assessment for the classified CIR image. Note that the percentage correct equals the sum of the diagonal divided by the total observations (e.g., 1737/1817 = 95.5 percent)

Classified data	Deciduous pixels	Coniferous pixels	Row total	Producer's accuracy	Omission error
Deciduous pixels	1230	17	1247	98.60%	1.40%
Coniferous pixels	63	507	570	88.90%	11.10%
Column total	1293	524	1817		
Consumer's accuracy	95.10%	96.70%			
Commission error	4.90%	3.30%			

RESULTS AND DISCUSION

Interpolation

IDW had the highest measure of predicted error and a root-mean-square of 0.24 m. IDW is a simple interpolation method that does not allow a standardized error, such as kriging, to be computed. IDW interpolation produced a generalized image for the bare ground and the predicted error was comparable to UK. The UK method had a predicted error of 0.00 (if using only two significant digits) and root-mean-square standardized error of 1.25 m. UK produced an image that was similar in error to the IDW image, but the IDW and UK results were not as close to the actual values when compared to the OK results. OK had a mean closest to zero and a root-mean-square standardized value of 0.98 m, meaning that the predicted values were close to the actual values. The OK image was selected to calculate the bare earth because the predicted error was near zero and the standardized error value was closest to 1. The vegetation returns were interpolated with OK because of the low error values for the predicted locations.

Tree Heights

The accuracy assessment of the CIR image is summarized in Table 1. The overall accuracy of the CIR image was 95.59 percent with a Kappa statistic of 89.55 percent. The resulting classified CIR photograph shows the location of the deciduous and coniferous trees in the study area (Fig. 3).

TreeVaw identified 739 deciduous trees with an average tree height of 17.78 m and a standard deviation of 2.96 m. The tallest deciduous tree generated from TreeVaw was 29.50 m and the shortest was 12.03 m. The coniferous tree results from TreeVaW were based on 2875 trees with a mean height of 17.99 m and a standard deviation of 2.29 m. The tallest coniferous tree detected with TreeVaw was 28.80 m and the shortest was 12.02 m.

Twenty-five deciduous trees and 38 coniferous trees were measured in the field. The average field measured deciduous tree height was 13.74 m (standard deviation 3.86 m) and the average coniferous tree height was 18.43 m (standard deviation 2.72 m). A t-test for difference in means revealed that the deciduous TreeVaw derived heights were statistically the same as the field-measured deciduous tree heights.

A t-test for difference in means between the coniferous field-measured tree heights and the TreeVaw tree heights showed that they were not significantly different. These results are in accordance with other studies (Popescu and others 2003, Koukoulas and Blackburn 2005, Brandtberg 2007) that have found no major difference between field-measured deciduous tree heights and the Lidar-derived deciduous tree heights. The results indicate that it is possible to accurately measure codominant and dominant tree heights using Lidar data in mixed pine-hardwood southeastern forests of the type in this study.
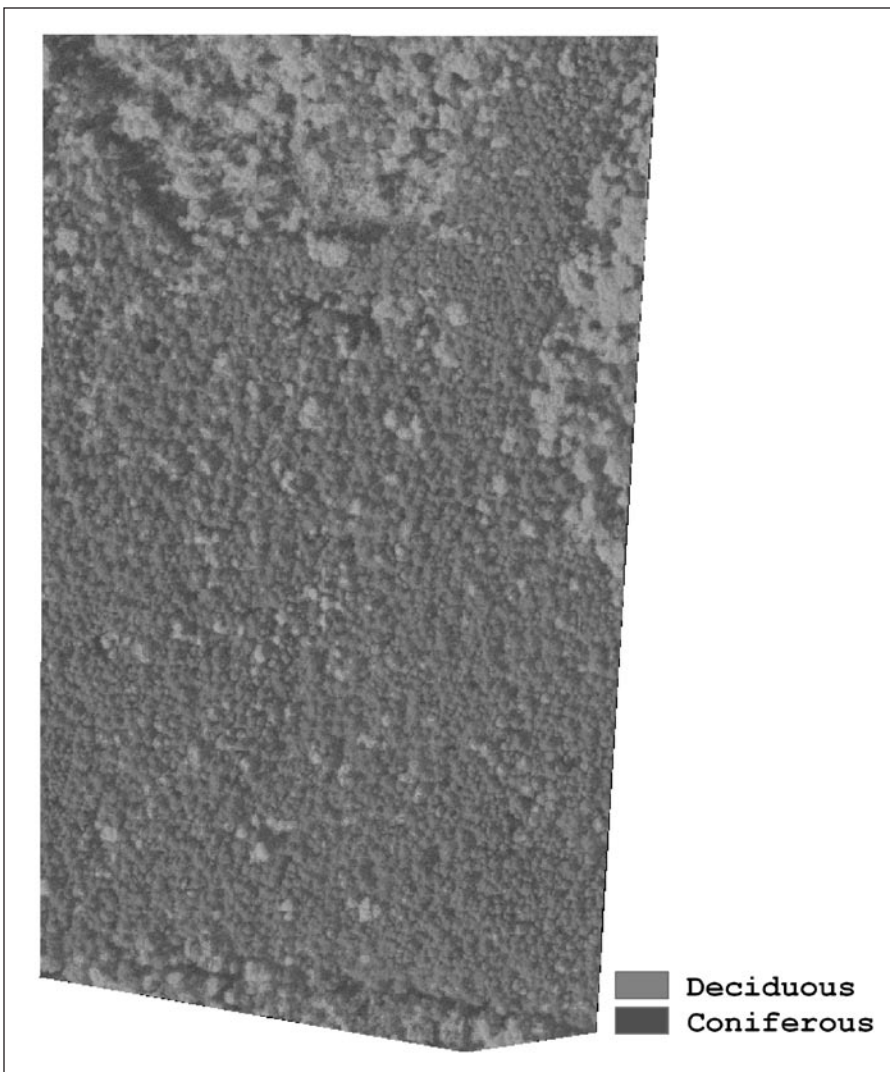
Figure 3.—Classified color infrared image into deciduous and coniferous categories.

CONCLUSIONS

The classification of the CIR photograph was accurate and improved the accuracy of the TreeVaw algorithm. This improvement was accomplished by using two different CHMs for the coniferous and deciduous trees in TreeVaw. This greatly reduced the erroneous number of trees detected using TreeVaw's local maximum filtering technique. The results of the TreeVaw output used in association with field data can assess the accuracy of Lidar derived tree heights. Our results indicate TreeVaw heights are statistically the same as field measured coniferous and deciduous tree heights. The information derived from Treevaw may be used to extract further information from forest stands such as biomass, leaf area index, d.b.h., and basal area.

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