BUILDING CAPACITY FOR PROVIDING CANOPY COVER AND CANOPY HEIGHT AT FIA PLOT LOCATIONS USING HIGH RESOLUTION IMAGERY AND LEAF-OFF LIDAR

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Abstract.—Tree canopy cover and canopy height information are essential for estimating volume, biomass, and carbon; defining forest cover; and characterizing wildlife habitat. The amount of tree canopy cover also influences water quality and quantity in both rural and urban settings. Tree canopy cover and canopy height are currently collected at FIA plots either in the field or by dot-grid interpretation of digital aerial imagery. These techniques can be time consuming and costly. The University of Vermont's Spatial Analysis Laboratory has developed an automated approach using Object-Based Image Analysis (OBIA) techniques for extracting canopy cover, canopy height, and land cover from readily available high resolution aerial imagery and leaf-off LiDAR. We used datasets generated by the OBIA approach for 10 different counties spread across 4 states, representing a range of conditions. Canopy cover, canopy height, and land cover information were computed for each FIA plot, at scales of 144-foot-radius (plot circle) and 3,280-foot-(1-km)-radius, and compared to FIA estimates at the plot level. Results are discussed in terms of the comparative assessment of the three canopy cover data sources (including what is missing when nonforest plot data are not available), and the prognosis for using the OBIA techniques to extract this type of information at the county and state levels. Acquiring tree canopy cover data using the OBIA approach would allow FIA to apply a consistent method for acquiring canopy cover to both visit and non-visit plots, and even potentially increase the reliability of the canopy cover data available. This approach also provided valuable data on canopy height for FIA plots not visited in the field and additional data on landscape context for all FIA plots, improving capacity to characterize and analyze forest characteristics with respect to local levels of urbanization.

INTRODUCTION

The importance of information on tree cover, irrespective of land use, has been recognized by the U.S. Forest Service's Forest Inventory and Analysis (FIA) Program for some time. In 2010 FIA decided to add it as a standard variable, to be collected in the field for all visited plots, and via photointerpretation at the prefield stage for all non-visit plots, with some overlap for quality assurance (QA) to assess the relationship between the two. Once the protocol is fully implemented, these data will provide FIA with tree canopy cover data on all plots, providing a much more complete and consistent estimate of tree canopy cover information than is currently available. Data collected via these two methods are directly relevant to the 1/6-acre plot cluster and thus the other inventory variables collected on the plot. There are some limitations with this data, however. Data from visited (mostly forest) and non-visited (mostly nonforest) plots are collected by different methods and at different scales, potentially

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resulting in systematic differences in measurement quality between the two populations. These effects will be unknown until enough QA overlap data are available for analysis. Furthermore, collecting tree canopy cover data in this manner is labor intensive. If semi-automated or fully automated approaches to determining canopy cover are available that provide data at similar scales and with similar estimates and standard errors, it could make the protocol more efficient in the long term.

Another source of tree canopy cover information has been developed by O'Neil-Dunne et al. (2009) using a combination of high resolution aerial imagery and LiDAR (Light Detection And Ranging) data. It has been used to generate citywide and countywide estimates of existing tree canopy cover for resource managers (e.g., O'Neil-Dunne and Pelletier 2011). This approach leverages the vast amounts of high resolution remotely sensed data available through the National Agricultural Imagery Program (NAIP) along with LiDAR data acquired by federal, state, and local governmental organizations. Object-Based Image Analysis (OBIA) techniques are used to extract seven-class land-cover datasets with an overall accuracy exceeding 90 percent. The combination of spectral (imagery) and height (LiDAR) data in conjunction with OBIA techniques enables features to be extracted using the same elements of image interpretation used by photointerpreters (see Olson 1960).

Our four primary goals in this study were to (1) compare plot-level estimates of tree canopy cover obtained from the OBIA technique with those obtained by FIA via ground inventory in the field and via photointerpretation in prefield procedures, (2) compare plot-level estimates of stand height with those obtained by FIA in the field, (3) examine the canopy cover and canopy height characteristics of forest vs. nonforest plots, and (4) illustrate the type of landscape context information that is available for each plot from the OBIA approach.

METHODS

Of the 10 counties for which OBIA data are already available, only 6 were included in this paper: Allegheny and Lancaster Counties in Pennsylvania, and Anne Arundel, Montgomery, Prince Georges, and Howard Counties in Maryland. The six counties range from 16 percent forested in Lancaster, PA, to 40 percent forested in Prince Georges, MD. Species composition is primarily hardwoods.

Our study was based on FIA field plots visited from 2006 to 2011. Tree height was available on all forested plots. Because canopy cover variables were just introduced last year, only a subset of these plots had canopy cover data. At the time of this study, about 20 percent of forested plots had field canopy data, collected in 2011. A different subset (~20 percent of all plots) had photointerpreted (PI) canopy cover collected using imagery from 2007 to 2010. Of the 369 plots in the 6 counties for which data were available at the time of this paper, we had PI percent canopy cover data for 75 plots (all counties) and field-collected canopy cover data for 19 plots (MD counties only). FIA canopy height and field canopy cover were calculated as the mean of all live trees on the forested conditions on the 1/6-acre plot. FIA photointerpreted canopy cover was estimated using a 100-point dot grid over a 1.5-acre (144-foot-radius) area surrounding each plot.

The imagery used for all the counties in the study consisted of NAIP 4-band 1-m data from 2009 to 2011. The LiDAR was sourced from a broad range of federal, state, and local agencies. The various LiDAR datasets were similar in that they had a nominal post spacing of 0.6 m to 1.4 m, had ground points classified (LAS class = 2), and were acquired during leaf-off conditions. Digital Elevation Models (DEM) and Normalized Digital Elevation Models (nDSM) were generated from the LiDAR data. The LiDAR surface models, imagery, and ancillary GIS datasets (e.g., road centerlines) were integrated into the OBIA system, which was built using the eCognition® software platform. Within eCognition®, a rule-based expert system was used to extract seven classes of land cover at a nominal resolution of 1 m: (1) tree canopy, (2) grass/shrubs, (3) bare soil, (4) water, (5) buildings, (6) roads/railroads, and (7) other paved surfaces. The rule-based expert system was built using the Cognition Network Language (CNL), which is the underlying programming language for eCognition®. In this approach, image processing, segmentation, classification, and morphology algorithms are iteratively applied, thereby successively building contextual information, which can then be used to improve the classification. To effectively process the billions of data points making up the imagery and LiDAR and support iterative processing approach, the OBIA system was built on 64-bit computing architecture and the processing load was distributed to multiple cores.

Following the development of the land cover dataset, the FIA plot data were integrated into the OBIA system. A separate rule-based expert system iteratively processed each FIA plot, extracting canopy coverage, topographic, and land cover information.

OBIA estimates of canopy height and canopy cover were calculated at two different neighborhood sizes for each FIA plot: a 144-foot-radius area around plot center (1.5 acres), representing the plot circle encompassing all four subplots, and a 3,280-foot-radius area around plot center (776 acres). OBIA estimates were calculated as the mean canopy height and canopy cover of all tree canopies greater than 8 feet in height. FIA and OBIA estimates were compared using linear regression (r-squared).

RESULTS

OBIA canopy cover estimates are strongly correlated to the FIA photointerpreted tree canopy estimates ($r^2 = 0.91$), but relative to the FIA data they tend to overestimate canopy values. OBIA and field-collected tree canopy estimates exhibited a poor correlation ($r^2 = 0.07$) (Fig 1).

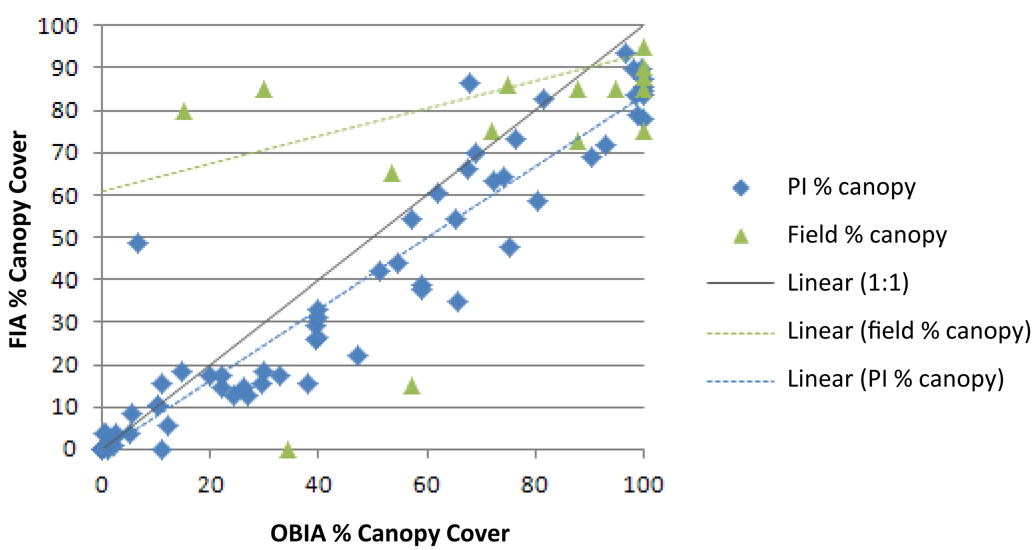

Figure 1.—Comparison of OBIA-based canopy cover information with FIA canopy cover information. OBIA information is derived from an automated classification procedure using NAIP high resolution aerial imagery and LiDAR data. FIA canopy cover information is either observed in situ or estimated from a NAIP image using a dot grid.

Agreement between FIA canopy height and LiDAR-derived OBIA height for forested plots is poor, with an r-squared of 0.23 (Fig. 2). Additional investigation needs to be done to determine if this is due to a locational mismatch between FIA plot locations and the OBIA data or if the difference in collection dates between LiDAR and FIA field visits accounts for the differences (or some combination of both). It is likely that the leaf-off nature of the LiDAR data is at least partly to blame, particularly in deciduous forests where the morphological profile of the trees (tall, thin, with few branches) results in relatively few LiDAR returns with the 0.6- to 1.4-m post spacing. FIA currently has no information on tree heights on nonforest plots. Based on the OBIA data, nonforest plots have trees ranging from 10 to 60 feet in height (Fig. 2), information not available from the FIA photointerpreted data for nonforest plots.

The OBIA data provide information on tree canopy cover and stand (mean tree) heights for all plots. From this information we can summarize characteristics for both forest and nonforest plots for these six counties. For example, in Lancaster County, the average canopy cover for the entire county is 23 percent, with an average height of 17 feet. Breaking this down, we find that the averages are 68 percent canopy cover and 37 feet high for forested plots, and 12 percent canopy cover and 12 feet high for nonforest plots. For a county that is 85 percent nonforest, this represents considerable tree canopy cover for which very little FIA data exist. Table 1 presents this information for six counties.

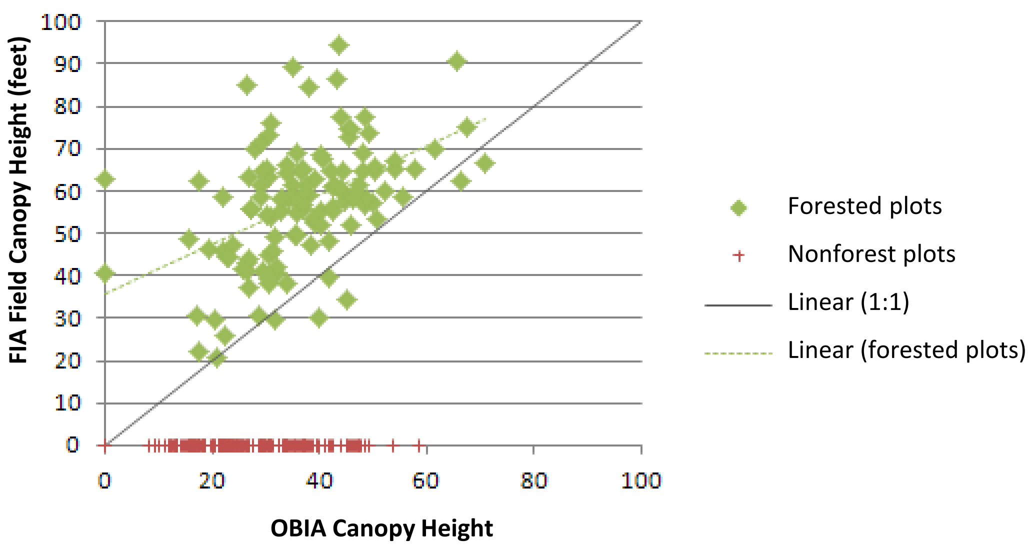

Figure 2.—Comparison of OBIA-based canopy height information with FIA canopy height information. OBIA-based heights are derived from a LiDAR point cloud while FIA height information is obtained using field methodology.

Table 1.—Summary of tree canopy cover and canopy height statistics for forest vs. nonforest plots from the OBIA data

	Percent Canopy Cover						Canopy Height					
	All Plots		Forested Plots		Nonforest Plots		All Plots		Forested Plots		Nonforest Plots	
County	Mean	SE (n)	Mean	SE (n)	Mean	SE (n)	Mean	SE (n)	Mean	SE (n)	Mean	SE (n)
Anne Arundel	49	5.3 (41)	76	7.1 (13)	36	5.5 (28)	33	2.6 (41)	45	3.1 (13)	28	2.9 (28)
Montgomery	46	4.8 (53)	75	4.7 (22)	26	4.9 (31)	25	3.3	31	5.5	20	1.4
Prince Georges	51	5.3 (53)	83	19.0 (19)	33	5.6 (34)	33	2.6	46	10.6	25	4.3
Allegheny	49	3.5 (84)	68	5.0 (37)	34	3.7 (47)	28	1.2	33	1.8	24	1.4
Lancaster	23	3.1 (107)	68	6.7 (20)	12	2.3 (85)	17	1.6	37	2.8	12	1.5
Howard	54	6.6 (28)	79	8.0 (11)	38	7.2 (17)	33	2.1	40	1.9	28	2.7

The OBIA datasets also provide information on the land cover context or neighborhood in which the plot occurs. This context can be important to understanding the status of an individual plot. For example, plots in the study area with relatively low canopy cover within the 1.5-acre circle were found to have substantially more canopy cover within the larger 776-acre circle (Fig. 3). And plots with 100 percent canopy cover within the 1.5-acre circle were found to contain other land uses within the larger 776-acre context area.

DISCUSSION AND CONCLUSIONS

The OBIA datasets offer several opportunities. First, the OBIA datasets provide an alternative assessment of the photointerpreted and field-collected tree canopy cover values. Second, it is an opportunity to provide consistent tree canopy cover information for both visited and non-visited plots at a scale relevant to the FIA plot data without additionally impacting the FIA prefield process. As can be seen in Table 1, the magnitude of tree canopy cover in nonforest areas supports the need to gather this information, whether via prefield interpretation or the OBIA approach. Third, the OBIA datasets offer an opportunity to gather canopy height information on all plots, not just those visited in the field. Finally, and equally importantly, these datasets can provide landscape context information important for understanding local urbanization pressures for each FIA plot at a scale and accuracy not possible from NLCD data sources and with an efficiency not possible from photointerpretation. The OBIA data provide information about the larger neighborhood and therefore can show us how well the FIA plot is representative of its surrounding area.

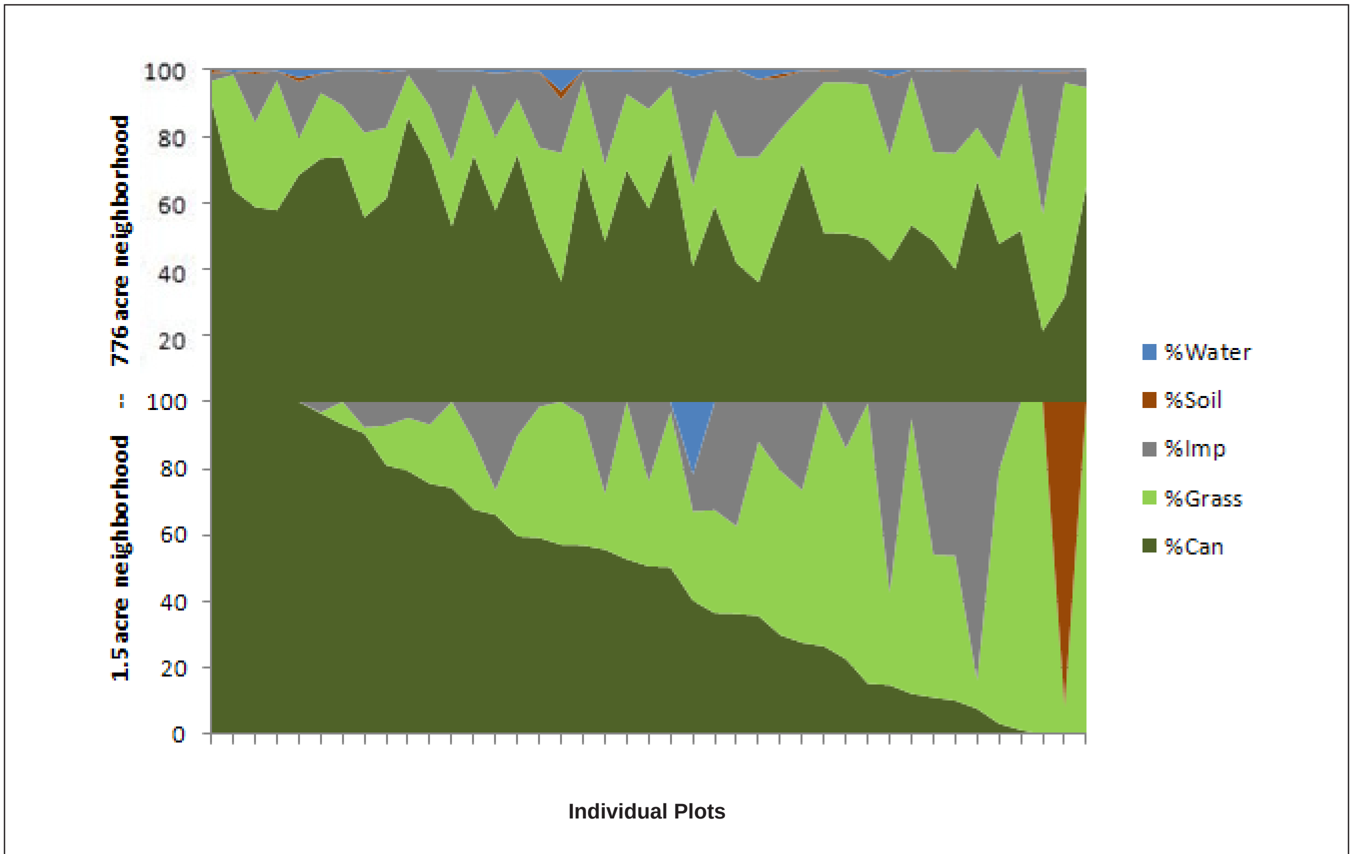

Figure 3.—Summary of the land cover context around individual plots in Anne Arundel County at two scales. Plots are sorted by the proportion of canopy cover present within the 144-foot- radius area.

OBIA approaches to land cover and FIA metric extraction have been shown to be efficient when applied to large datasets, providing those datasets have somewhat consistent properties. Although OBIA systems require a great deal of expertise to design and deploy, they are cost effective over large areas due to economies of scale. Furthermore, in addition to computing plot metrics, the OBIA approach provides a means by which to conduct a complete census, which is increasingly important as development pressures stemming from urbanization and natural resource exploitation fragment the forested landscape. The greatest barrier to the OBIA approach is the availability of data. Although NAIP data are acquired for each state aside from Alaska at least every 3 years, there is no nationally coordinated LiDAR program. For states that do have comprehensive coverage, the LiDAR data are typically available for only a single point in time and are frequently leaf-off to create terrain DEMs. The approach used in this study allowed us to take advantage of leaf-off LiDAR for estimating tree canopy cover and height to generate data comparable to current FIA estimates.

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