

CANOPY COVER ESTIMATES FOR INDIVIDUAL TREE ATTRIBUTES

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Abstract.—In most forest inventory data, it is not feasible to estimate the canopy coverage of trees having certain characteristics due to the lack of information on crown size. In this study, data from the Forest Inventory and Analysis (FIA) program was used to assign crown sizes to individual trees using published crown width models. This process effectively links trees to area such that canopy cover area estimates can be made using domains that include tree-level attributes (e.g., canopy cover of red maple having total height ≥ 80 feet). Advantages of implementing this approach are 1) estimation can proceed as with any other estimate of area derived from FIA data, and 2) canopy cover estimates provide different information than classical indicators such as number of trees. A disadvantage is the need to dissolve overlapping crowns after the tree-level domain is selected. Two examples are provided to illustrate applications of the method.

INTRODUCTION

Tree canopy cover is the proportion of an area covered by the vertical projection of tree crowns (Jennings et al. 1999). Canopy cover plays a critical role in defining current and future forest characteristics via impacts on understory species composition and structure (Canham et al. 1990). Canopy cover is often a primary indicator of wildfire risk and behavior of both modeled and actual wildfires (Agee and Skinner 2005).

Additionally, amounts and types of canopy cover and structure influence habitat suitability for many forest-dwelling vertebrate species (Massé and Côté 2009). A key factor in studies of the aforementioned relationships between canopy cover and forest-related phenomena is that relevant analyses often focus on specific aspects of canopy cover, e.g., cover of trees having certain characteristics such as species, diameter at breast-height (d.b.h.), and total height (Abrahamson and Gohn 2004). Thus, expansion of research results to landscape-scale assessments can be difficult.

Area coverage estimates for tree-level attributes are usually not feasible from forest inventory data due to the lack of information on how much area is represented by an individual tree. Alternatively, the area occupied by each inventory tree can be approximated from the plot data using techniques such as Thiessen polygons or crown width models (Bechtold 2003). Applying crown width models to forest inventory data with mapped tree locations allows for spatial representation of canopy cover while also allowing for gaps between trees. Because the crown width approach is specific to individual trees, there is an explicit relationship that links area coverage to tree-level attributes. In this paper, we present methodology to estimate the area coverage of virtually any tree-level attribute(s) available in forest inventory data.

METHODS

A three-phase forest inventory and monitoring effort is implemented by the Forest Inventory and Analysis (FIA) program within the U.S. Forest Service (Bechtold and Patterson 2005). Phase 1 (P1) is the development of a post-stratification scheme using remotely-sensed data. The second phase (P2) entails

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measuring sample plots on the ground for the usual suite of forest mensuration variables such as tree species, d.b.h., height, forest type, stand age, etc. Overstory trees (d.b.h. ≥ 5.0 in.) are measured on four 24-ft radius subplots; saplings ($1.0 \leq \text{d.b.h.} \leq 4.9$ in.) are recorded on four microplots of 6.8-ft radius each. Phase 3 (P3) occurs on a subset of the P2 plots, where additional data on forest health indicators are collected (e.g., down woody material). To evaluate the efficacy of the methods presented below, one full cycle of data from Pennsylvania was used (data collected between 2006 and 2010).

To estimate the amount of canopy cover for each tree measured in the inventory, the crown width models described by Bechtold (2003) were used. When species were encountered that were not listed in Bechtold (2003), coefficients for species of similar form were used. For this analysis, the model using d.b.h. and crown ratio as input variables was used.

$$[1] \quad \hat{C}\hat{W} = \hat{\beta}_0 + \hat{\beta}_1 D + \hat{\beta}_2 D^2 + \hat{\beta}_3 CR$$

where: $\hat{C}\hat{W}$ = estimated crown width (feet)
 D = d.b.h. (inches)
 CR = crown ratio
 $\hat{\beta}_{0-3}$ = species-specific coefficients

Spatial representation of plot canopy cover was accomplished by centering circles of estimated crown width at the tree location recorded during the plot visit. To assess cover of overstory trees (d.b.h. 5.0+ inches), overlapping crowns from neighboring trees were combined such that crown overlap was accounted for, i.e., the cover as it would appear as viewed from above. A geographic information system (GIS) was employed to dissolve the boundaries between individual tree crowns in order to create polygons of non-overlapping crown cover for each FIA plot condition (Fig. 1). A key point in the analytical method is that crowns extending beyond the sample plot boundary are included in the total canopy cover for the plot. It is surmised that, on average, this will account for crown areas of nonsampled trees extending into the plot that are not explicitly accounted for.

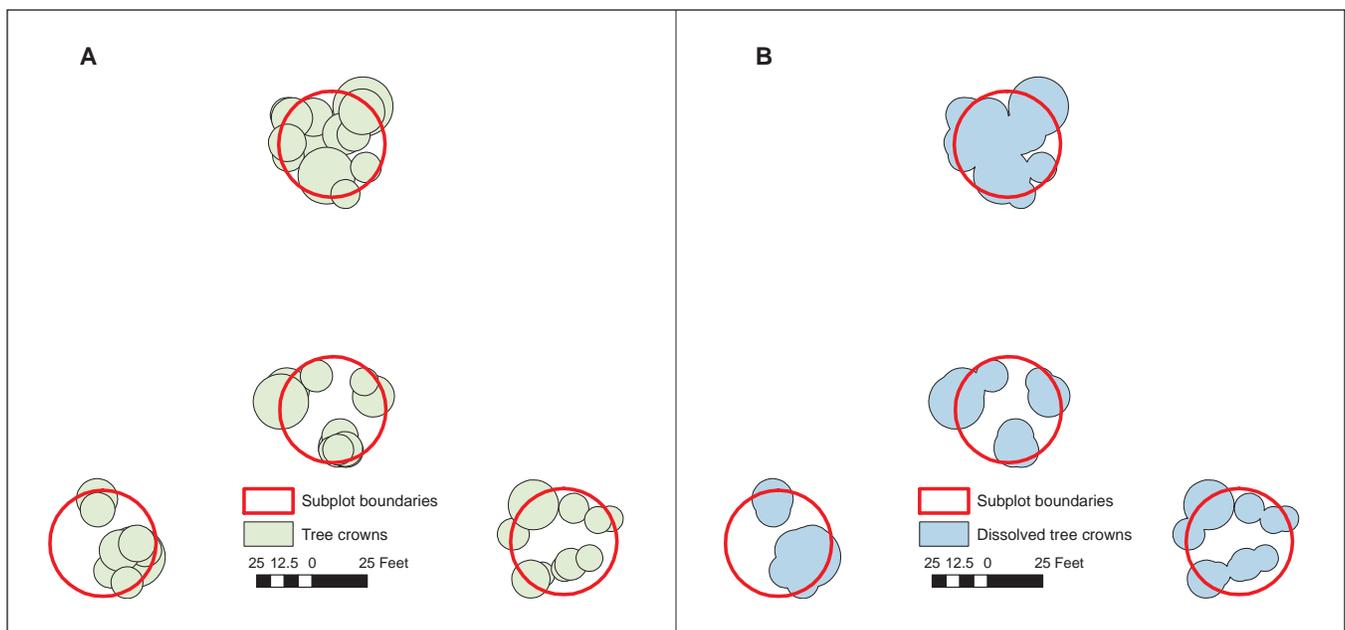


Figure 1.—Maps of (A) individual tree crowns on an FIA plot, and (B) dissolved polygons of crown cover on an FIA plot.

While the models presented by Bechtold (2003) were fitted to subplot trees (d.b.h. ≥ 5.0 in.), these same models were used to quantify sapling (d.b.h. 1.0 to 4.9 inches) crown cover on the microplot area. At this point, there are estimates of overstory and sapling tree cover on forested portions of subplots and microplots, respectively. These cannot simply be summed to obtain the total cover as 1) overstory trees may partially/wholly obscure sapling cover, and 2) the overstory and sapling cover estimates are on a different area basis. To reconcile total cover at the subplot level, the amount of overstory cover for trees whose stems occur within the microplot was calculated. Also, the amount of sapling cover remaining visible once overstory trees were accounted for was quantified. This was accomplished by using GIS to remove the sapling cover that had microplot tree crown cover growing above (Fig. 2). The ratio of remaining sapling cover to overstory microplot cover was used to estimate the amount of sapling cover that would be visible if saplings were measured over the entire subplot area—producing an estimate of cover for all trees and saplings combined. Due to the use of crown area occurring outside plot boundaries and the method of estimating the contribution of saplings, the area of crown cover exceeded the forested area of the subplot in some cases. When this phenomenon occurred, the cover estimate was constrained to the forested area. As the plot is the primary sampling unit, plot-level cover estimates were obtained by summing over subplots.

Under standard FIA protocols, the total height of saplings is measured only on P3 plots. To facilitate analyses related to vertical structure, tree heights for saplings on non-P3 plots were predicted from linear models developed using observed sapling height data obtained on P3 plots. Due to the relatively small amount of model fitting data available, coefficients were estimated for hardwood and softwood species categories (Table 1).

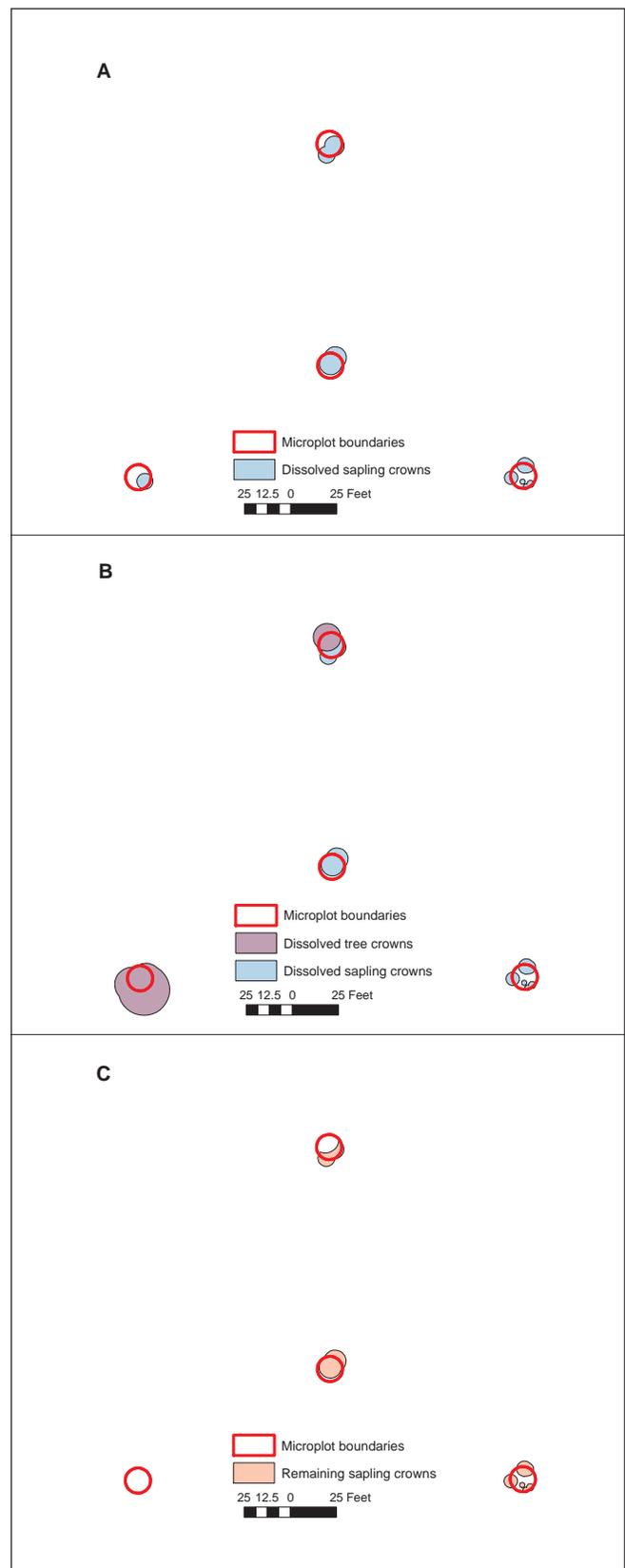


Figure 2.—Maps of (A) dissolved polygons of sapling crown cover on an FIA plot, (B) microplot tree cover above sapling cover, and (C) sapling cover remaining after tree cover is accounted for.

Table 1.—Linear regression analysis results for equation [2] by major species group. RMSE is the square-root of mean squared error.

Species Group	n	$\hat{\theta}_0$ (Std. Error)	$\hat{\theta}_1$ (Std. Error)	R ²	RMSE
Hardwood	1481	9.3057 (0.3424)	5.4529 (0.1332)	0.53	5.7
Softwood	33	2.0837 (1.5163)	5.3902 (0.5501)	0.76	3.4

[2] $\hat{H}_S = \hat{\theta}_0 + \hat{\theta}_1 D$

where: \hat{H}_S = estimated sapling height (feet)
 D = d.b.h. (inches)
 $\hat{\theta}_{0-1}$ = coefficients estimated from the data

Computation of area of forest land, area of crown cover within forest land, and the proportion of forest land area having canopy cover was accomplished using the standard FIA methods documented in Scott et al. (2005).

Two example analyses are presented to illustrate the utility of the method for assessing contemporary forestry issues like forest health and wildlife habitat. First, beech bark disease kills or injures American beech (*Fagus grandifolia* Ehrh.). The estimated tree cover susceptible to the disease was estimated for trees of 8.0 inches d.b.h. and larger, as these are the most susceptible to mortality (Houston and O'Brien 1983). The second example assesses habitat availability for the cerulean warbler (*Dendroica cerulean*). Jones and Robertson (2001) found that successful nesting of

cerulean warblers most often occurred where crown cover occurred at 19.7 to 39.4 feet with additional high cover above 59.1 feet. In the absence of crown shape models, estimates of canopy area were calculated for trees having height of 19.7 to 39.4 feet when there also existed at least one tree having height of 59.1 feet or greater on the same subplot.

RESULTS

A preliminary analysis was conducted to estimate the proportion of forest area in Pennsylvania having tree cover. The area of forest land was estimated to be 16,482,968.6 acres with a standard error (SE) of 156,471.9 acres. The estimated area of tree cover was 14,821,653.7 acres (SE = 150,823.1) (Table 2). The resultant proportion \hat{R} was 0.899 (SE = 0.007). The roughly 10 percent of forest land area without tree cover is due to gaps between tree canopies (9.0 percent), with a modest contribution (1.0 percent) from forested areas having no tree or sapling cover (e.g., areas only having seedlings).

Table 2.—Estimates with standard errors (SE) for area (acres) and proportion of all forested canopy cover (\hat{R})

Attribute	Area	(SE)	\hat{R}	(SE)
Total canopy cover	14,821,653.7	(150,823.1)	0.899	(0.007)
Beech bark disease	422,893.6	(25,637.3)	0.029	(0.002)
Cerulean warbler habitat	4,149,383.5	(91,977.7)	0.280	(0.005)

The canopy cover of American beech having d.b.h. 8.0 inches and larger was estimated to be 422,893.6 acres (SE = 25,637.3). While this area estimate is informative, it is also useful to assess this area in context of total canopy cover. The corresponding proportion of existing canopy cover this area represents is $422,893.6/14,821,653.7 = 0.0285$ (SE = 0.0017). Thus, approximately 3 percent of the canopy cover in Pennsylvania is potentially at risk due to beech bark disease.

Using the criteria outlined above for cerulean warbler habitat, the estimated area of canopy cover was 4,149,383.5 acres (SE = 91,977.7). Put in the context of total canopy cover, the proportion of area containing desirable conditions for cerulean warbler is $4,149,383.5 / 14,821,653.7 = 0.2800$ (SE = 0.0054). This outcome suggests that more than one-fourth of forest land area having canopy cover in Pennsylvania may be suitable for cerulean warbler.

DISCUSSION

Estimates of canopy cover provide a different viewpoint than classical indicators such as forest land area or numbers of trees. An example is the difference between area of forest land and area of forest land with canopy cover. At first glance, one may assume that all forest has canopy cover. However, this study has shown there to be an approximate 10 percent difference in these two characteristics. Starker contrasts are seen when comparing different metrics for identical domains of tree variables. FIA estimates for number of American beech trees having d.b.h. ≥ 8.0 inches as a proportion of all trees is 0.0056. The proportion of canopy cover is roughly five times larger than the proportion of trees (0.0285).

Forest managers should consider adding canopy cover area to their portfolio of analytical metrics. Canopy estimates provide new information that has largely been unavailable in the past and may suggest alternative management strategies. The individual tree crown size predictions can be added to most

existing forest inventory data and estimation can proceed in a manner similar to other estimates such as area by forest type, stand size, etc. A disadvantage is this method is not easily implementable in standard analytical tools such as FIA's FIDO or EVALIDator software. This is due to the need to perform the dissolution of overlapping crowns, which must be accomplished after specification of the domain of interest. This exercise takes approximately 5 to 15 minutes, depending on the number of trees in the domain. However, the additional effort may be worthwhile in cases where canopy cover is of particular importance.

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