AN ALTERNATIVE METHOD FOR ESTIMATING CROWN CHARACTERISTICS OF URBAN TREES USING DIGITAL PHOTOGRAPHS

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ABSTRACT

The USDA Forest Service Forest Inventory and Analysis (FIA) program has concluded that statewide urban forest inventories are feasible based on a series of pilot studies initiated in 2001. However, much of the tree crown data collected during inventories are based on visual inspection and therefore highly subjective. In order to objectively determine the crown characteristics of urban trees and assure reliability of the data, researchers with the U.S. Forest Service Southern Research Station have developed a computer software tool called UrbanCrowns that can potentially be used to assist with crown data collection on urban FIA plots. In addition to its operational use, the software can also be used as a training tool. UrbanCrowns analyzes a single, side-view digital photograph of an urban tree and computes crown measurements similar to those collected during FIA inventories. UrbanCrowns output includes estimates of crown height, live crown ratio, crown diameter, crown density, transparency, and crown volume.

INTRODUCTION

Urban forests provide a wide range of aesthetic, health, economic, and environmental benefits to urban communities (Nowak and others 2007). For this reason, many municipalities conduct periodic inventories to quantify and characterize urban tree resources. These inventories are very useful when developing management plans at the local level but not suited for broader management planning at the state, regional, or national scale. Even though there is much urban inventory data available, the methods used to obtain the data and the type of data collected are not standardized among communities. In order to meet the needs of state and federal resource managers and to expand the range of data collection, the Forest Inventory and Analysis (FIA) program of the USDA Forest Service initiated a series of urban forest inventory and health monitoring pilot studies in 2001. The purpose of the pilot studies was to determine the feasibility and logistics of conducting statewide urban forest inventories.

FIA has long been responsible for conducting national forest inventories, but urban areas have always been excluded. This is because data collected are exclusively on lands that meet the specific definition of “forest” and urban forests do not meet this definition. The purpose of the urban inventory is to account for the trees in urban areas not measured during traditional FIA inventories. Since results from the pilot studies have shown that urban forest inventory and health monitoring data collection and analysis is feasible (Cumming and others 2008), annual FIA urban inventories are likely to continue sometime in the future if funded.

The data collected on urban sampling plots include the standard FIA data as well as additional urban health monitoring variables, which are grouped into four general data types: plot, trees, tree damages, and tree crowns. The tree crown variables include: uncompacted live crown ratio, crown light exposure, crown position, crown density, crown dieback, foliage transparency, foliage absent, and crown diameter. Of all the data types, the tree crown measurements are the most difficult to obtain as well as the most subjective. For this reason, an alternative method of measuring urban tree crown characteristics has been developed and is presented here.

The USDA Forest Service Southern Research Station has developed a computer software tool to address many of the problems associated with urban tree crown measurements, both for FIA and municipal tree inventories. The software, called UrbanCrowns, analyzes digital photographs of urban trees and produces various crown metrics important for urban tree inventories (Winn and others 2010). Output produced by UrbanCrowns includes: crown height, crown diameter, live crown ratio, crown volume, crown density, and transparency. The program supports both broadleaf and coniferous tree analysis. The next sections describe the methodology currently used for FIA urban data collection, followed by a description of the UrbanCrowns software.

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CURRENT FIA URBAN DATA COLLECTION

FIA field crews periodically visit urban sampling plots and collect standard FIA data as well as additional urban forest health monitoring variables on trees and tree crowns. Crown variables collected during the inventory include: uncompacted live crown ratio, crown light exposure, crown position, crown density, crown dieback, foliage transparency, foliage absent, and crown diameter. FIA definitions and field measurement procedures for select crown variable are shown below (Schomaker and others 2007).

UNCOMPACTED LIVE CROWN RATIO

Uncompacted live crown ratio is the length of a tree that supports live foliage relative to the actual tree length. First, the live crown base and the live crown top are established. The live crown base is the point of the lowest live foliage and the live crown top is the highest point of the crown containing live foliage. Uncompacted live crown ratio is then determined by dividing the distance between the live crown base and the live crown top by the total length of the tree. A reference card is typically used by FIA crews to estimate ratios (figure 1). The card is held parallel to the tree and moved closer and farther from the crew member's eye until the zero mark is at the live top of the tree and the 99 is at the base of the tree. The point at which the live crown base intersects with the reference card scale shows the uncompacted live crown ratio.

CROWN DENSITY

Crown density, expressed as a percentage, is the amount of crown stem, branches, twigs, shoots, buds, foliage, and reproductive structures that block light penetration through the crown. This includes dead branches and dead tops. First, a vertically symmetrical outline is visualized around the tree crown that extends from the live crown base to the top and outward to the branch tips. If the top is broken or missing, it is visually reconstructed before determining the density rating outline. The area within the imaginary outline is then compared to the crown density-foliage transparency card to determine the density (figure 1). Density is typically estimated by two crew members at perpendicular views of the tree. If ratings differ by more than 10 percent, they discuss the reasons for their ratings and the final rating is derived by averaging the two crew members' final ratings.

CROWN DIEBACK

Crown dieback is recent mortality of branches with fine twigs that begins at the terminal portion of a branch and proceeds toward the trunk. Only branch mortality occurring in the upper and outer portions of the crown is considered dieback. To estimate dieback, crew members first visualize an outline around the crown, extending from the live crown base to the top and outward to the branch tips. Next, the area classified as dieback is determined and compared to the total live crown area. Dieback is expressed as the percentage of the total live crown area that is affected. Crew members then compare their estimates and reach an agreement as to what's recorded.

FOLIAGE TRANSPARENCY

Foliage transparency is the amount of skylight visible through microholes in the normally foliaged portion of the live crown. Large holes, dieback, and dead branches are excluded from the estimate. Foliage transparency differs from density in that it ignores stems, branches, and fruits in the crown. Each crew member first draws an imaginary two-dimensional outline around the live tree crown, similar to the region used to estimate dieback but in this case, dieback regions are excluded. Crew members then use the crown density-foliage transparency card (figure 1) to estimate the amount of skylight penetrating the foliated crown (expressed as a percentage of the total foliated crown area). Crew member estimates are compared, adjusted if necessary, and averaged to determine the final rating.

CROWN DIAMETER

Crown diameter is the average width of the crown, extending from the drip line on one side of the tree to the drip line on the opposite side of the tree. The drip line is determined by projecting a vertical line upward from the ground to the outermost branch tip. Crew members measure the diameter at the widest part of the crown using a tape and then again at 90 degrees from the widest point.

SRS URBANCROWNS SOFTWARE

UrbanCrowns is a software tool developed by the Southern Research Station that could potentially be used by FIA to obtain crown metrics on urban sampling plots. As opposed to FIA data collection methodologies commonly used, UrbanCrowns offers an objective approach to evaluating urban tree crowns. The software quickly calculates crown height, crown diameter, live crown ratio, crown volume, crown density, and transparency from a single digital photograph and several field measurements. The steps involved in the analysis process, including photographing the tree, gathering field data, and analyzing the tree image, are described below.

ACQUIRING THE TREE PHOTO

The first step in the analysis procedure is to acquire a single ground-based digital photograph of the subject tree. The UrbanCrowns computer program is designed to be used with basic digital imagery, so the use of specialized camera equipment is not necessary. The only requirements for the program is that the entire tree is visible and centered in the photograph, there are no obstructions between the camera and the tree, and that a portion of the tree crown is free from background vegetation or buildings (meaning only sky in the background). This area will be used to estimate crown transparency which uses color contrasts to identify the crown. This means that the program cannot easily distinguish between foreground and background vegetation as well as filter out buildings and other man-made obstructions, depending on the contrast in color. Weather conditions can also affect the photograph, as they influence the amount of available light. Optimum lighting occurs on clear sunny days when the sun is high in the sky, and the camera should never be pointed directly at the sun. Since the photo is the basis for all analyses within the program, careful consideration should be taken when choosing a photo location. Realistically, it may not be possible to find a vantage point that satisfies all of the photographic requirements. If this is the case, the photographer should find the best photo location for the conditions but understand that it may affect the UrbanCrowns output.

UrbanCrowns allows the use of only one photo by making the assumption that the tree crown is relatively symmetrical and that transparency and density are constant regardless of the vantage point. However, a single photograph of a significantly asymmetrical crown (such as a tree pruned around a power line) may not provide an accurate representation of true crown volume. If this is the case, a second photograph of the tree should be taken perpendicular to the first. Results can then be averaged to obtain the best possible estimates for that tree.

FIELD MEASUREMENTS

In addition to photographing the tree, several tree measurements must also be collected. These measurements are necessary in order to scale the photograph within the UrbanCrowns program. First, the angles (in degrees) to the top and base of the tree must be measured using a clinometer or other vertical angle measuring device. The measurements should be taken from the same location and height at which the photograph was taken. The program also requires the horizontal distance (in feet) from the photo location to the trunk of the tree. This can be determined using a laser or sonic rangefinder or a tape measure. Several instruments are currently available that measure both horizontal distance and vertical angles from a single location, and though they cost a bit more than traditional measuring tools, they can significantly reduce the data collection time at each tree. Though not required by the program, the azimuth from the photo location to the tree should also be recorded. By combining the azimuth with the horizontal distance measurement, it will be possible to return to the original photo location during subsequent inventories. The program has the capability to store the azimuth and any other tree or site information (species, location, weather conditions, etc…) within that tree's data file.

PROGRAM OVERVIEW

The UrbanCrowns software is comprised of two main windows: the Tree Image window and the Data Control window (figure 2). The Tree Image window contains the uploaded photograph of the tree to be analyzed. All image controls are located in this window, including: opening, rotating, scaling, printing, and saving the image. The Data Control window is used for inputting data, initiating assessment, viewing output, and managing the database. Within the Data Control window, there are two tabs: *Information* and *Assessment*. The *Information* tab is where the user enters the input parameters for the tree image. The *Assessment* tab is where the results of the analysis are displayed once the image is processed.

INPUT DATA

The first step in analyzing a tree crown is to upload the desired photo into the UrbanCrowns program. Once the photo has been uploaded, the field data and other input parameters are entered under the *Information* tab of the Data Control window (figure 2). The input consists of: tree ID, tree species, photo location, photo date, azimuth to tree, horizontal distance, angle to the top of the tree, angle to the base of the tree, and user comments.

REFERENCE LINES

The next step is to draw a series of reference lines on the photo (figure 3). The first reference line (shown in yellow) extends from the base of the tree stem to the top of the tree crown, following the lean of the tree. This line, combined with the angle and horizontal distance measurements entered earlier, is used to scale the photograph (determine the actual area represented by each pixel). The second reference line (shown in pink) is a polygon drawn around the portion of the tree crown that is free from background vegetation or other obstructions. This is the area that will be used by the program to determine transparency and density. The final reference line (shown in blue) is another polygon drawn around the entire tree crown and is used to estimate crown volume. Note that neither of the polygons needs to be drawn close to the crown in areas that have a clear background. When the image is processed, the program shrink-wraps the selection regions so that they conform to the unobstructed outline of the tree crown.

CROWN ASSESSMENT

Once the field measurements have been entered and the reference lines have been drawn, the image is processed by clicking on the *Assess* button in the Data Control window. The results of the analysis are then displayed under the *Assessment* tab (figure 4). For this example, the results are as follows: tree height and length are 42.6 feet, crown height is 40.1 feet, crown diameter is 47.4 feet, crown ratio is 94 percent, crown density is 94.8 percent, transparency is 5.2 percent, and crown volume is 43,041 feet^3. Though the true crown volume can't be determined without destructive sampling, all other output for this example are within 5 percent of actual measurements obtained on site.

After an image is processed, a pop-up window will appear that contains a contour image of the tree (figure 5). The contour image shows the shrink-wrapped crown assessment areas that were used in the analysis. A summary page can then be printed that shows the input parameters, the output data, and the tree image including reference lines. The same information can also be stored in a database and later imported back into the program. Other available program options include saving the image and reference lines as a JPG file, saving the contour image as a JPG file, and saving the input and output data to a text file.

DISCUSSION

Many of the crown variables collected by FIA field crews during urban tree inventories are provided as output in the UrbanCrowns computer program. Overlapping variables include: crown diameter, uncompacted live crown ratio, transparency, and crown density. UrbanCrowns does not provide an estimate of light exposure, foliage absent, or dieback but it does provide an additional measurement of crown volume. Each of the overlapping variables, as well as the volume estimate produced by UrbanCrowns, is discussed in more detail below.

CROWN DIAMETER

Of the four variables, crown diameter is the only one measured directly by field crews. Since both methods of determining crown diameter rely on objective measurements, no improvement in accuracy is expected by using UrbanCrowns. In fact, if only one photograph is taken, the FIA method of averaging two perpendicular diameter measurements is probably a better representation of the overall crown diameter. One advantage of using the software, however, is that the diameter can be measured at a later date in the office, freeing up valuable data collection time in the field.

UNCOMPACTED LIVE CROWN RATIO

Whereas crown diameter is measured directly at the tree by field crews, uncompacted live crown ratio is measured indirectly from a distance using the crown density-foliage transparency reference card. However, the fact that it's a ratio and not a measured distance means that diminished accuracy is not likely. Both FIA field estimates and UrbanCrowns output should be comparable. Similar to crown diameter, the advantage of using UrbanCrowns to determine crown ratio is that the measurement can be performed at a later time, requiring less time for measurements in the field.

TRANSPARENCY

The methods used by FIA crews and by UrbanCrowns to determine transparency are somewhat similar but also have some differences. FIA estimation starts with creating an outline of the live crown that extends from the base to the top of the live crown and out to the branch tips. Dieback, dead branches, and large holes are excluded from the rating area. Crew members then estimate the amount of light penetrating the normally foliated portion of the rating region, ignoring stems, branches, and fruits.

Instead of rating the entire live crown, UrbanCrowns determines transparency from partial crown analysis (using only the portion of the crown that has no obstructions in the background) and assumes that the transparency of the partial crown is representative of the full crown transparency. Since UrbanCrowns cannot distinguish between foreground vegetation and background vegetation, the program is only able to analyze full crowns if the entire crown is free from background interference. However, realistically, it is difficult to find a photo vantage point that would allow for full crown analysis. Once the rating region has been established, UrbanCrowns measures the amount of light penetrating the crown, but unlike the FIA methods, does not exclude any crown structures such as branches or large holes. For this reason, UrbanCrowns does not use the FIA terminology "foliage transparency" but instead, "crown transparency."

In summary, FIA measures the amount of skylight visible through the full foliated crown whereas UrbanCrowns measures the amount of skylight visible through all crown structures for a portion of the crown. Though these methods seem very different, there is one major advantage of using UrbanCrowns to compute transparency; it is objective. FIA transparency estimation, on the other hand, is highly subjective. Some of the factors that can contribute to discrepancies in visual estimation include: observer bias, observer training, weather and lighting conditions, background vegetation, and obstructions. With the increased likelihood of obtaining inaccurate transparency estimates using FIA methods, UrbanCrowns could be a viable alternative.

CROWN DENSITY

FIA defines crown density as the amount of crown structures blocking light penetration through the crown. The area used to rate crown density differs from the transparency rating region in that it assumes a symmetrical crown. Areas that would normally have crown structures if it were a perfectly health tree are included in the outline. UrbanCrowns, however, uses the same partial crown rating region that the program uses to determine crown transparency. In fact, UrbanCrowns defines crown density as the complement of crown transparency (calculated by subtracting crown transparency percent from 100 percent). In other terms, crown density is a measure of the amount of crown structures blocking light within the partial crown rating region. Again, the methods used by FIA and UrbanCrowns to determine crown density are quite different. However, like foliage transparency, FIA density estimates are highly subjective while UrbanCrowns provides an objective estimate of crown density.

CROWN VOLUME

Accurate estimates of crown volume can be beneficial for predicting ecosystem functions such as carbon sequestration, rainfall interception, pollution removal, and surface temperature reductions. Crown volume of urban trees is typically calculated using allometric equations with crown length and crown diameter as the dependent variables (Schomaker and others 2007). One problem with using this method to determine crown volume is that it does not take the shape of the crown into account. Even by incorporating a shape variable into the equation, the assumption is still made that the tree is vertically symmetrical when viewed from the side. For an accurate estimate of crown volume, the true shape of the crown needs to be considered.

The UrbanCrowns software is unique in that it can provide an accurate estimate of crown volume using only one photograph of the tree, and it does so without assuming vertical crown symmetry. Instead, it assumes that if you take a cross section anywhere in the crown, that cross section is circular. In a recent study comparing UrbanCrowns volume output to crown volume estimates obtained through traditional methods, a high correlation was found between the two (Patterson and others, in press). Though destructive sampling is necessary to determine the true accuracy of the program, the results suggest that the volume estimates produced by UrbanCrowns are reasonably accurate. To determine crown volume, the program first calculates the actual width and height represented by each row of pixels within the crown selection region. An imaginary cylinder is generated for each row of pixels that has a height equal to the calculated height of one pixel and a diameter equal to the calculated width of the row (figure 6). The volume estimates for each row of pixels are summed to obtain the volume estimate for the entire crown selection region. This estimate includes tree structure and void areas, so the volume is then multiplied by the crown density to get a volume estimate that includes tree structures only. This method of determining volume works well for crowns that are relatively symmetrical around the stem. For crowns that are significantly asymmetrical, such as trees pruned around power lines, it may be necessary to analyze a second photograph taken perpendicular to the first and calculate the average volume.

TRAINING

In addition to UrbanCrowns' potential use in FIA urban inventories, the software could also serve as a valuable training tool for FIA field crews and trainers. Regional trainers currently train, test, and certify field crews for their ability to measure trees within the tolerances specified by the FIA program. For objective crown measurements, such as crown diameter and live crown ratio, the training is straightforward and success is probably not trainer dependent. However, for more subjective measurements such as foliage transparency and crown density, using multiple regional trainers to teach field crews can introduce individual trainer bias into the rating procedures. This can result in crown ratings that are not consistent at a broader level. Though there is no substitute for field training, the software could supplement current training programs and provide a standardized platform for learning crown measurement procedures, particularly with the more subjective crown measurements. In addition, the program can also be used to pre-analyze test trees used to certify trainers and field crews. This would provide objective estimates of crown features that student ratings can then be compared to.

CONCLUSION

As urban areas expand, statewide urban forest inventories (such as those conducted by the Forest Inventory and Analysis program) will become more and more important. However, current methodologies used by FIA to conduct crown assessments of urban trees are highly subjective. The UrbanCrowns software developed by the USDA Forest Service Southern Research Station could be a useful tool for FIA urban inventories, as it provides an objective and efficient means of determining various crown metrics. In addition to the program's potential for operational use, the software can also be a valuable training tool for field crews. Crown measurements generated by UrbanCrowns include: crown diameter, uncompacted live crown ratio, transparency, crown density, and crown volume.

LITERATURE CITED

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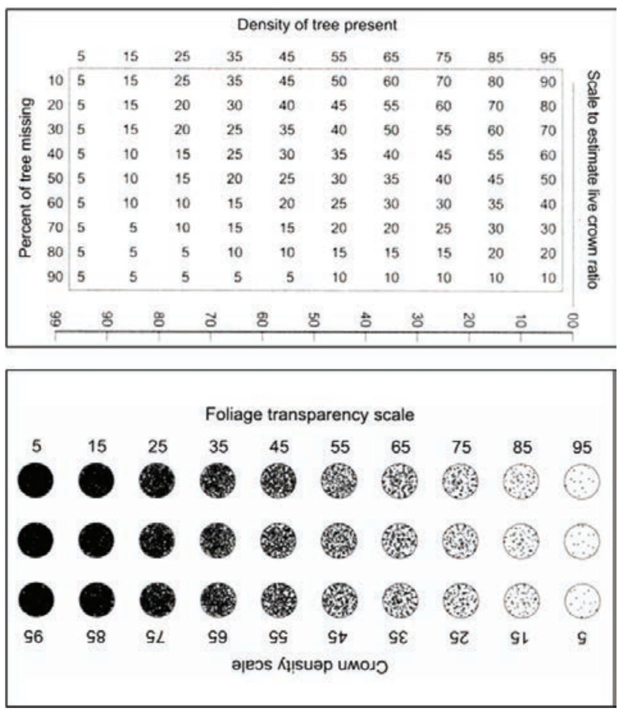

Density of tree present

Percent of tree missing	5	15	25	35	45	55	65	75	85	95
10	5	15	25	35	45	50	60	70	80	90
20	5	15	20	30	40	45	55	60	70	80
30	5	15	20	25	35	40	50	55	60	70
40	5	10	15	25	30	35	40	45	55	60
50	5	10	15	20	25	30	35	40	45	50
60	5	10	10	15	20	25	30	30	35	40
70	5	5	10	15	15	20	20	25	30	30
80	5	5	5	10	10	15	15	15	20	20
90	5	5	5	5	5	10	10	10	10	10

Figure 1—Front and back of reference card used by FIA field crews to estimate crown density, foliage transparency, and uncompacted live crown ratio.

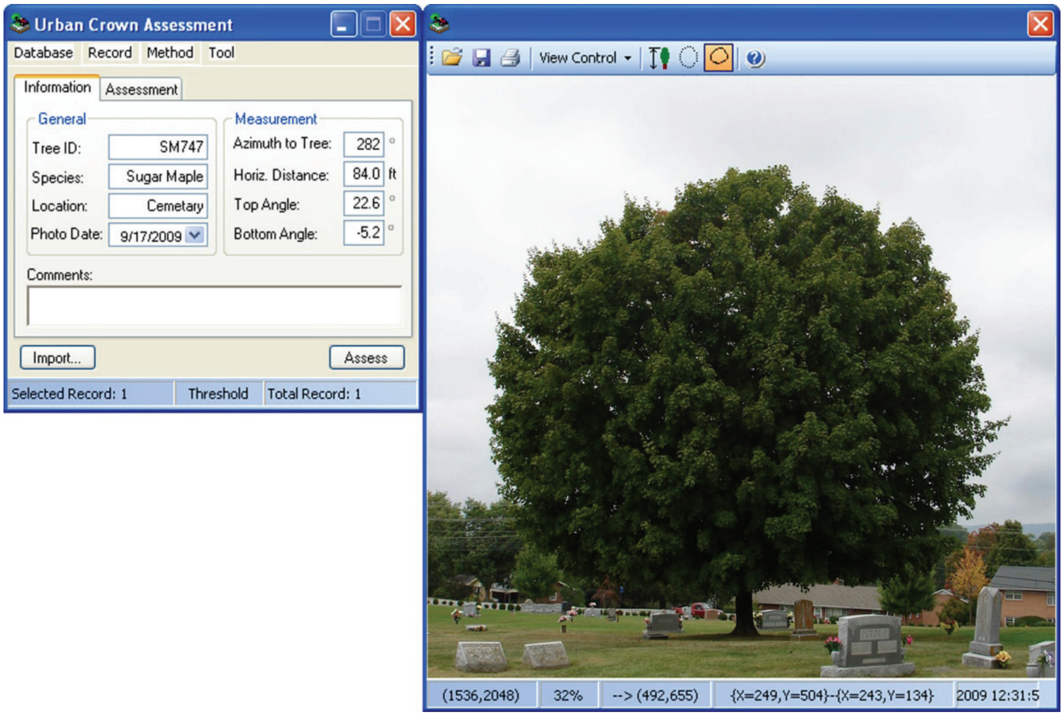

Figure 2—Screen capture of the UrbanCrowns program showing the Data Control window with input parameters on the left and the Tree Image window with uploaded image on the right.

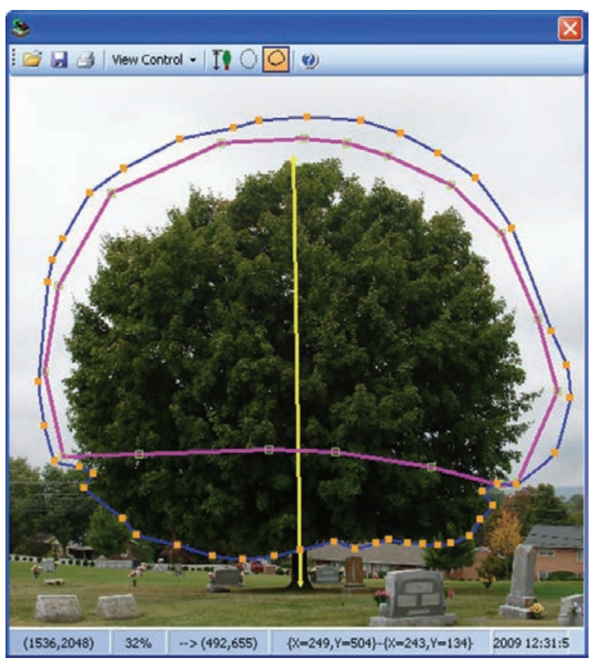

Figure 3—Screen capture of the UrbanCrowns program showing reference lines drawn on the photo to calculate tree height (yellow), transparency (pink), and crown volume (blue).

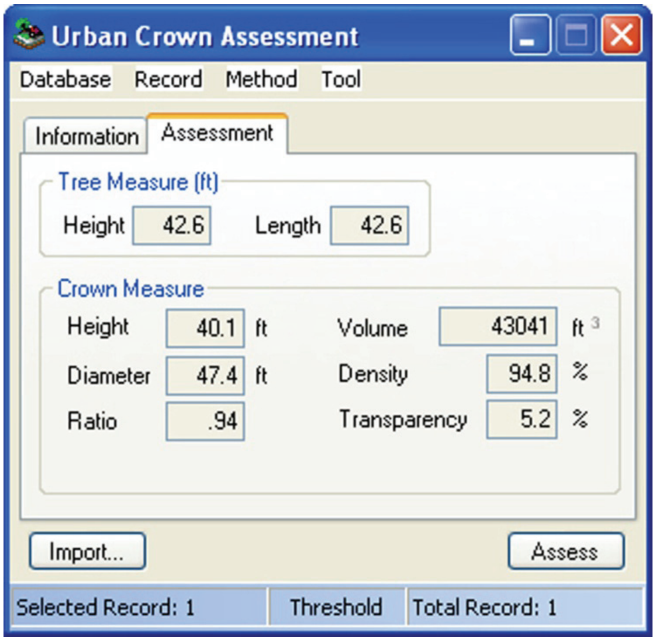

Figure 4—Screen capture of the UrbanCrowns *Assessment* tab showing the post-processing results of the crown analysis.

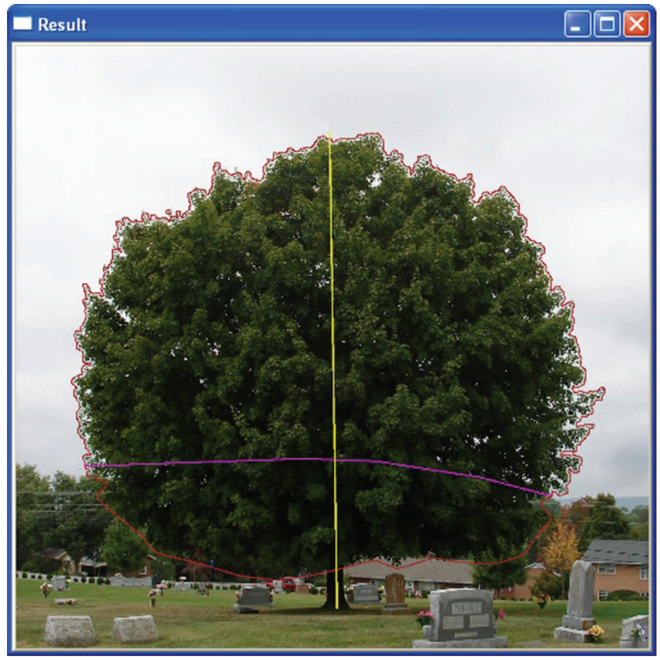

Figure 5—Contour image generated by UrbanCrowns that shows the transparency and full crown regions used in the analysis.

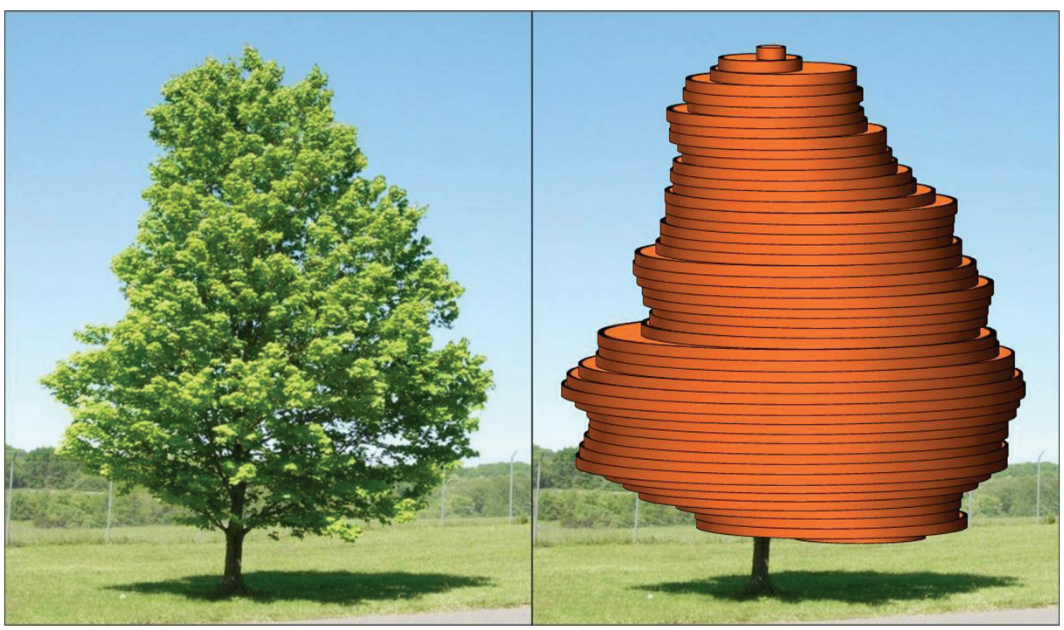

Figure 6—Illustration showing the method used by UrbanCrowns to determine crown volume.