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UrbanCrowns: An Assessment and Monitoring Tool for Urban Trees

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Abstract

UrbanCrowns is a Windows®-based computer program used to assess the crown characteristics of urban trees. The software analyzes side-view digital photographs of trees to compute several crown metrics, including crown height, crown diameter, live crown ratio, crown volume, crown density, and crown transparency. Potential uses of the UrbanCrowns program include monitoring individual tree growth over time, detecting disease or insect damage in early stages, and providing data to quantify tree benefits such as carbon sequestration, rainfall interception, energy conservation, pollution removal, and oxygen production.

Keywords: Crown characteristics, crown volume, monitoring, transparency, urban forestry, urban trees.

Introduction

Trees are important assets to the urban environment. In addition to providing aesthetic, social, and economic values to urban communities, they provide many environmental benefits as well. They improve air quality by reducing temperatures, lowering volatile organic compound (often referred to as VOC) emissions, producing oxygen, and removing harmful pollutants from the air (Nowak and others 2006). They can improve water quality by intercepting and filtering rainfall, thus reducing urban runoff and the pollutants they carry (Nowak and others 2007). Strategically placed trees can also reduce heating and cooling energy use by providing shade in the summer and windbreaks in the winter (Heisler 1986).

The urban environment, however, can often produce added stresses to these trees. Soil compaction, limited root growth, and groundwater contamination are just a few of the factors that can influence tree growth and vigor (Roberts 1977). Only when urban forests are healthy and free from serious hazards, do they add value to communities. Unhealthy, hazardous trees diminish urban forest value and create liabilities for tree owners. For this reason, trees should be monitored periodically to permit early detection of disorders and hazards so that appropriate actions can be taken to maintain forest health, safety, and value.

Current assessment methods for urban trees use a combination of ground-based measurements and visual estimation of tree features. A large emphasis is placed on

tree crowns, since crown size, shape, and density can be good indicators of overall tree health. This is also where a good portion of the visual estimation takes place because of the difficulty in accessing the crown from ground level. Visual assessment of tree characteristics often produces very subjective results that vary by surveyor, tree species, weather conditions, etc. For more accurate tree assessments, a more objective approach is needed.

The Forest Service, U.S. Department of Agriculture has developed a computer software tool to facilitate urban tree assessment and monitoring. The software, called UrbanCrowns, can be used by anyone with or without a background in urban forestry to analyze urban tree crown characteristics using only a digital photograph and a few easily collected field measurements. The program, which supports both broadleaf and coniferous tree analysis, can be used in conjunction with monitoring programs to detect changes in crown conditions and can assist with quantifying tree functions and benefits. UrbanCrowns can also be a useful tool for heritage tree programs, where trees are considered to be of special importance due to their age, size, type, or historical significance.

Analyzing an urban tree using the UrbanCrowns program is a simple procedure. First, a digital photograph is taken of the subject tree and several field measurements are collected from the photo location. Field measurements include the horizontal distance to the tree and the vertical angles to the top and base of the tree. The photograph is then uploaded into the program and a series of reference lines are drawn on the image. The lines are used to scale the image and delineate portions of the crown. The image is then processed and returns to the user the following crown measurements: height, diameter, live crown ratio, volume, density, and transparency. The results of the analysis can then be printed or saved to a database.

Photographing the Tree

The first step in the analysis procedure is to acquire a digital photo of the subject tree. This image will be used to perform all analyses within the program, so the quality of the photo can directly affect the accuracy of the computations. By using some forethought and following some simple photographic guidelines, the user can obtain

the best possible results from the analysis software. A basic digital camera is all that is needed and image resolution is not critical. However, avoid using attachable wide angle or telephoto lenses.

First, determine the best time and location for acquiring a photo. Be sure to photograph trees after full leaf out and before leaves start shedding in the fall. Midday is the best time to photograph because the sun is high in the sky and glare is reduced. Never shoot directly into the sun. The weather can also affect image quality so attempt to photograph on sunny days with high visibility and low wind.

For the most accurate estimate of crown transparency, minimize the amount of background vegetation visible through the tree's crown as well as any structures such as buildings or light poles. The software cannot distinguish between crown foliage and background vegetation and may not be able to filter out urban structures, depending on the color contrast. It is not necessary (nor possible in most situations) to obtain a photograph where there is no background interference, but the less interference in the photograph, the more accurate the transparency estimates.

Choose a distance from the tree that allows the full tree (stem and crown) to appear in the image, and if the vantage point is far from the tree, zooming is permissible. There should be no obstructions (buildings, other trees, etc.) between the camera and tree that block the view of the crown or tree base. Pictures can be taken in portrait or landscape format, but be sure to center the tree image both vertically and horizontally in the viewfinder.

Urban trees often reside near buildings, roads, and other urban structures which can make it difficult to fulfill all of the photographic requirements. In those cases, determine the best photo location under the circumstances, but recognize that the accuracy of the computations may be diminished. Be wary of the surroundings and never photograph from a street or other unsafe environment.

Examples of correctly photographed urban trees are shown in figure 1. Notice that in all photos, the tree image is centered both vertically and horizontally, there are no obstructions between the camera and the tree, and a large portion of the crown is free from background interference. Figure 2 shows examples of poorly photographed trees. In the first photograph (fig. 2A), a building is obstructing the view of the bottom portion of the tree. Figure 2B shows a tree containing too much interference from background vegetation. In addition, the tree is not centered vertically in the photograph. Figure 2C shows a photograph taken under poor lighting conditions. The camera should never be aimed directly at the sun. Also, the photo does not include the entire tree stem. Assessing low-quality photographs with UrbanCrowns will produce inaccurate results.

Field Measurements

In addition to photographing the tree, several tree measurements must also be collected from the photo location in order to scale the photograph within the program (fig. 3). Without these additional inputs, the program will not function correctly. First, measure the angles (in degrees) to the top and base of the tree using a clinometer

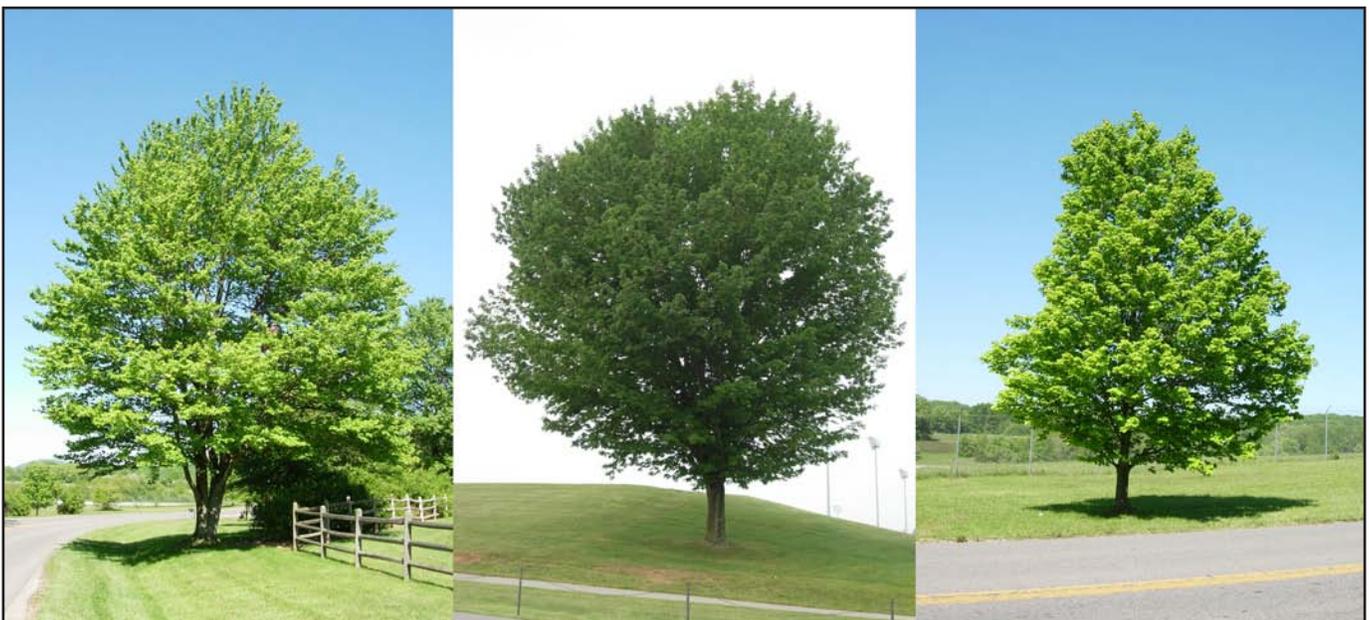


Figure 1—Examples of correctly photographed urban trees.

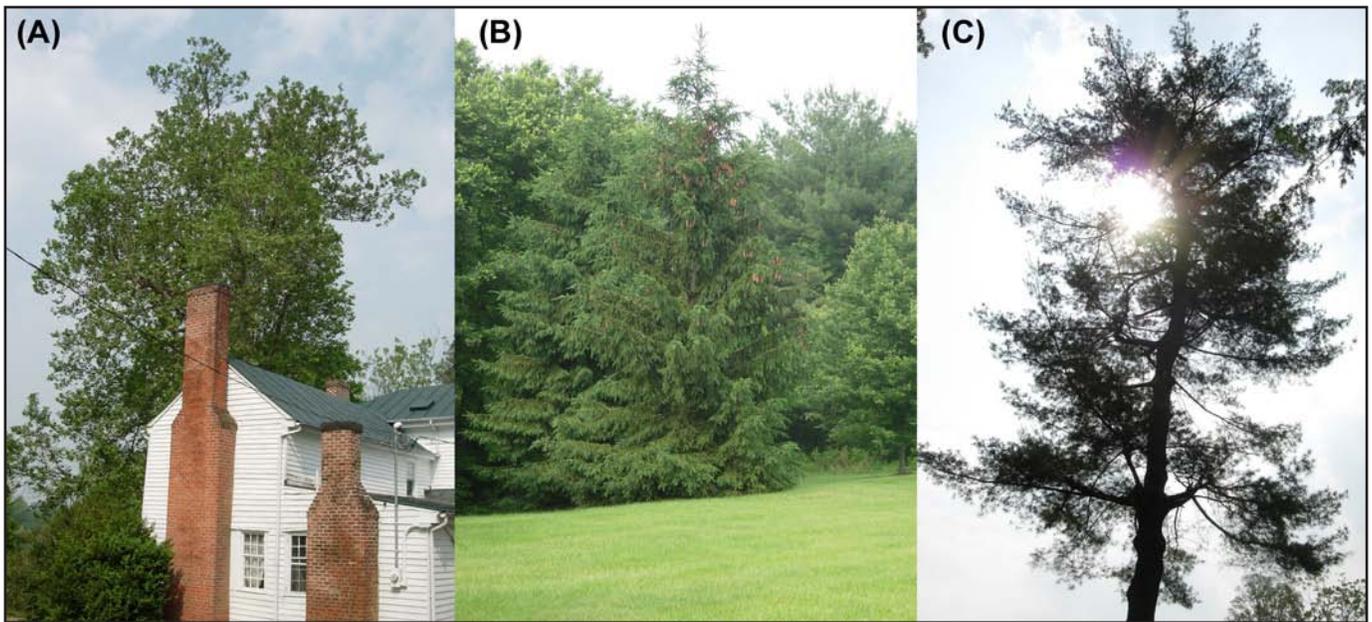


Figure 2—Examples of poorly photographed urban trees.

or other vertical angle measuring device. Be sure to record whether the angle is negative or positive. Next, measure the horizontal distance to the lower stem of the tree using a laser rangefinder or tape measure. There are several instruments on the market 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.

In addition to the angle and horizontal distance measurements, it is recommended (though not required) that several other pieces of information be recorded as well. If the tree will be monitored periodically, it is necessary to know the exact location from which the photograph was taken. Any deviation from the original photo location may produce non-comparable results. By measuring the azimuth to the tree with a compass and combining that with the

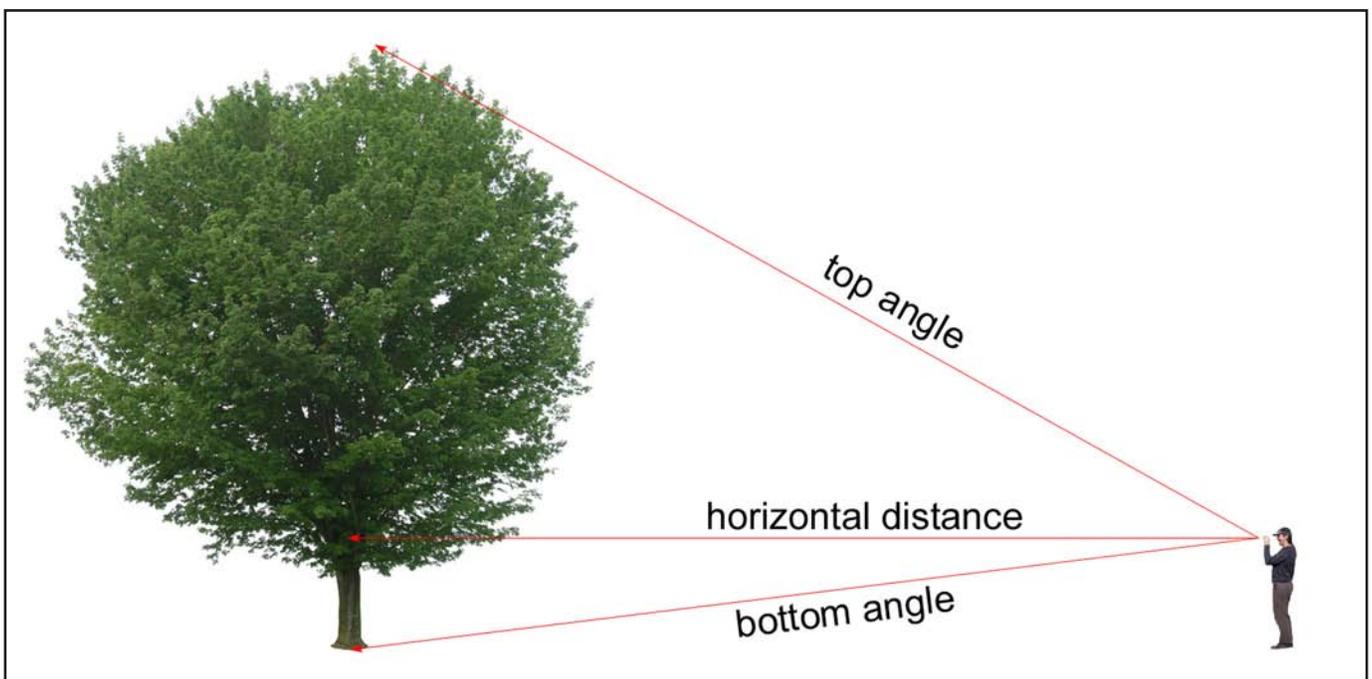


Figure 3—Required field measurements taken from photo location.

horizontal distance measurement collected earlier, it will be possible to return to the original photo location in the future. Other useful information worth recording is the tree species, location of tree, weather conditions, photo date, and any comments worth noting. This information can be stored in an UrbanCrowns data file for each tree.

Software Installation

Before installing the UrbanCrowns software, be sure that the computer is running Microsoft® Windows® XP or later. The program may run on older versions of Windows® but has only been tested on XP. The software also requires the use of the Windows® .NET Framework 2.0, which is a Microsoft® library package for Windows® programming. During installation, the program will check the computer to see if this version is installed. If not found, the installation program will automatically download and install the necessary files from the Microsoft® Web site. For this reason, the computer should be connected to the internet during the installation process.

The UrbanCrowns installation files can be downloaded at the following address: <http://www.srs.fs.usda.gov/pubs/software/urbancrowns.zip>. Unzip and save the contents of the “urbancrowns.zip” file to the computer’s desktop. Navigate to the desktop and double-click the “setup.exe” file. A screen will appear that reads “Welcome to the UrbanCrown Setup Wizard”. Click the “Next” button to continue. The following screen prompts for the folder where the program is to be installed (fig. 4). Install to the default folder or select a new location by clicking on the “Browse” button and selecting a new folder. Make sure there are at least 27 megabytes of free disk space available at the chosen location. To see how much space is available on the hard drive(s), click on the “Disk Cost” button. At the bottom of

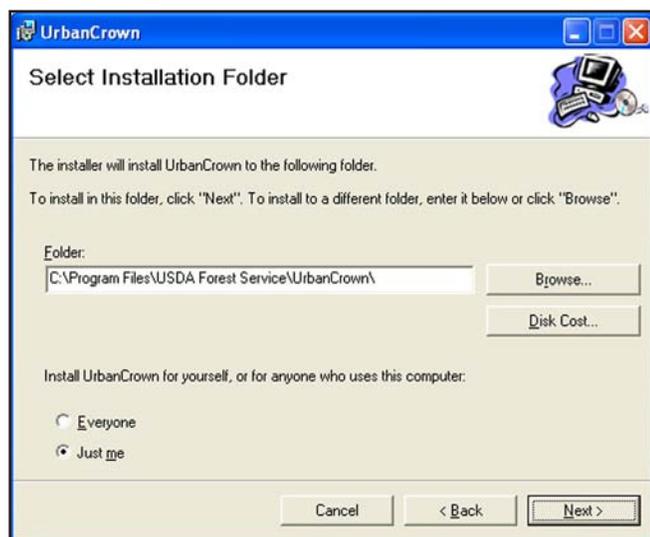


Figure 4—UrbanCrowns setup window prompting for installation location and user access.

the screen, specify who will have access to the program. To limit access to the current user, select the “Just Me” radio button, or select “Everyone” to allow access to all users. When finished, click the “Next” button to continue. The next screen is the installation confirmation screen. Click the “Next” button to proceed with the installation or the “Back” button to change the installation configuration. To abort the installation, click the “Cancel” button. After a short period of time, a confirmation screen will appear indicating that the installation was successful. A shortcut to the program labeled “UrbanCrown” will be placed on the computer’s desktop.

Program Overview

To begin using the program, double-click on the UrbanCrowns icon located on the computer’s desktop. The UrbanCrowns software comprises two main windows: the Tree Image window and the Data Control window (fig. 5). 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 and includes: 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. The Assessment tab is where the results of the analysis are displayed once the image is processed and includes: tree height, tree length, crown height, crown diameter, crown ratio, crown density, crown transparency, and crown volume. Since crown measurement terminology and definitions vary, it is important to know how the output parameters are defined with respect to UrbanCrowns. The terminology used in the program’s output is defined below:

- **Tree height**—The vertical distance from the base of the tree stem to the highest point of the tree crown
- **Tree length**—The distance from the base of the tree to the top of the tree following the lean of the main stem
- **Crown height**—The vertical distance between the lowest point of the crown and the highest point of the crown
- **Crown diameter**—The horizontal distance between the leftmost and rightmost regions of the crown
- **Crown ratio**—The vertical crown height divided by the vertical tree height
- **Crown transparency**—The amount of skylight visible through the crown expressed as a percentage of the total 2-dimensional tree crown area
- **Crown density**—The complement of transparency, or the amount of crown structures blocking light (calculated by subtracting transparency percent from 100 percent)
- **Crown volume**—Volume of all tree structures (leaves, branches, twigs, and stem) occurring within the crown

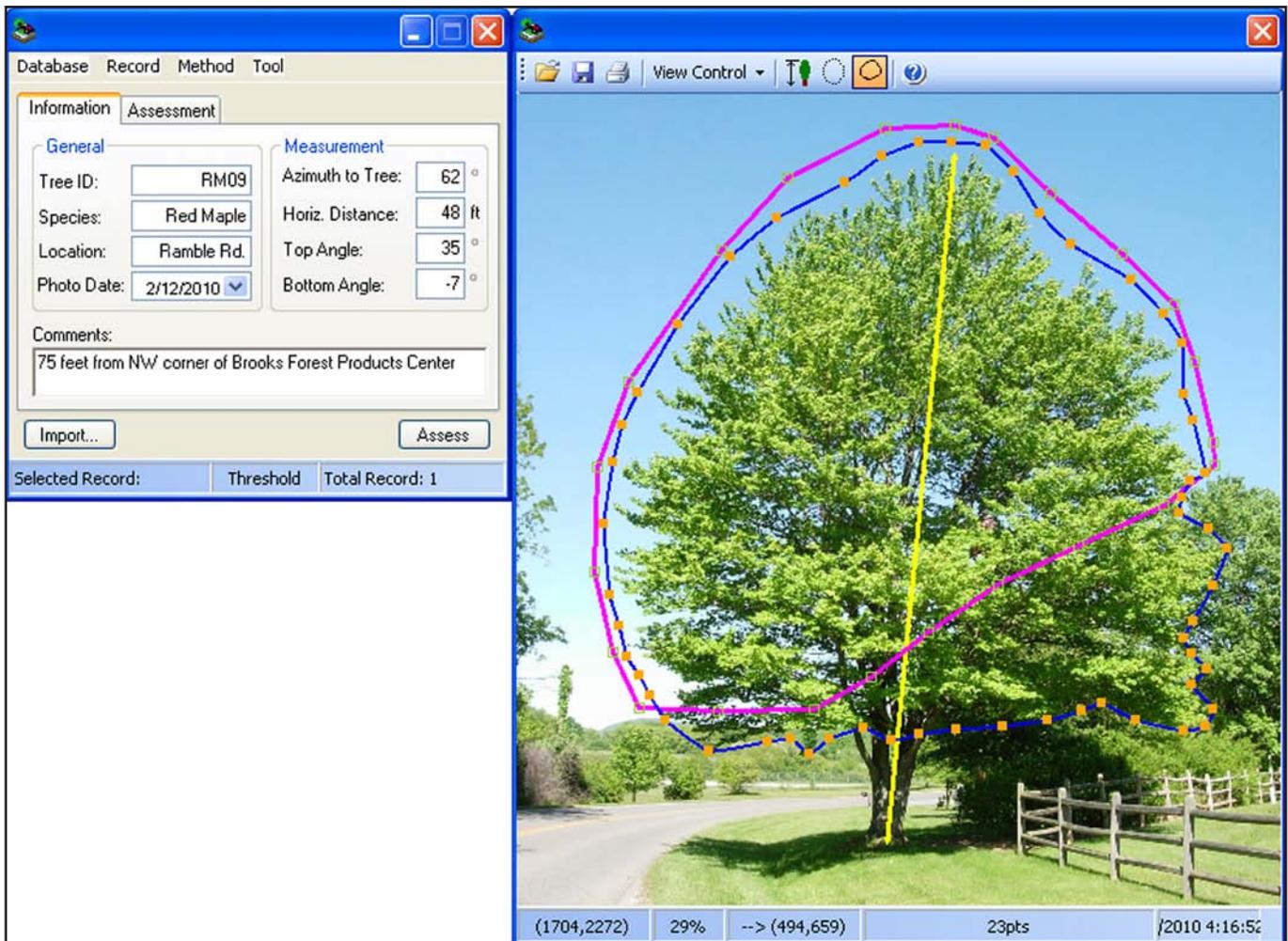


Figure 5—Screen capture of the UrbanCrowns program showing the Data Control window on the left and the Tree Image window on the right.

Input Parameters

To load a tree image into UrbanCrowns, click on the yellow folder icon located on the left side of the menu bar in the Tree Image window. Navigate to the folder where the image is stored, select the desired image, and click the “Open” button. If the image needs to be rotated, select the “View Control” pull-down menu, then select “Rotate Left” or “Rotate Right” as needed.

Once the image has been opened and rotated, the next step is to enter the field measurements and other tree information collected when the tree was photographed. In the Data Control window, select the Information tab and enter the input parameters for the tree. Certain input fields require values while other fields are optional. Required fields include: tree ID, horizontal distance, top angle, and bottom angle. Optional fields include: species, location, photo date, azimuth, and comments. Figure 6 shows sample input for a sugar maple (*Acer saccharum*). In this example, the tree ID (a unique identifying label created by the user) is “SugMap1”. The horizontal distance is 74.0 feet. The

vertical angle from the camera location to the top of the tree is 21.5 degrees and the angle to the base of the tree is -7.0 degrees.

Image Reference Lines

In addition to the input data, several reference lines also need to be drawn on the tree image before it can be processed (fig. 7). To have each of the lines displayed on the image after drawing them, select the “Show drawings” option under the “View Control” pull-down menu. The first line (shown in yellow) extends from the base of the tree to the top-most portion of the crown and follows the lean of the stem. 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). To draw the line, select the Tree Length button, which is just to the right of the “View Control” pull-down menu in the Tree Image window. Click on the base of the tree and drag a line to the top of the tree following the lean of the stem.



Figure 6—The Information tab of the Data Control window showing sample input for a sugar maple tree.

The second reference line (shown in blue) is a polygon drawn around the entire tree crown and is used to compute crown volume. To begin, select the “Crown Region” button, which is just to the right of the “Tree Length” button. Click somewhere outside of the tree crown and drag a line around the crown back to the starting point. Release the mouse button to close the polygon. This is a rough outline so it does not need to be drawn tightly to the edge of the crown. Once the rough outline has been drawn, right click on the image to go into editing mode. While in editing mode, the outline will change from blue to red. For any portion of the tree that has background interference (other trees, grass, buildings, etc.), drag the nodes of the outline tight against the edge of the crown. To add a node, click anywhere between existing nodes. The outline does not need to hug the crown in areas where there is no background interference (sky). When the image is processed, the program will shrink-wrap the selection region so that it conforms to the unobstructed outline of the crown.

The final reference line (shown in pink) is drawn around the portion of the crown that is free from background vegetation or other obstructions. This is the area that will be used by the program to compute crown transparency and density. First, select the “Transparency Measurement Region” button located to the right of the Crown Region button. Next, click near the outside of the crown where there is no background interference. Continue clicking around the unobstructed portion of the crown until the starting point is reached. Click on the first point to close the polygon. Inspect the polygon to be sure that no background vegetation is selected. If necessary, relick on the image to redraw a new polygon. No editing is necessary for this outline since no background

vegetation is included in the selection region. Similar to the crown selection region, the program will contract the line to the edge of the crown when processed.

In the rare case that the entire tree crown is free from background interference (meaning nothing but sky in the background), UrbanCrowns allows drawing of a single outline around the tree crown instead of two outlines (fig. 8). This one outline will be used to estimate both crown transparency and volume. To use a single outline, check “Use one outline” under the “View Control” pull-down menu. Select the “Crown Region” button and draw the outline around the tree crown. Since there should only be sky in the background, no editing of the polygon is necessary, except at the intersection of the crown and the stem. Make sure that only the stem section that falls within the crown is selected.

Image Assessment and Output

Before assessing the tree image, verify that “Auto Threshold” is checked under the “Method” menu item in the Data Control window. This is the default setting and shouldn’t be changed. To process the tree image, click

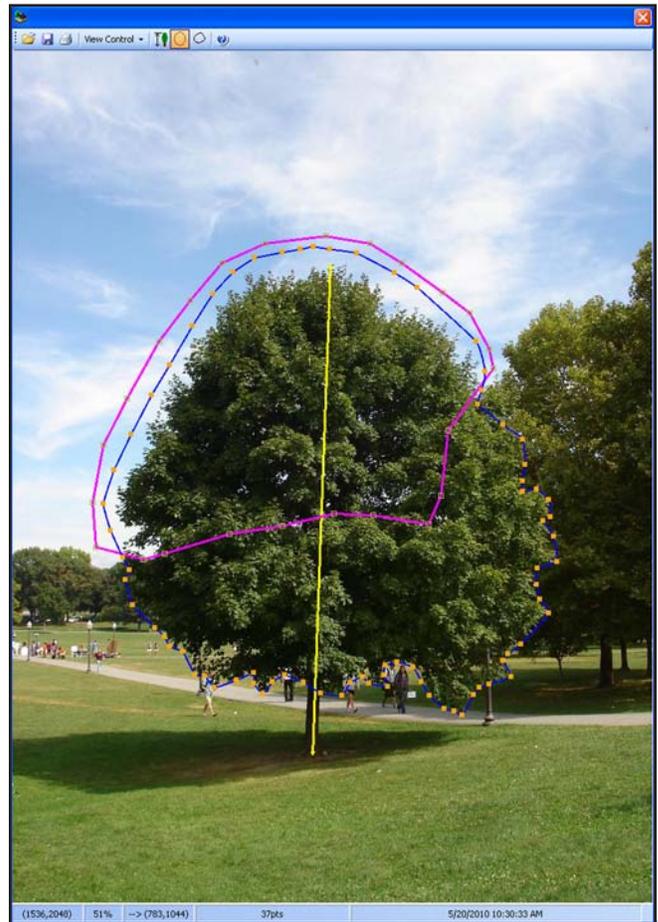


Figure 7—Reference lines drawn on the tree image to scale the photograph as well as delineate the crown and transparency regions.

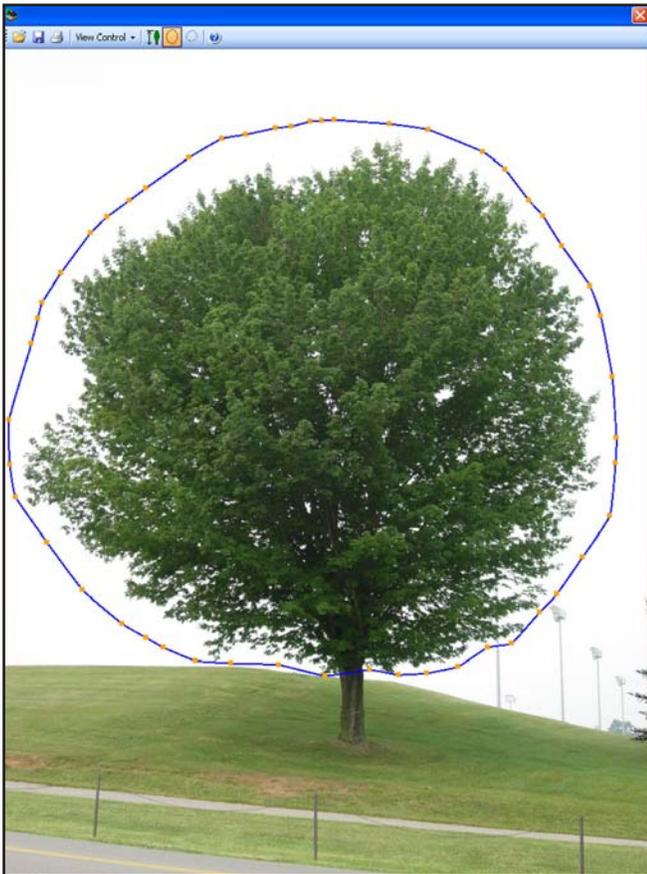


Figure 8—Single outline used to determine crown transparency and volume for a tree image containing no background interference.

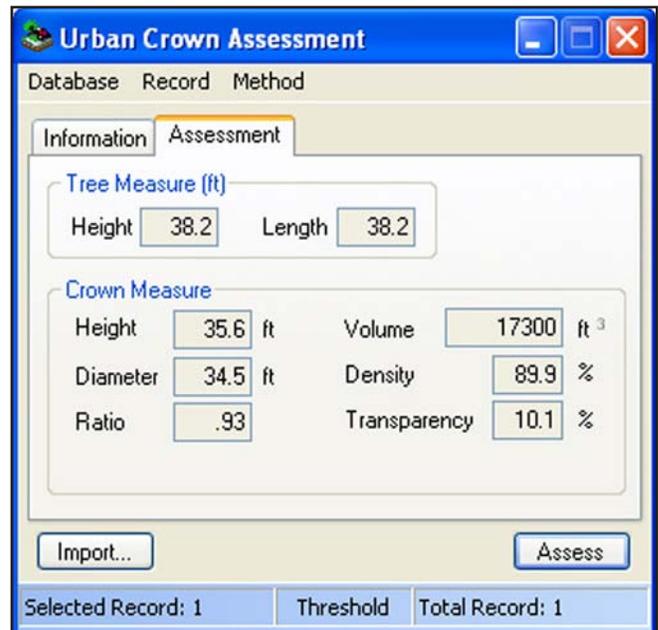


Figure 9—Post-assessment results for the sugar maple example.

on the “Assess” button in the bottom right corner of the Data Control window. The results of the analysis are then displayed under the Assessment tab (fig. 9). For this example, the results are as follows: tree height and length are 38.2 feet, crown height is 35.6 feet, crown diameter is 34.5 feet, crown ratio is 93 percent, crown density is 89.9 percent, crown transparency is 10.1 percent, and crown volume is 17,300 cubic feet. If the “Show result” option is checked under the “View Control” pull-down menu, a pop-up window will also appear that contains a contour image of the tree (fig. 10). The contour image shows the shrink-wrapped crown assessment areas that were used in the analysis.

To save a copy of the image (including reference lines), click on the “Save Image” icon located in the upper left corner of the Tree Image window. Choose the location and image format, then click the “Save” button. Once saved, a report will be displayed showing all of the input and output parameters for the analysis (fig. 11). The report can be saved to a text file by clicking on the “Save to a File” button or copied to the computer’s clipboard by clicking on the “Copy to Clipboard” button. To save a picture of the contour image, select the checkbox for “Save Contour Image” prior to clicking the “OK” button. To print a report that shows the tree image (including reference lines) along with input



Figure 10—Post-assessment contour image showing the shrink-wrapped crown assessment areas.

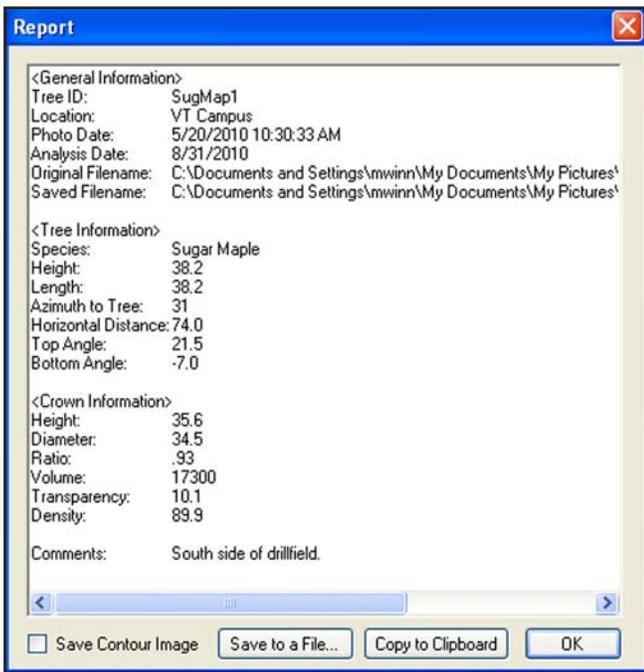


Figure 11—Report generated by UrbanCrows showing input parameters and assessment results.

parameters and assessment results, click on the printer icon in the upper left corner of the Tree Image window.

Using the Database

UrbanCrows can store all of the input and output from an assessment in a database. Once in the database, a tree can then be imported back into the program with the original input and reference lines. To save an assessed tree to the database, first create a new database by clicking “Database” and then “New” in the Data Control window. Choose a name and location for the database and click the “Open” button. To open an existing database, select “Open” under the “Database” menu item. All databases will have the file extension “.cdb”. Under the “Record” menu, select “Append” to add a new record to the database, “Update” to change an existing record, or “Delete” to delete the record from the database. Once a database has been modified, save the database by selecting “Save” in the “Database” menu. To create a text file showing all of the information housed in the current database, select “Record” then “Log” in the Data Control window.

To import a tree from the database, first make sure the desired database is open. Then click on the “Import” button in the bottom left corner of the Data Control window. A window will appear showing all trees stored in that database (fig. 12). When the mouse cursor is placed over

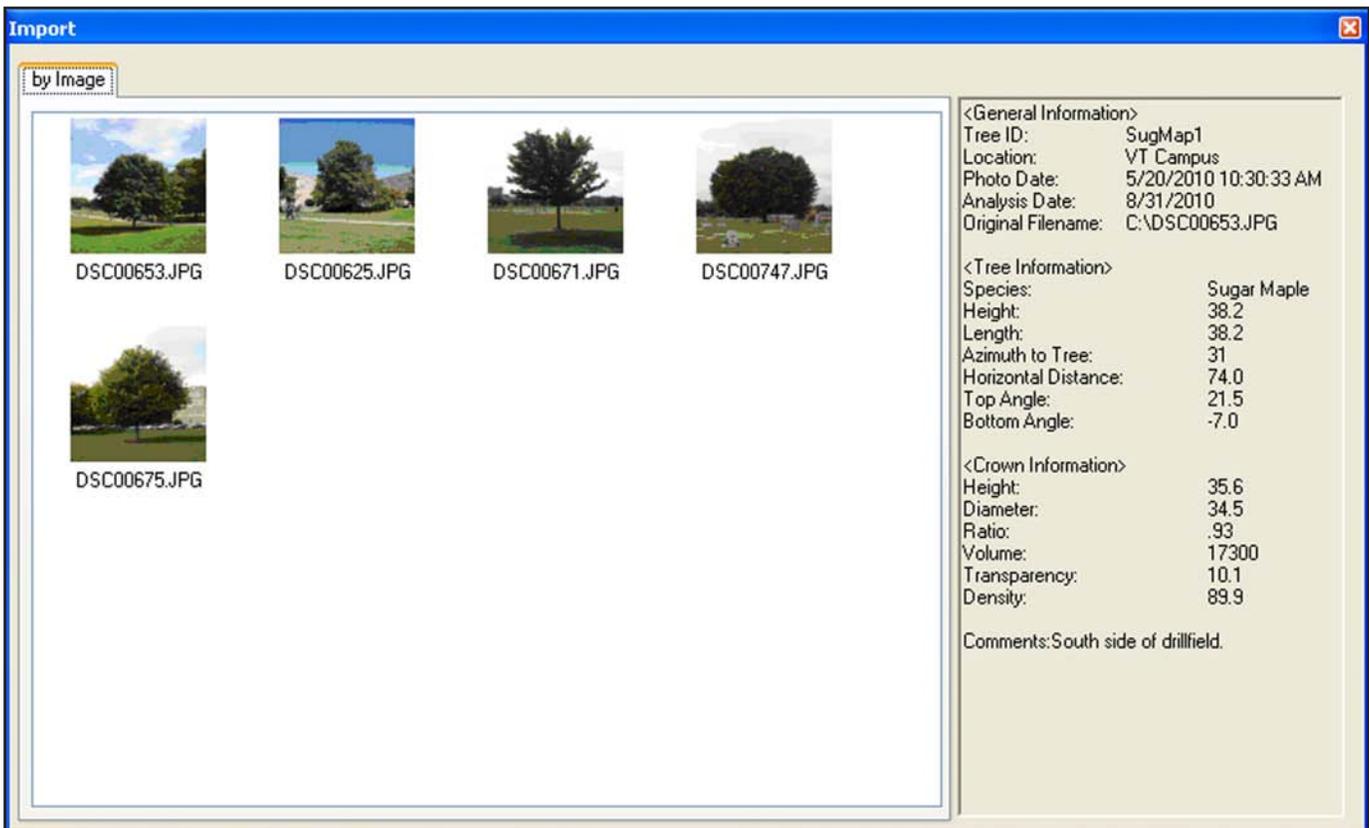


Figure 12—UrbanCrows window showing trees available for import from current database as well as information stored with selected tree.

the thumbnail picture of each tree, the information stored with that tree will be shown in a preview window just to the right. Double-click on the desired tree to import it into the program.

Crown Transparency

The program computes crown transparency by analyzing the relative color of each pixel within the transparency selection region. Each pixel is classified as either background (sky) or tree structure (stem, leaves, branches, etc.). Transparency is then calculated as the percentage of pixels within the selection region that are classified as background.

Transparency is one of the key measurements used to assess the health of urban trees. An increase in transparency from one year to the next can indicate that the tree is experiencing stress, which in turn can reduce growth potential, vigor, survivability, and reproductive potential. Some causes of increased crown transparency include: insect infestation, disease, environmental stresses, increased seed production, declining tree vigor, decreased leaf size, and loss of branches (Schomaker and others 2007). Inversely, an increase in crown density can be caused by: resurgence after insect or disease damage, recovery from environmental stresses, improved tree vigor, increased leaf size, and the addition of tree branches. Traditionally, people have estimated transparency by comparing the crown to a reference drawing or photograph. This method is very

subjective and usually varies from one observer to another. UrbanCrowns, however, provides a more accurate, objective measurement of crown transparency.

Crown Volume

Crown volume estimates can be used to quantify many tree functions including: carbon sequestration, pollution removal, rainfall interception, surface temperature reductions, and oxygen production. The most common method currently used to estimate crown volume from the ground involves first measuring crown ratio, crown diameter, tree length, and crown density. These variables are then plugged into a volume equation to obtain an estimate of crown volume. One problem with using this method is that it does not take into account the shape of the crown.

UrbanCrowns is unique in that it can provide an accurate estimate of crown volume using only one view of the tree. The program first determines the actual width and height represented by each row of pixels within the 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. The volume estimates for each row of pixels are summed to obtain the volume estimate for the entire crown selection region (fig. 13). 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

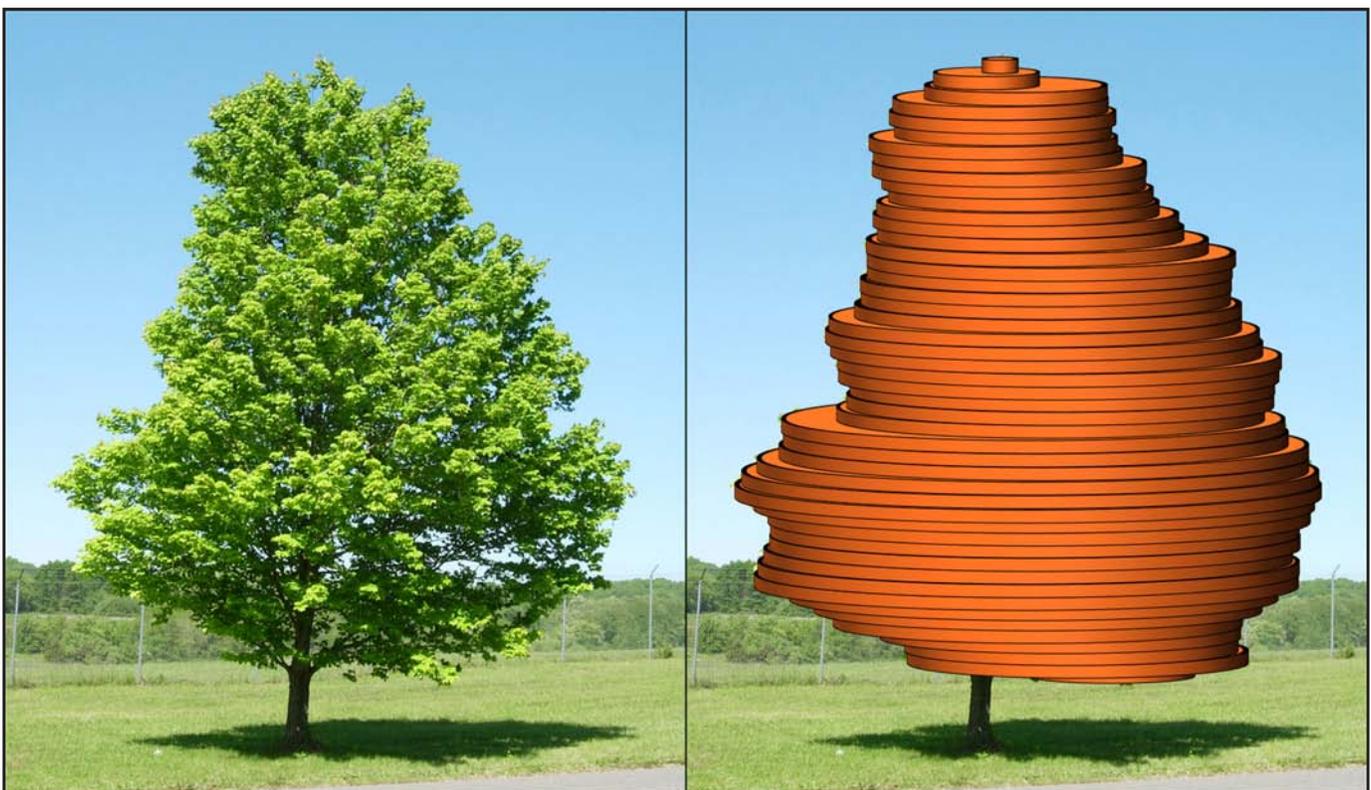


Figure 13—Illustration showing how UrbanCrowns determines crown volume using a single view of the tree.

structures only. This method of determining volume works well for crowns that are relatively symmetrical around the entire tree. 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.

Conclusion

Trees are a vital part of urban communities. To ensure their health and survival in such a stressful environment, inventories are often conducted to identify declining or hazardous trees. To more efficiently and accurately evaluate the condition of an urban forest, tree managers need intuitive, practical, and cost-effective tools to assess individual trees and monitor their condition. Since tree crown characteristics serve as good indicators of overall tree health, the Forest Service developed the UrbanCrowns computer program to assist with urban tree assessment. The software can be used to monitor individual tree growth or decline over time and can also help quantify tree benefits such as rainfall interception, carbon sequestration, energy reductions, and pollution removal.

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UrbanCrowns Could Aid i-Tree Applications

According to itreetools.org, “i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban forestry analysis and benefits assessment tools. The i-Tree Tools help communities of all sizes to strengthen their urban forest management and advocacy efforts by quantifying the structure of community trees and the environmental services that trees provide.” Key variables used in the i-Tree Eco assessment tool (such as tree height, crown width, and transparency) are similar to the data generated by UrbanCrowns. Another potential use is in the i-Tree Storm tool, which analyzes storm damage debris from urban trees. UrbanCrowns could be used to document the condition of damaged tree crowns and monitor their recovery for years after the damaging event. The approaches are slightly different and changes to the i-Tree applications would be necessary in order to incorporate UrbanCrowns data.

The UrbanCrowns software is available for download at the following address:

<http://www.srs.fs.usda.gov/pubs/software/urbancrowns.zip>

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