Urban Crowns: Crown Analysis Software to Assist in Quantifying Urban Tree Benefits

*Matthew F. Winn**
U.S. Forest Service
Southern Research Station
Sang-Mook Lee Bradley
Department of Electrical and Computer Engineering
Va. Tech
Philip A. Araman
U.S. Forest Service
Southern Research Station
*mwinn@fs.fed.us

Abstract

UrbanCrowns is a Microsoft® Windows®-based computer program developed by the U.S. Forest Service Southern Research Station. The software assists urban forestry professionals, arborists, and community volunteers in assessing and monitoring the crown characteristics of urban trees (both deciduous and coniferous) using a single side-view digital photograph. Program output includes estimates of tree height and length as well as crown height, diameter, ratio, volume, density, and transparency. This paper gives an overview of the UrbanCrowns program with a more detailed discussion on the crown volume output and its potential to aid in quantifying functions and benefits of urban trees.

Introduction

Trees provide many benefits to urban communities. They improve air quality by reducing temperatures, lowering VOC emissions, and removing harmful pollutants from the air. They can improve water quality by intercepting and filtering rainfall, thus reducing urban runoff and the pollutants they carry. Strategically placed trees can also reduce heating and cooling energy use by providing shade in the summer and windbreaks in the winter. In addition to the environmental benefits urban trees provide, they add aesthetic, social, and economic value to urban communities as well. One of the difficulties facing researchers and urban planners, however, is how to accurately quantify the benefits that urban trees provide. Many tree benefits are linked directly to crown volume, leaf surface area, or leaf biomass, but obtaining these measurements can be costly and time-consuming.

Researchers with the U.S. Forest Service Southern Research Station have developed a crown analysis software tool that can easily estimate the volume of urban tree crowns. The program (UrbanCrowns) requires only a single side-view digital photograph of the tree and a few easily collected field measurements. The volume estimate can potentially be used to quantify a variety of tree functions and benefits. Species-specific equations could also be developed to convert the volume estimates into leaf area or biomass estimates.

Program Input

The input for UrbanCrowns consists of a ground-based digital photograph of the subject tree and several field measurements.

Digital Photograph
The photograph can be taken with any standard digital camera. Use of attachable lenses, however, such as telephoto or wide angle lenses should be avoided as these can produce erroneous results. The entire tree should be visible in the photograph and centered both vertically and horizontally. Since this image will be the foundation for all analyses within the program, the quality of the photo can directly affect the accuracy of the results. Things to consider when choosing a photo location include: the time of day, orientation of the sun, weather conditions, and obstructions. Also, the program requires that the photograph contain a portion of the tree crown that is free from background vegetation or buildings (meaning only sky in the background). This area will be used to estimate foliage transparency and the program has difficulty distinguishing between foreground and background vegetation. The program may or may not be able to filter out buildings and other man-made obstructions, depending on the contrast in color.

Field Measurements
In addition to photographing the tree, several tree measurements must also be collected in order to scale the photograph within the UrbanCrowns program. First, the angles to the top and base of the tree must be measured using a clinometer or other vertical angle measuring device from the same location and height where the photograph was taken. Next, the horizontal distance from the photo location to the tree stem should be determined. This can be measured using a laser or sonic rangefinder or a tape measure. There are several instruments on the market that will 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 order to landmark the photo location, the azimuth to the tree should also be recorded. The azimuth, in combination with the horizontal distance, will make it possible to return to the original photo location in the future. 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. Once the photograph and field measurements have been collected, the tree image can be analyzed using the UrbanCrowns software.

Program Overview

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 into the program (Figure 1). 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.

The next step is to draw a reference line and a set of polygons on the photo (Figure 2). The 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 first

Figure 1. Sample input data for the UrbanCrowns computer program.

polygon (shown in pink) is 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 crown transparency and density. The final polygon (shown in blue) is 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 where there is sky in the 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.

Once the input data have been entered and the reference lines have been drawn, the image can be processed. Output generated by the UrbanCrowns program consists of: tree height, tree length, crown height, crown diameter, crown ratio, crown volume, crown density, and foliage transparency. Figure 3 shows the post-processing results for the above example. Tree height and length are 38.2 ft, crown height is 35.5 ft, crown

Figure 2. Reference lines drawn on the photo to scale the image and delineate the transparency and crown regions.

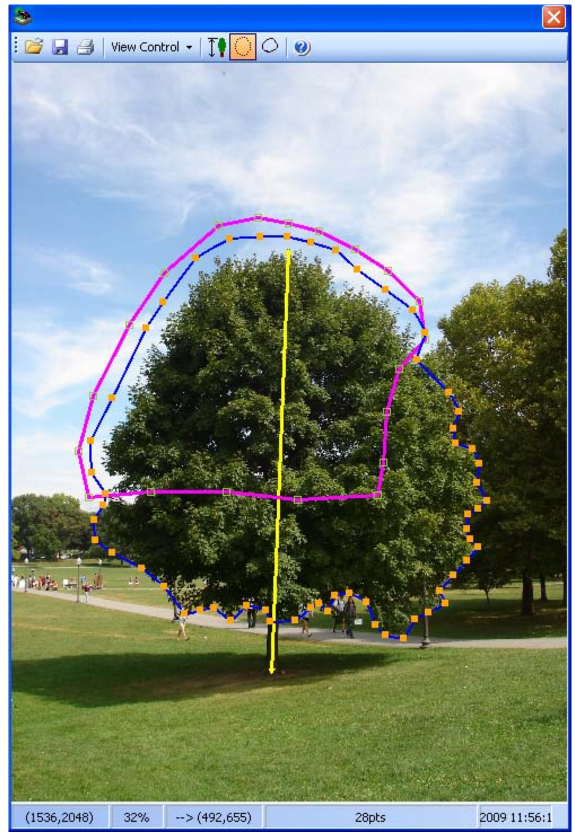
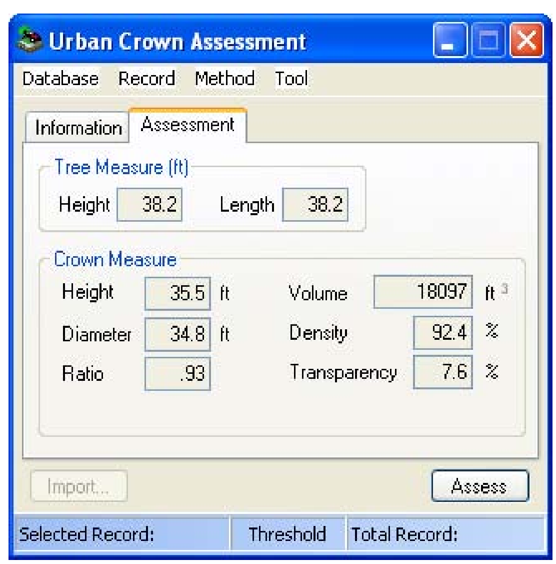


Figure 3. Output generated by the UrbanCrowns computer program



diameter is 34.8 ft, crown ratio is 93%, crown volume is 18,097 ft^3, crown density is 92.4%, and crown transparency is 7.6%.

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 tree crown area.
- *Crown density* – The inverse of transparency, or the amount of crown structures blocking light.
- *Crown volume* – Volume of all tree structures (leaves, branches, twigs and stem) occurring within the crown.

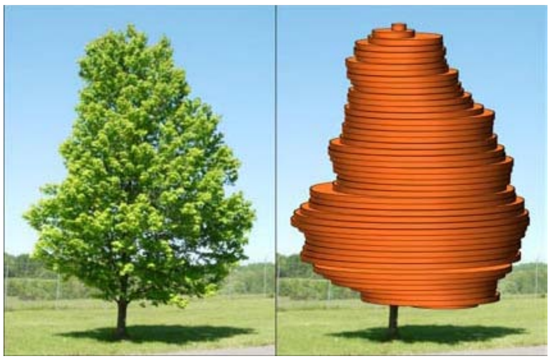
Crown Volume Estimation

The most common methods currently used for ground-based estimates of urban tree crown volume involve using easily attainable tree measurements (such as DBH, crown width, and crown height) and some measure of crown shape. Typically, the assumption is made that the crown takes the shape of a common geometrical solid such as a cone, ellipsoid, or paraboloid. Though many open grown trees typically have some type of radial symmetry, their true shape cannot always be easily defined by geometric equations. Also, volume estimates based on geometric shapes may not take into account the density of the crown. That is, they provide gross volume estimates which include the stem, leaves, and branches, as well as the air between them. The volume calculation used in the UrbanCrowns program not only uses the actual shape of the crown to determine volume, but it also takes into account crown density. Therefore, the result is an estimate of crown volume that includes tree structures only.

Studies have shown that crown volume can be accurately estimated using two or more photographs taken at different view angles around the tree. UrbanCrowns is unique in that it can provide an accurate estimate of crown volume using only one view of the tree. Similar to other methods, the program assumes crown symmetry, but not for the crown as a whole. The assumption is made that if you pass an imaginary plane horizontally through any section of the tree crown, the portion of the crown that intersects the plane will be circular in shape. If it's obvious when photographing a tree that this assumption doesn't hold true (such as trees pruned around power lines), it may be necessary to analyze a second photograph taken perpendicular to the first. After both images are processed, the two estimates can then be averaged.

Figure 4 shows an example of how UrbanCrowns derives its estimate of crown volume. The program first determines 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. 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.

Figure 4. Illustration showing how volume is determined in UrbanCrowns



Potential Uses

Many of the benefits urban trees provide are directly correlated to the size and density of the crown. Therefore, the volume output generated by UrbanCrowns program can be a valuable tool when trying to quantify these benefits. Below are some of the volume-based benefits and tree functions that UrbanCrowns could potentially be used for.

- Air pollution removal
- Emissions of volatile organic compounds (VOCs)
- Carbon storage and sequestration
- Oxygen production
- Reduction of air temperatures
- Energy use reduction on buildings
- Evapotranspiration
- Rainfall interception
- Noise reduction
- Wind reduction
- Wildlife habitat
- Psychological and aesthetic values
- Structural values

Conclusion

Trees provide numerous environmental and health benefits to urban communities, but measuring these benefits has long been a challenge. In order to properly plan for and manage an urban landscape, decision makers need to have some means of quantifying the benefits that urban trees provide. Since many of these benefits are directly correlated to the size and density of the crown, the first step in quantifying the benefits is to obtain an accurate estimate of leaf cover. UrbanCrowns is a software tool that can be used by urban forestry professionals to estimate the volume of individual tree crowns and assist in quantifying many tree benefits and functions.

References

Clark, N.A., S.M. Lee, W.A. Bechtold, and G.A. Reams. 2006. Digital photography for urban street tree crown conditions. *In*: Proceedings of the Society of American Foresters 2005 National Convention. Ft. Worth, TX [published on CDROM]: Society of American Foresters, Bethesda, MD. 4 pp.

Dwyer, J.F., E.G. McPherson, H.W. Schroeder, and R.A. Rowntree. 1992. Assessing the benefits and costs of the urban forest. *Journal of Arboriculture*. 18(5): 227-234.

Maco, S.E. and E.G. McPherson. 2003. A practical approach to assessing structure, function, and value of street tree populations in small communities. *Journal of Arboriculture*. 29(2): 84-97.

Mawson, J.C., J.W. Thomas, and R.M. DeGraaf. 1976. *PROGRAM HTVOL: The determination of tree crown volume by layers*. USDA Forest Service Research Paper. NE-354. 9 p.

McPherson, E.G. and R.A. Rowntree. 1988. Geometric solids for simulation of tree crowns. *Landscape and Urban Planning*. 15: 79-83.

Nowak, D.J. 1996. Estimating leaf area and leaf biomass of open-grown deciduous urban trees. *Forest Science*. 42(4): 504-507.

Nowak, D.J., D.E. Crane, J.C. Stevens, R.E. Hoehn, J.T. Walton, and J. Bond. 2008. A ground-based method of assessing urban forest structure and ecosystem services. *Arboriculture & Urban Forestry*. 34(6): 347-358.

Nowak, D.J., J. Wang, and T. Endreny. 2007. Environmental and economic benefits of preserving forests within urban areas: air and water quality. P. 28-47 in The economic benefits of land conservation, de Brun, C.T.F., (ed.). The Trust for Public Land, San Francisco, CA.

Phattaralerphong, J. and H. Sinoquet. A method for 3D reconstruction of tree crown volume from photographs: assessment with 3D-digitized plants. *Tree Physiology*. 25: 1229-1242.