Trees in cities, a main component of a city's urban forest, contribute significantly to human health and environmental quality. Urban forest ecosystem assessments are a key tool to help quantify the benefits that trees and urban forests provide, advancing our understanding of these valuable resources.

Over the years, a variety of assessment tools have been developed to help us better understand the benefits that urban forests provide and to quantify them into measurable metrics. The results they provide are extremely useful in helping to improve urban forest policies on all levels, inform planning and management, track environmental changes over time and determine how trees affect the environment, which consequently enhances human health.

American Forests, with grant support from the U.S. Forest Service's Urban and Community Forestry Program, developed this resource guide to provide a framework for practitioners interested in doing urban forest ecosystem assessments. This guide is divided into three main sections designed to walk you through the process of selecting the best urban forest assessment tool for your needs and project. In this guide, you will find:

- **Urban Forest Management**, which explains urban forest management and the tools used for effective management
- **How to Choose an Urban Forests Ecosystem Assessment Tool**, which details the series of questions you need to answer before selecting a tool
- **Urban Forest Ecosystem Assessment Tools**, which offers descriptions and usage tips for the most common and popular assessment tools available

Urban Forest Management

Many of the best urban forest programs in the country have created and regularly use an Urban Forest Management Plan (UFMP) to define the scope and methodology for accomplishing urban forestry goals. Such plans often include maintenance standards, tree inventories, planting, removal, reforestation, rotation planting, tree selection processes, personnel training and development, and budgets, to name a few. Recently, UMFPs have started including more language geared towards private property owners and community organizations because in order to successfully maintain a healthy urban forest, it's important to include all urban forest stakeholders in the management process. Later in this guide, we outline some great resources to help with urban forest management and planning.

The day-to-day management of an urban forest can involve operations-based tools such as tree inventories or asset-management software to help keep track of routine activities like tree maintenance. Tree inventories are an important part of the planning and management process, and there are a variety of software programs that exist to help track local inventory and urban forests management activities. Visit the U.S. Forest Service Northeastern Area's guide to some inventory programs that urban foresters are using.

This resource guide will focus on the urban forest ecosystem assessment tools that urban forest managers often turn to for further assistance with urban forest planning beyond the day-to-day management.

Urban forest assessment tools provide a snapshot of the health status, extent and structure of an urban forest in order to quantify the benefits that it provides. Ecosystem assessment tools can also help track trends or changes to the urban forest and inform future management decisions.

Assessments sometimes involve collecting field data and analyzing an inventory of the urban forest, a process known as the "bottom-up approach." Other types of ecosystem assessments use aerial imagery for analysis, which is known as the "top-down approach." The bottom-up and top-down approaches will be explained in more detail in the coming pages of this resource guide.

How to Choose an Urban Forest Assessment Tool

With dozens of urban forest ecosystem assessment tools available, before selecting one, you should consider a series of questions that will lead you to the best tool for your project.

- What are your goals? What do you want to gain from doing an assessment?
- What is the scope of your project, including what ecosystem services, if any, you want to measure?
- What type of resources, including funding, data and time, do you have at your disposal for this project?
- What type of approach do you want to use: top-down or bottom-up?

Once you have determined the answers to these questions, you'll ready to determine what type of tool will suit your needs best.

Define Urban Forest Objectives and Goals

What objectives and goals are you trying to achieve?

Laying out goals and objectives prior to conducting an assessment will help you determine what you will measure and how you will measure it.

One common goal for undertaking an assessment is to gain a better understanding of the current composition and structure of the urban forest. This understanding will create a base for planning, management and advocacy.

Other common goals of assessments are:

- To quantify the ecosystem services an urban forest provides.
- To give the public a better understanding of the urban forest and the benefits it provides.
- To identify new planting opportunities to increase benefits to the community.
- To understand how much canopy cover exists, what the opportunity is to create more and what locations have the greatest need or potential to maximize benefits of return on investment. Results can also be used in some ecosystem offset markets and conservation credit systems.

If one your goals is to develop a tree inventory, you should also determine if you want a complete or sample inventory:

- Complete inventories are for communities that are able to collect data from every tree in an assessment area. While complete inventories provide excellent accuracy, they can be costly and

time consuming. Complete inventories are best for folks who want to use data in a day-to-day management setting, typically for public trees or campus environments.

- Sample inventories look at street segments or plots to generate a random sampling. This type of inventory generally looks at three to six percent of the full assessment area and has around a 10 percent margin of error. Sample inventories are a good option when a complete inventory is not necessary or a community lacks the time and resources necessary for a complete inventory.

Determine Urban Forest Assessment Scope

What is your study area or scope?

There are two main scales at which you can conduct an urban forest assessment: the urban forest of an entire city or metropolitan area or a discrete tree population, such as a neighborhood, street trees, a single tree or a park.

Once you've determined your scale, you need to decide what environmental benefits or ecosystem services, if any, you want to assess in your urban forest.

Some examples of ecosystem benefits or services that can be quantified with urban forest ecosystem assessment tools include:

- air pollution removal
- emissions reduction
- carbon storage
- water interception and stream flow
- energy use of buildings
- UV radiation reduction
- wildlife habitat and biodiversity

Socio-economic benefits and services are more difficult to measure, but there are some tools to measure them separately. Social conditions of the environment, like effects on health and crime, can be evaluated through conducting studies and surveys of the community. Statistical data on health and crime may also be useful in a social assessment of an urban forest. Economic conditions, such as job opportunities and property values, can also be tracked with statistical data. With these and other non-physical characteristics, correlations between urban forest conditions and social and economic conditions might appear. For more information on the social sciences related to urban forestry, you can check out the University of Washington's Human Dimensions of Urban Forests and Urban Greening.

Consider Available Urban Forest Data and Resources

What resources and data are available to you for your urban forest assessment?

Determining your resources ahead of time will help determine which tools to use. Although some assessment tools are available for free, there are often costs involved in conducting an urban forest assessment, such as staff time, software, data collection or digital imagery. Sometimes, technical expertise might be required to process and analyze the data. To help with funding needs, you might want to look into partnering with city, state or federal entities to acquire grants or share the costs of an assessment.

Another important factor to help determine costs is to consider how much data you already have and how much you still need to collect. For instance, do you already have an up-to-date tree inventory? Once you know what you already have to work with, you'll be better equipped to choose the type of approach you want to use for your assessment.

Choose a Type of Urban Forest Assessment Approach

What type of assessment do you want? What is the difference between a top-down and bottom-up assessment?

There are two basic ways of assessing an urban forest. The top-down approach involves assessing aerial or satellite images of canopy and other land cover, while the bottom-up approach involves collecting field data on the composition and physical structure of the trees.

A top-down approach is relatively easy to conduct, is comprehensive across a landscape and is quite accurate, but it is limited in the structural information that is obtained and can be costly depending on what tools are used. Top-down approaches can produce a good estimation for tree cover and planting potential by using high-resolution imagery and detailed maps to zoom-in on specific tree locations. However, the top-down approach is limited to only assessing quantity and distribution, whereas tree species and height is difficult to determine using this approach.

A bottom-up approach involves collecting field data and may provide more detailed information needed to assess urban forest structure and ecosystem services. Species composition, number of trees, tree locations, tree sizes and tree health can all be determined using the bottom-up approach. This is also a good method for assessing and projecting ecosystem services and values, such as carbon storage and air pollution removal. However, there are limits to this approach as well, including a potential limited geographical area of data since it takes more time and resources to assess a large area.

Urban Forest Assessment Tools

There are a variety of urban forest assessment tools available depending on what kind of approach you want to use and what specifically you want to analyze or measure.

One of the most ubiquitous assessment tools available today is the i-Tree suite, which is a state-of-the-art, peer-reviewed software suite from the U.S. Forest Service. The suite provides a variety of urban forestry analysis and benefits assessment tools, calculating a dollar value of ecosystem services by using equations to predict environmental and economic benefits. Throughout the rest of this guide, we'll go into more detail about specific tools in the i-Tree suite, as well as other common and useful assessment tools.

The following is a list of the most common categories of assessment tools. To find out more about the specific tools in each category, click on the links below.

- Top-Down Assessment Tools
- Bottom-Up Assessment Tools
- Watershed and Stormwater Management Tools
- Individual Tree Calculator Tools
- Park Tools
- Management and Modeling Toolkits
- Mobile Apps

Top-Down Assessment Tools

Top-down approaches are used to describe urban tree canopies (UTCs), which are simply areas of trees that — when viewed from above — block the view of the ground. Accuracy of top-down assessments depends on image quality, or spatial resolution. The cost of top-down assessments varies depending on the technology and programs used, as well as the level of analysis and tools in the project scope. Some data sets are free to access online, while others can cost several thousand dollars. Below are the common categories of top-down assessment tools and specific programs and software that can be used to conduct these types of analyses.

- Aerial Photo Interpretation Tools
- Geographic Information System (GIS)-based Tools
- Remote Sensing-based Tools

Aerial Photo Interpretation Tools

Aerial photos are easy to access through services like Google Earth and i-Tree Canopy, which uses Google Maps. By looking at different areas and dates, users are able to get a more complete picture of the urban forest. However, photo interpretation is limited in detail, which can lead to misinterpretation of data. Data also cannot be summarized on multiple scales.

- **High-resolution imagery** of a UTC uses digital aerial imagery gathered from satellites to create a cover map with detailed — typically less than one meter pixel resolution — and accurate tree canopy data. It can be used with GIS, another top-down approach, and is able to show users potential spaces to plant trees at different scales. This method may be time consuming and costly, ranging anywhere from $5,000 to $40,000, and requires a trained technician and special software to develop cover maps. Discover how Phoenix used high-resolution imagery.

- **i-Tree Canopy** uses Google Maps aerial imagery to conduct a tree cover assessment. The user is able to assign boundaries on the online map to create a defined project area. i-Tree Canopy then generates random sample points within the project area. The user is able to zoom-in on each point and choose from a list of cover types for that point. The more points that are defined, the more accurate the cover estimate will be. For example, 100 sample points usually have a standard error of about 4.6 percent, while 1,000 points will have a standard error of about 1.4 percent.

- **i-Tree Vue** uses National Land Cover Database (NLCD) satellite imagery and data (updated by Google Maps) to assess an area's land cover, which includes tree canopy and some ecosystem services. Modeling with i-Tree Vue can be used to plan out future impacts and benefits of planting scenarios. Outputs such as carbon sequestration, pollution removal and carbon storage can be calculated based on modeling scenarios.

    - **NLCD** is a 16-class land cover classification database, available for free online, that includes the entire conterminous United States (the lower 48 states) at a spatial resolution of 30 meters. The 2006 NLCD database is based primarily on classification of Landsat Enhanced Thematic Mapper+ using 2006 satellite data. However, NLCD also tends to underestimate canopy cover by 10 percent.

Geographic Information System (GIS)-based Tools

GIS software (such as Esri ArcGIS and open source packages such as GRASS, Quantum, GDAL and Saga) works with maps and geographic information online and is used for creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database. GIS software prices can range from free online tools to several thousand dollars a year.

- **InVEST** (Integrated Valuation of Environmental Services and Tradeoffs) is a host of tools that map and value the ecosystem services in a given area. The user inputs GIS data such as land use, land cover and topography.

Remote Sensing-based Tools

Remote sensing is a type of geospatial technology used to map and monitor urban canopy cover and other urban landscape features. Passive remote sensing works by detecting naturally emitted or reflected radiation, while active remote sensing sends out energy in order to sense and measure the energy reflected back. This tool can track ecosystem features such as carbon storage and heat island effect. The accuracy of remote sensing can depend on factors like technology performance, viewing conditions and quality of data processing. The criterion for remote sensing accuracy is 85 percent. Remote sensing costs include data acquisition, image processing and image interpretation, causing a range in price range from a few hundred dollars to several thousand.

- **LiDAR** (**Li**ght **D**etection **a**nd **R**anging) relies on reflected light, and LiDAR sensors emit their own energy in the form of a laser. The advantage of LiDAR is that it essentially sees through shadows. Incorporating LiDAR into the tree canopy mapping efforts will improve the ability to detect trees, particularly smaller, recently planted trees, resulting in a more accurate and visually coherent representation of a city's tree canopy. Assessments that use LiDAR are very accurate and can cost several thousands of dollars.
- **Hyperspectral imagery** is a process that collects information across an electromagnetic spectrum through sensors and provides highly detailed mapping of changes in reflected energy. Hyperspectral imagery is a very high-resolution type of remote sensing that measures 300 spectral bands or energy levels. Sensors that detect energy wavelength create digital maps based on the leaf-pigments (the chlorphyll or color) that are detected. This technology can be expensive, but cheaper and smaller alternatives, like **IMEC**, are being developed. Milwaukee and Oakville, Ontario, for example, have used this technology to map their ash trees in order to prepare for and manage emerald ash borer outbreaks.

Bottom-Up Assessment Tools

Bottom-up approaches use tree inventory and field data to calculate the ecosystem service value of urban forests. Accuracy of bottom-up assessments depends on the sample plot size in relation to the total project area. Consultants typically recommend collecting data from at least 200 one-tenth-acre plots for a standard error of less than 15 percent. The cost of these projects can also vary depending on the size and scope of the project. A typical i-Tree Eco assessment of 200 sample plots could cost up to $40,000 for professional consulting services. Cost drastically drops when students or volunteers collect data rather than highly trained technicians. Bottom-up tools can not only track ecosystem benefits, but they can also help better inform policy or management decisions for urban forests.

- **i-Tree Eco** (previously known as UFORE) can be used to assess an entire urban forest. It uses sample or complete tree inventory data to calculate the ecosystem service benefits of those trees. Summary reports are generated with detailed information such as air pollution removal, carbon storage capabilities, annual rainfall interception and pest risk analysis. I-Tree Eco is compatible with mobile devices, making data entry available in the field.

- **BenMAP**, from the Environmental Protection Agency (EPA), is integrated in i-Tree ECO. It is a computer program that uses geographic information system (GIS) data to estimate economic and health implications of urban forests based on air quality. When changes in air quality occur, BenMAP is able to calculate the changes to economic and health factors. This program can be useful for policy analysts, decision makers and urban ecologists.

- **i-Tree Streets** (previously known as Stratum)is limited to assessing street tree population benefits. Users can use a sample or existing street tree inventory to analyze a specific area. Summary reports are generated with detailed information such as stormwater control, property value increase and air quality improvement.

Watershed and Stormwater Management Tools

There are a number of tools available for those who want to focus on measuring the ecosystem benefits of an urban forest in terms of water management and health.

- **i-Tree Hydro (beta)** is the newest of the i-Tree applications and is designed for users interested in analyses based on watershed levels and the effects of tree and land cover on hydrological functions. This tool uses available data to model changes in stream flow and water quantity within a defined watershed. By modeling these changes, urban foresters can better understand how trees and impervious surfaces affect water flow and quality.

- **Green Long-Term Control-EZ Template**, developed by the Environmental Protection Agency (EPA), can assess the impacts that green roofs, permeable pavement and vegetation swales can have on a city. This tool helps to assess the costs, benefits and environmental outcomes associated with incorporating green infrastructure. The template is available for free online.

- **Green Values National Stormwater Management Calculator** is a free online tool developed by the Center for Neighborhood Technology. It can help determine the impact of green roofs, planter boxes, rain gardens and trees using statistical data on land cover, precipitation, runoff averages and soil types. This tool is also able to compare current landscapes with hypothetical, user-generated landscapes. Hypothetical landscapes may include features like more trees. The calculator can quantify the difference in hydrological functions and the economic impacts for both scenarios.

- **LandServer** is an assessment tool used by the Bay Bank, the conservation marketplace for the Chesapeake Bay. LandServer is the first step for landowners to engage in ecosystem markets and advocate for conservation funding. This tool assesses and values property and ecosystem services. Using a database of geographical and ecological information, LandServer can collect data on several environmental features, such as land use, source water watersheds and hydric soils.

- **SUSTAIN** (System for Urban Stormwater Treatment and Analysis Integration) is an EPA tool used to assist in stormwater management in urban areas. It is useful in planning for stormwater flow, reaching water quality goals, controlling water pollution and protecting source water. SUSTAIN is also a decision-support system that's helps identify best stormwater-management practices (BMPs) to implement them in areas where they will be both cost effective and low impact on the environment.

- **TR-55** is a computer-based urban hydrology tool for small watersheds. It was developed by the Natural Resources Conservation Service (NRCS) and can calculate stormwater runoff volume and rate and storage volumes for floodwater reservoirs.

- **Watershed Forest Management Information System (WFMIS)** is an extension of ArcGIS — a mapping and analysis tool — and is used to evaluate a forest and plan for conservation efforts, pollution mitigation, road maintenance and tree planting. There are three submodels of WFMIS: the Watershed Management Priority Indices (WMPI), the Forest Road Evaluation System (FRES) and the Harvest Schedule Review System (HSRS). WMPI helps users prioritize critical areas for restoration and conservation, while FRES evaluates road networks and their impacts on water quality and HSRS evaluates forest harvesting in relation to impacts on water quantity and quality. WFMIS also allows users to look at public and private properties to get a better picture of a full watershed's characteristics and needs.

Individual Tree Calculator Tools

If you're interested in the benefits of individual trees, there are a number of calculator tools designed to estimate the environmental services of singular trees.

- **i-Tree Design** is a simple, parcel-based tool that allows users to estimate the benefits of individual trees. By inputting the location, size, species and condition of an individual tree, an estimate of benefits is generated. Users can also forecast the tree's benefit into the future. i-Tree Design is a useful tool for homeowners and landowners looking to assess the value of trees on their property.

- **National Tree Benefit Calculator** is an online tool that allows users to calculate the value of a tree by entering a zip code or using the map feature.

- **The Center for Urban Research Tree Carbon Calculator** (CTCC) was developed in 2008 by the U.S. Forest Service as a resource for information on tree planting projects and their carbon dioxide sequestration. The CTCC format is an Excel spreadsheet that is based on 16 different climate zones in the U.S. For each zone, sequestration is determined based on an individual tree's species, size and age. Once a tree is selected and defined, the CTCC estimates how much carbon the tree has sequestered in a year and over its lifespan. It can also calculate a tree's

biomass potential. Based on proximity to buildings, a tree's energy-saving capabilities can also be calculated using CTCC.

Park Tools

For cities or organizations interested specifically in the benefits provided by their urban parks, The Trust for Public Land has developed two tools to measure the environmental services of public parks.

- **Park Value Calculator** (PVC) allows users to calculate the annual monetary value of city park systems. The calculator looks at seven elements of a park: property value, tourism, direct use, health, community cohesion, clean water and clean air. This tool has been used by park managers in several big cities to help inform park management and policies. The results from the calculator can also be used as an advocacy tool to ask for more parks funding at the local, regional and even national level.
- **ParkScore** uses geographic information system (GIS)-based data to measure park performance in the 40 largest U.S. cities and ranks them on a 0-100 scale. A city's rating is based on park acreage as a percentage of the total city, investment in park system per resident and accessibility for residents.

Management and Modeling Toolkits

If you're looking for tools to help develop an urban forests management plan or tools to help justify an urban forests management plan, there are a variety of helpful resources and toolkits available.

- **CommunityViz** is a geographic information system (GIS)-based modeling software that allows users to envision changes to their current landscape (such as new trees, shrubs, etc.) and understand the ecosystem service impacts associated with those alternatives. Users can create potential scenarios and are able to analyze impacts in a realistic 3-D setting.

- **The Urban Forest Management Plan Toolkit** is an online resource for users looking to develop a management plan for their urban forest. The website takes you through the steps of figuring out what elements should go into a management plan, like goals and objectives, what monitoring needs to be done and when, and what steps will help reach the desired goals.

- **The American Public Works Association Urban Forest Management Plan** provides detailed information and resources on public tree management. The plan outlines the main components of tree management, such as inventories, mapping software, tree advisory councils and cost-benefit analyses.

- **The Urban Forestry Modeling and Prioritization Toolkit**, by Azavea, is a suite of tools that allows users to model and map trees in urban areas. The suite accounts for factors such as heat island effect, air quality and stormwater. By digitally planting trees in the model, users can calculate the environmental impacts of the trees based on the planting location and management plan.
- **Urban Forest Cloud**, from Plan-It Geo, provides web-based modules and tools connecting urban tree canopy (UTC) data with goal setting, implementation and volunteers in a planning context.

- **Open Tree Map** is an open source tree inventory platform available online and as a smartphone application that enables users to add trees to a map and create an interactive and collaborative tree inventory and dynamic map of a city's trees. Cities like Philadelphia, San Francisco, Grand Rapids, Asheville and San Diego are already using Open Tree Map.

Mobile Apps

To make analysis and data collection of urban forests easier in the field, a few organizations have adapted their tools to mobile versions.

- **i-Tree Mobile** is a new data collection system that is available for i-Tree Streets and i-Tree Eco. This allows users to enter data from the field and take advantage of the GPS abilities of smartphones and tablets.
- **The Urban Forest Cloud** has a free mobile app that allows users to inventory trees in an easy-to-use webmap and export the data to an ESRI shapefile or MS Excel/Access file for use in other software applications. It serves as a tool for individuals without tree inventory software and as a supplemental, highly accessible tool for those with inventory software.
- **Tree Sense** is a mobile app from The Davey Tree Expert Company. The app allows users to quantify and qualify the benefits of trees, including air quality, electricity savings and stormwater reduction. Users can also figure out the best placement for future tree plantings in order to maximize their benefits.