Urban Forest Health Monitoring in the United States

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Abstract—*Trees in cities can contribute significantly to human health and environmental quality. Unfortunately, little is known about the urban forest resource and what it contributes to the local, regional, and national societal and economic interests. To help better understand the urban forest resource and its numerous values, the USDA Forest Service has initiated a pilot program to sample urban forests and street tree populations across various states. Pilot tests of monitoring the total tree population in urban areas have been or are being conducted in Indiana, Wisconsin, and New Jersey. Pilot tests of monitoring state-wide street tree populations have been conducted in Maryland, Wisconsin, and Massachusetts. Results from the pilot studies include information on urban forest population size and composition, health, potential risk from insects and disease, and various forest functions (for example, carbon storage, air pollution removal, building energy conservation) and values. Results from the pilot study in Indiana reveal that there are approximately 92.7 million urban trees ($55.7 billion structural value) and that these trees removed about 6,600 metric tons of air pollution in 2000 ($53.4 million value) and store about 8.4 million metric tons of carbon ($170.2 million value).These base values provide insight into urban forest structure, functions, and tree health to aid in urban forest planning and management. Through long-term monitoring of these plots, critical information can be obtained to assess how this resource is changing.*

Introduction

People are having an ever increasing impact on local, regional, and global environments. This impact is particularly significant in and around urban areas (for example, cities, towns, villages). Urban forests (trees in urban areas) can mitigate certain detrimental human impacts and improve environmental quality and human health. Urban forests can provide clean air and water, recreation, energy conservation, carbon storage, protection from ultraviolet radiation, cooler air temperatures, habitat for wildlife, forest-based products, and aesthetic values, and enhance the social and psychological well-being of millions of Americans. As a valuable national resource that will continue to increase in extent and importance in the years ahead, urban forests face many pressures (for example, insects, diseases, storms, and pollution) that can affect forest health and numerous related benefits.

In 1997, a National Research Council report titled "Forest Lands in Perspective" recognized that urban and community nonfederal forests are the fastest growing forests in the United States and recommended strengthening federal forest health monitoring of these forests. In 1998, USDA Forest Service Chief Michael Dombeck developed a Natural Resource Agenda that emphasized sustainable development of communities, and Deputy Chief Phil Janik released an action strategy for State and Private Forestry that would increase forest health monitoring in urban areas. In 1999, former USDA Secretary Dan Glickman noted "We still have plenty of work to do to make Americans take notice of the dwindling natural resource base in their cities" (Glickman 1999)

In a survey of forestry professionals regarding urban forest health needs, less than 25 percent of the respondents ranked the overall health of the urban forests in their state as good to excellent, 99 percent indicated that preserving the health of community forests should be an integral part of urban and community forest programs, and more than 90 percent identified long-term tree care and maintenance programs as critical to preserving the health and sustainability of urban forests in the Northeast (Pokorny 1998).

Although urban forests are a significant resource affecting the vast majority of the population, little is known about the nation's urban forests, how this resource is changing, or the factors that might lead to changes in urban forest structure and health. By knowing how the urban forest is changing, better policies can be developed to protect, sustain, and/or enhance urban forest health and benefits for future generations. In an attempt to learn more about this resource and to aid in its management and planning, various pilot studies were developed to test the application of a National Urban Forest Health Monitoring (UFHM) Program. This program is being designed to acquire information about the urban forest while concurrently establishing a nationwide system of urban forest pest detection and forest health monitoring (Nowak and others 2001). The program is a cooperative effort involving the United States Department of Agriculture's (USDA) Forest Service's Forest Health Monitoring Program, Urban and Community Forestry, Forest Inventory and Analysis, Northeastern Research Station, and state agencies.

As part of this program, two separate field sampling protocols were developed. One protocol is designed to assess the entire urban forest resource (known as Urban Forest Inventory); the second focuses specifically on the street tree resource (known as Statewide Urban Street Tree Monitoring). The purpose of this paper is to review the status of the UFHM program and provide results from the first Urban Forest Inventory pilot study in Indiana and the Statewide Urban Street Tree Monitoring pilots in Maryland and Massachusetts.

Urban Forest Inventory

Urban Forest Inventory seeks to extend the Forest Inventory and Analysis (FIA) sampling grid that is used to collect information about forests nationwide. FIA personnel are responsible for providing periodic assessments of the nation's forest resources and conducting statewide inventories. Currently data are only collected on "forested" plots, which are defined as areas that are at least 1 acre in size, at least 120 feet in width, at least 10 percent stocked, and the intended use is forest (in other words, not agriculture, urban, etc.). Thus, field data are not collected on "nonforest" plots (for example, urban areas), though many trees may be present on the plot. As most urban areas are classified as "nonforest," data on urban vegetation are not collected as part of this national forest inventory program. The urban forest inventory phase of the UFHM Program is designed to collect information on the FIA plots in urban areas and fill this critical "data gap."

Plots in urban areas are sampled using the FIA sampling grid (one plot every 6,000 acres). Boundaries of urban areas are based upon data from the U.S. Census Bureau and overlaid with the FIA grid. Plots falling within the urban boundaries that are classified as "nonforest" are included in the UFHM inventory. The plots are sampled during the growing season to collect an extended suite of ecological data including a full vegetation inventory and evaluation of tree damage and crown conditions, plus additional variables that were needed for conducting analyses using the Urban Forest Effects (UFORE) model (for example, percent crown missing, distance from building) (Nowak and Crane 2000). For the existing FIA forest plots in urban areas, data collected by FIA crews were used for analysis and combined with the new urban FHM plots. Recent research has shown that the cost of measuring non-forest plots is about 1/3 the cost of a forested FIA plot (Riemann 2003).

Pilot implementation of the inventory took place in Indiana in 2001 and 2002. The pilot, conducted by the Indiana Department of Natural Resources, was designed to extend the on-going FIA statewide inventory into urban areas. This extension resulted in 32 sample locations within urban boundaries (six of these sample locations met the FIA definition of "forested" and were not included in the urban pilot as data were already collected at these locations as part of the national FIA program). As the Indiana inventory was designed to be collected over a five-year period, only 1/5 of the total number of urban sample locations were collected the first year.

A second pilot took place in Wisconsin in 2002 and was conducted through the Wisconsin Department of Natural Resources. Using Census-defined urban areas, 119 urban plots were sampled (plus an additional 28 plots from FIA "forest" plots). All urban plots in Wisconsin were established and measured the first year. After the first year of complete data collection, the inventory was designed to monitor 1/5 of the plots every year so that all plots are updated every five years. A third inventory pilot was initiated in New Jersey in 2003.

Urban forest inventory plots conform to all standards of Forest Inventory and Analysis and the National Forest Health Monitoring programs. They consist of four 24-foot fixed-radius sub-plots spaced 120 feet apart. This particular plot layout, though useful in forested situations, has proven difficult within the urban setting. The distance between sub-plots often results in numerous property owner contacts to establish a plot. In Wisconsin, there was an average of five property owner contacts per plot, with a record 12 property owner contacts for one plot. Training of field crews included extensive manual review and field demonstrations of plot layout and tree measurements.

The FIA National Core Field Guide was modified to include urban data: urban land-use codes, plantable space, sub-plot tree cover, and ground cover and shrub information. An extended tree species code list has been incorporated. All trees one inch in diameter and larger are measured. This Urban Forest Field Guide is located at http://www.fs.fed.us/ne/syracuse/Tools/tools.htm.

Indiana Urban Forest Inventory

Within urban areas of Indiana there are an estimated 92.7 million trees (standard error (SE) =32.8 million). Of these trees, approximately 49.1 million (SE=26.8 million) are found in forests in urban areas and the remaining 43.6 million (SE=19.1 million) in other urban land uses (for example, residential, vacant, commercial – industrial). The most common tree species overall were sassafras (15.1 percent), silver maple (14.6 percent), and eastern cottonwood (10.9 percent). In forest areas, sassafras (28.6 percent), northern red oak (15.8 percent), and white oak (11.0 percent) dominated; on other urban lands, silver maple (24.5 percent), eastern cottonwood (18.2 percent), and Siberian elm (9.5 percent) were the most common. Overall tree cover in the urban forest is estimated at 20 percent. Most of the trees in the total urban forest are small with diameters less than 3 inches (fig. 1).

The species that dominates in terms of basal area (which is related to tree size and functional value) is silver maple. Trees that are relatively small (that is, percent basal area much less than percent of total population) in this population are sassafras, eastern cottonwood, American basswood, and boxelder (fig. 2). Species that are not native to the state comprise about 7 to 14 percent of the urban forest stands, and about 18 to 20 percent of the remaining urban lands.

While trees cover approximately 20 percent of Indiana's urban area, shrubs cover about 8 percent. Other cover types include herbaceous cover (for example, grass, gardens) (46 percent), impervious surfaces, including buildings (28 percent), duff, mulch and bare soil (24 percent), and water (2 percent). Ground cover in forested stands is dominated by duff/mulch, while the other urban lands are dominated by herbaceous ground cover.

Urban forests have a structural value based on the tree resource itself (for example, the cost having to replace the tree with a similar tree), and annually produce functional values (either positive or negative) based on the functions the tree performs. The structural or compensatory value (Nowak and others 2002) of Indiana's urban forest is approximately $56 billion dollars.

Urban trees in Indiana removed an estimated 6,600 metric tons of pollution per year, with an associated value of about $35.4 million dollars (based on estimated national median external costs associated with air pollution). Pollution removal was greatest for ozone (O3), followed by particulate matter less than 10 microns (PM10), sulfur dioxide (SO2), nitrogen dioxide (NO2) and carbon monoxide (CO) (fig. 3).

Urban trees in Indiana are estimated to store 8.4 million metric tons of carbon ($170.2 million value). Of all the species sampled, silver maples store the most carbon (approximately 32 percent of carbon stored). Urban trees are also estimated to sequester about 280,000 metric tons of carbon annually ($5.7 million/year).

Urban trees in Indiana are estimated to save homeowners $14.7 million annually by reducing MWh of energy consumed, but increase costs by $20.8 million annually due to increased MBtu usage to heat buildings in winter due to tree shade from branches. The net effect of the current structure is an annual cost of $6.1 million dollars. Even though costs go up, Indiana's urban forest helps to reduce about 23,600 metric tons of carbon emissions from power plants due to energy conservation from trees. This disparity is due to the difference between cost and carbon production involving the

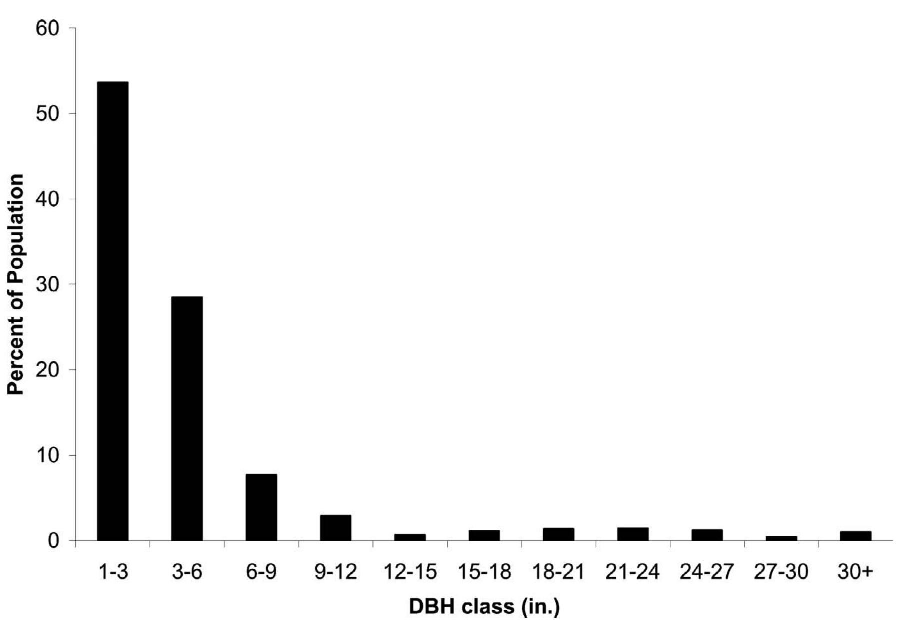

Fig. 1. Tree diameter distribution of Indiana's urban forest.

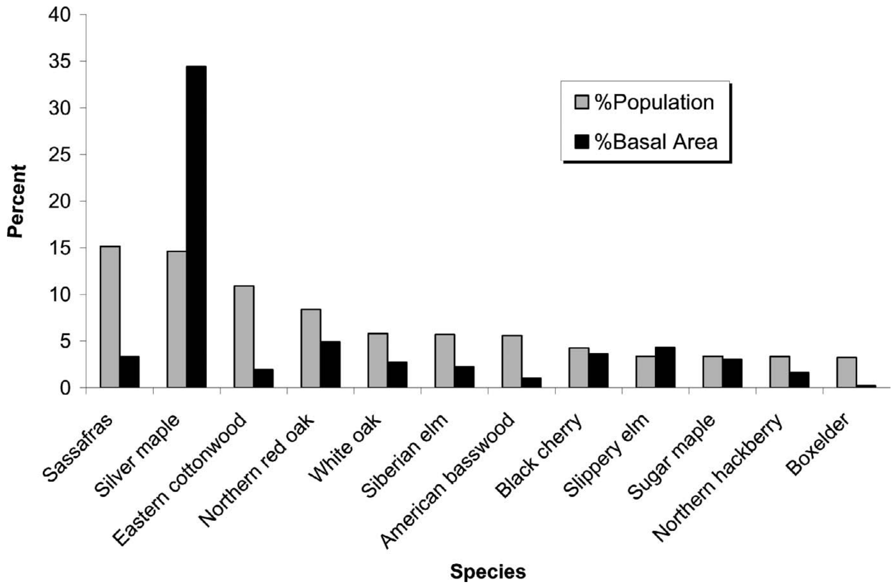

Fig. 2. Percent of population and percent basal area of 12 most common tree species in Indiana's urban forest.

winter and summer season energy use. As tree location around buildings and tree size are key determinants of energy effects, the small sample size compounded with relatively few trees in energy effect positions, means the results of this analysis are highly uncertain.

Exotic pests can also have a significant influence on Indiana's urban forest. The Asian long-horned beetle (ALB) is an insect that bores into and kills a wide range of hardwood species (USDA Forest Service 2004a). The risk of ALB to Indiana's urban forest is a loss of $30.3 billion dollars in structural value (57.8 percent of the population). The gypsy moth is a defoliator that feeds on a wide variety of tree species and can cause widespread defoliation and tree death if outbreak conditions last several years (USDA Forest Service 2004b). The risk of this pest is a loss of $9.0 billion dollars in structural value (22.7 percent of the population) in Indiana. The risk of the emerald ash borer, an insect that has killed thousands of ash trees in Michigan and Ohio (USDA Forest Service 2004c), is a structural value loss of $4.5 billion dollars (2.3 percent of the population) in Indiana.

The overall pilot test was based on 32 plots, which is a relatively small sample size. Increased sample size with future sampling will lead to increased confidence in the analyses.

Statewide Urban Street Tree Monitoring

Statewide Urban Street Tree Monitoring seeks to implement a statewide street tree assessment using plots established within the public right-of-way in urban areas. Though street trees represent only a small portion of the urban forest (approximately 5 to 10 percent), they are the trees that municipal foresters are responsible for and are often the most visible component of the urban forest. A street tree monitoring system provides information about the nature and condition of the street tree population and can be used for detection of new or exotic insect or pathogen problems. Like urban forest inventory plots, the street tree plots are to be continually updated to provide information on change in street tree populations.

Statewide street tree monitoring is based upon urban areas as defined U.S. Census Bureau boundaries. Sample locations are randomly located in urban areas in the right-of-way along public roads. The statewide sample consists of 300 plots. In year one, all 300 plots are installed, and this becomes the baseline sample. In subsequent years, a sub-sample of plots is revisited to allow for assessments of change.

A state may choose to intensify the baseline sample. Baseline intensification was done in Wisconsin in 2002, with 900 plots installed through the efforts of the Wisconsin Department of Natural Resources. The Massachusetts Division of Forests and Parks (2002) and Maryland Department of Agriculture (2001), each installed 300 baseline plots. In 2002, Maryland initiated the first revisit. Plots were revisited using a rotating panel design to get an estimate of year-to-year change in condition. A panel consists of one-fifth of the 300 baseline plots (60) along with a re-measurement of one-third of the previous year's plots (20 overlap plots) for a total of 80 plots per year.

Each plot consists of four sub-plots, two on each side of the roadway. Plots were installed within the public right-of-way so property owner contacts were not an issue. Each sub-plot is 181.5 feet in length and 10 feet in width (area equals the area of an urban forest inventory sub-plot). Instructions were provided for cul-de-sacs, dead-end roadways, and roadways with median strips. While not permanently set with monument markers, plot locations are identified by distance and azimuth to landmarks. Divided highways, private communities, interstate access ramps, and military installations were excluded from the sample location selection. Plot locations were provided to the State along with replacement plot locations in case the original plots could not be accessed (for example, plots with dangerous access or located in private or gated communities).

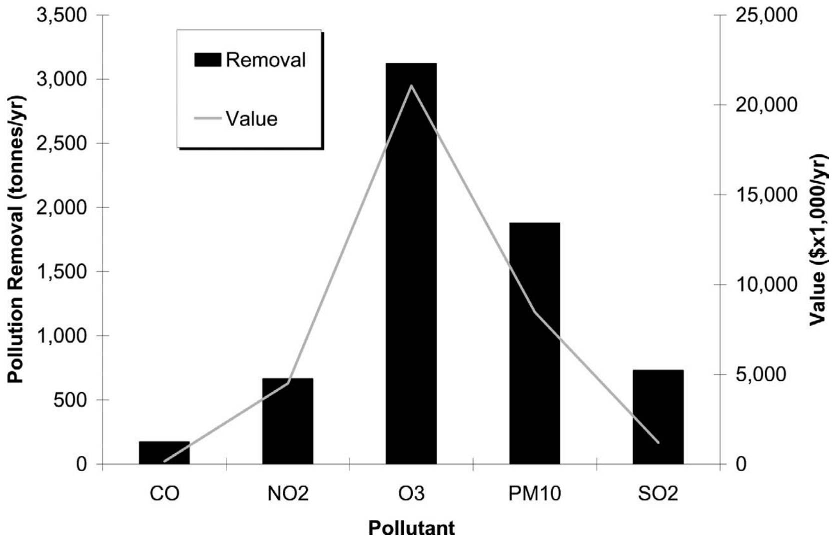

Fig. 3. Estimated pollution removal (2000) by Indiana's urban forest. Removal value estimated using median externality values in United States for each pollutant: nitrogen dioxide (NO2) = $6,750 t-1, particulate matter < 10 microns (PM10) = $4,500 t-1, sulfur dioxide (SO2) = $1,650 t-1, carbon dioxide (CO) = $950 t-1 (Murray et al.1994). Externality values for O3 were set equal to those for NO2.

A street tree data collection manual has been developed and includes information on plot location guidelines, plot establishment procedures, and data collection. All trees 1 inch in diameter and larger are tallied. Data includes tree diameter and height, crown condition, and damage. Ground cover types on the plot are also estimated. Sidewalk conflicts and utilities information are recorded. Training was conducted for all field crews. Training included a review of the field manual and in-field plot establishment procedures.

Street Tree Monitoring in Maryland and Massachusetts

There are an estimated 643,958 trees along Maryland's 14,139 miles of urban roadway (approximately 46 trees/mile). In Massachusetts, the 20,384 miles of urban roads are lined with an estimated 1,184,776 trees (58 trees/mile).

In Maryland, the street tree population contained 67 different species, none comprising more than 13 percent of the total population (table 1). Species diversity at the genus level showed 32 different genera, with over 70 percent of the trees falling into only five genera (Acer, Pyrus, Quercus, Prunus, and Platanus).

In Massachusetts, Norway maple clearly dominates the population, with more than 34 percent of all 66 species encountered (table 2). Massachusetts street trees are represented by 29 different genera, with over 50 percent of all trees falling into only two: Acer and Quercus.

Overall, the street population in both states is dominated by maples with nearly 50 percent of the trees in Massachusetts and 40 percent of the trees in Maryland being Norway, Sugar, Red, Silver, or other maple species. This distribution has implications for insect or disease infestations that could cause significant losses in street tree populations. An example is the recently introduced Asian long-horned beetle, which is known to attack and kill at least six species of maple. Other potentially significant pests are the gypsy moth, which could have a significant impact on oaks; Emerald ash borer, which could kill many ash trees, and Dutch elm disease, which has been killing elm trees.

Available planting space was determined by factoring an accepted planting space between trees (50 feet), knowing what proportion of the roadways do not currently have street trees, and taking into consideration trees adjacent

Table 1. Ten most frequent species found on Maryland's urban roadways

Species	Percent of total	Mean DBH (inches)
Callery pear	13	9
Red maple	11	13
Maple spp.	10	10
Norway maple	6	11
Silver maple	5	13
Cherry Plum	3	6
Oak spp.	3	16
Crabapple	3	10
Honey locust	3	12
Sweetgum	2	8

Table 2. Ten most frequent species found on Massachusetts' urban roadways

Species	Percent of total	Mean DBH (inches)
Norway maple	34	15
Red maple	9	12
Northern red oak	8	16
Callery pear	4	6
Pitch pine	4	8
White ash	3	19
Black oak	3	9
White oak	3	15
Sugar maple	3	18
Silver maple	3	25

to the public right of way whose crowns overlap the right of way and essentially function as street trees. In Maryland, there are an estimated 23 plantable spaces/mile of urban roadway, and 20 spaces/mile in Massachusetts. In Maryland, the planting potential spaces would almost double the number of street trees, while in Massachusetts, planting available spaces would increase the street tree total by roughly 30 percent. However, this potential planting space estimate is liberal as it includes the amount of hardscape including driveways, sidewalks, and other impervious surfaces that may limit tree planting.

Tree size distribution as reflected by diameter class distribution indicates that street tree populations in Maryland are relatively well distributed with the largest proportion of trees falling within the five to 15 inch diameter classes. In Massachusetts, larger trees (15 inches and greater in diameter) constitute about 50 percent of the total, indicating a somewhat older or maturing street tree population. While large street trees are aesthetically pleasing in terms of how they shade the roadway and sidewalk, they often can present additional management needs such as pruning or sidewalks and overhead wire interference. The relatively mature street tree population in Massachusetts had a higher incidence of sidewalk conflicts (28 vs. 18 percent) and overhead wire conflicts (25 vs. 18 percent) than the Maryland street tree population.

In Maryland, 64 percent of the trees did not have damage that met the minimum threshold for recording, compared to 71 percent in Massachusetts. In Maryland, the most common damage recorded was open wounds (16 percent of damage recorded); in Massachusetts it was conks and signs of advanced decay (17 percent).

Street tree monitoring results, particularly long-term monitoring results that will reveal rates of change, can provide useful information to the state to sustain the street population and benefits, and minimize liability.

Conclusion

The National Urban Forest Health Monitoring Program is developing protocols for national urban forest data collection. Pilot studies in various states are revealing new information about urban forests at the state level, as well as allow for improvements in the National Urban Forest Health Monitoring and Urban and Community Forestry programs. It is hoped that an Urban Forest Health Monitoring Program will be established nationwide in the upcoming years after the pilot program develops and tests the most appropriate procedures and methods of reporting results.

National urban forest monitoring can provide critical information for improving urban forest health, management, and benefits across the country. Though the type of information provided by UFHM plots can be used immediately to aid in management and planning, increased value will be derived after the plots have been re-measured. A long-term tree and forest monitoring effort in urban areas provides essential information on rates of change, as well as a means to detect and monitor the spread and range of numerous tree health-related factors (for example, spread and damage associated with the introduction of exotic pests). By knowing how the urban forest is changing, better policies can be developed to protect, sustain, and/or enhance urban forest health and benefits for future generations.

Acknowledgments

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