Urban Forest Health Monitoring in the United States

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Abstract.—To better understand the urban forest resource and its numerous values, the U.S. Department of Agriculture Forest Service has initiated a pilot program to sample the urban tree population in Indiana, Wisconsin, and New Jersey and statewide urban street tree populations in Maryland, Wisconsin, and Massachusetts. Results from the pilot study in Indiana revealed that about 92.7 million urban trees exist with a structural value of $55.7 billion. These trees removed about 6,600 metric tons of air pollution in 2000 ($35.4 million value) and store about 8.4 million metric tons of carbon ($170.2 million value).

People are having an ever-increasing impact on local, regional, and global environments, particularly in and around urban areas (cities, towns, villages). Urban forests (trees in urban areas) can mitigate certain detrimental human impacts and improve environmental quality and human health. Urban forests help provide clean air and water, reduce building energy use, store carbon, protect against ultraviolet radiation, and cool air temperatures. They also provide forest-based products, recreation opportunities, habitat for wildlife, aesthetic enjoyment, and enhance the social and psychological well-being of millions of Americans. This valuable national resource will continue to increase in extent and importance in the years ahead, yet faces numerous pressures such as insects, diseases, storms, and pollution that affect forest health and related benefits.

In 1997, a National Research Council report, "Forest Lands in Perspective," recognized that urban and community non-Federal forests are the fastest growing forests in the United States. It recommended strengthening Federal monitoring of the health 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, 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."

In a survey of forestry professionals regarding the health needs of urban forests, 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 affect the vast majority of Americans, little is known about them, how they are changing, or the factors that might lead to changes in the structure and health of this valuable resource. Knowing how the urban forest is changing can aid in developing more effective policies for protecting, sustaining, and otherwise enhancing the health of and benefits derived from this resource for future generations. To learn more about urban forests and aid in their management and planning, pilot studies were conducted to evaluate the implementation of

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a national Urban Forest Health Monitoring (UFHM) program. The purpose of this program is to acquire information about the urban forest while concurrently establishing a nationwide system of pest detection and health monitoring in urban forests (Nowak *et al.* 2001). The UFHM program is a cooperative effort among the USDA Forest Service's Forest Health Monitoring program, Urban and Community Forestry, Forest Inventory and Analysis (FIA), Northeastern Research Station, and State agencies.

As part of this program, two field sampling protocols were developed. The first is designed to assess the entire urban forest resource (Urban Forest Inventory); the second focuses on the street tree resource (Statewide Urban Street Tree Monitoring). This article reviews the status of the UFHM program and reports results from the first Urban Forest Inventory pilot study in Indiana and the Statewide Urban Street Tree Monitoring pilot studies in Maryland and Massachusetts.

Urban Forest Inventory

Urban Forest Inventory uses the FIA sampling grid that was designed to collect information about forests nationwide. FIA is responsible for periodic assessments of the Nation's forest resources as well as statewide inventories. Currently data are collected only on "forested" plots, defined as areas at least 1 acre in size and at least 120 feet wide, at least 10-percent stocked, and not intended for uses other than forest. Thus, field data are not collected on "nonforest" plots, such as urban areas, even though such plots might contain many trees. As most urban areas are classified as nonforest, data on urban vegetation are often not collected as part of the national FIA program. The urban forest inventory phase of the UFHM program is designed to collect data on FIA plots in urban areas to fill this critical "data gap."

The FIA grid was used to sample plots in urban areas (1 plot for every 6,000 acres). Boundaries of urban areas are based on data from the U.S. Census Bureau and overlaid on the FIA grid. Plots within the urban boundaries classified as nonforest are included in the UFHM inventory. Urban nonforest plots are sampled during the growing season to provide an extended suite of ecological data that includes a full vegetation inventory and evaluation of tree damage and crown conditions, and information on variables needed for analyses using the Urban Forest Effects model (e.g., percent crown missing, distance from building) (Nowak and Crane 2000). For a complete urban analysis, data from existing FIA forest plots in urban areas were combined with the new nonforest UFHM plots. Riemann (2003) found that the cost of measuring urban nonforest plots is about one-third of that for a forested FIA plot.

Pilot implementation of the inventory in Indiana, conducted in 2001 and 2002 by the Indiana Department of Natural Resources, was designed to extend the ongoing FIA statewide inventory into urban areas. This extension resulted in 32 sample locations within urban boundaries (six locations met the FIA definition of forested and were excluded as data already existed at these locations as part of the national FIA program). Because the Indiana inventory was designed to be completed (all plots) over a 5-year period, only one-fifth of the total number of urban sample locations were collected during the first year.

A second pilot study in Wisconsin in 2002 was conducted in cooperation with the Wisconsin Department of Natural Resources. In all, 119 urban nonforest plots were sampled (plus 28 previously measured FIA forest plots in urban areas). All urban nonforest plots in Wisconsin (1 plot every 6,000 acres) were established and measured in the first year. After the first year of complete data collection, the inventory was designed to monitor one-fifth of the plots each year so that all plots are updated in 5 years. A third inventory pilot was initiated in New Jersey in 2003.

Urban forest inventory plots consist of four 24-foot, fixed-radius subplots spaced 120 feet apart. This particular plot layout, although useful in forested situations, has proven more difficult in urban settings. The distance between subplots often results in numerous contacts with property owners to establish a plot. In Wisconsin, an average of five owner contacts was made per plot, and 12 owner contacts were recorded for a single plot. Training of field crews included extensive manual review and field demonstrations of plot layout and tree measurements. Plot remeasurements and checks were conducted to maintain data quality.

The FIA National Core Field Guide was modified for urban nonforest data collection to include urban land-use codes; plantable space; and subplot tree, shrub, and ground cover information. An extended tree species code list has been incorporated, and all trees 1 inch and larger in diameter on urban nonforest plots are measured. An urban FIA field guide can be accessed at http://www.fs.fed.us/ne/syracuse/Tools/tools.htm.

Indiana Urban Forest Inventory

Within the urban areas of Indiana are an estimated 92.7 million trees (standard error [SE] = 32.8 million). Of these trees, about 49.1 million (SE = 26.8 million) are in forests in urban areas; the remaining 43.6 million (SE = 19.1 million) are in other urban uses (e.g., residential, vacant, and commercial/industrial). The most common tree species 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. Most trees in the total urban forest are small (less than 3 inches in diameter) (fig. 1).

Silver maple is the dominant species in basal area, which is related to tree size and functional value. Trees that are relatively small (percent basal area much less than percent total population) include sassafras, eastern cottonwood, American basswood, and boxelder (fig. 2). Species that are not native to Indiana make up 7 to 14 percent of the urban forest stands and 18 to 20 percent of the remaining nonforest urban lands.

Trees cover about 20 percent of Indiana's urban area versus about 8 percent for shrubs. Other cover types include herbaceous cover (e.g., grass and 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 other urban lands are dominated by herbaceous ground cover.

Urban forests have a structural value based on the tree resource itself (e.g., the cost of replacing the tree with a similar one), and annually produce positive or negative functional values based on functions performed by the tree. The structural or compensatory value (Nowak *et al.* 2002) of Indiana's urban forest is nearly $56 billion.

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

Figure 1.—*Diameter distribution of trees in Indiana's urban forest.*

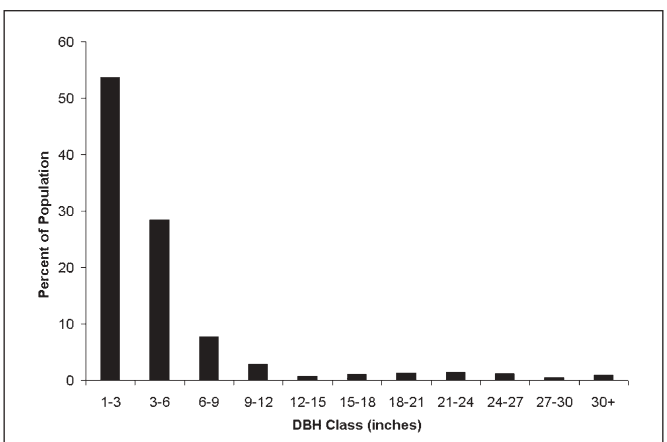


Figure 2.—*Percentage of population and percentage of basal area for the 12 most common tree species in Indiana's urban forest.*

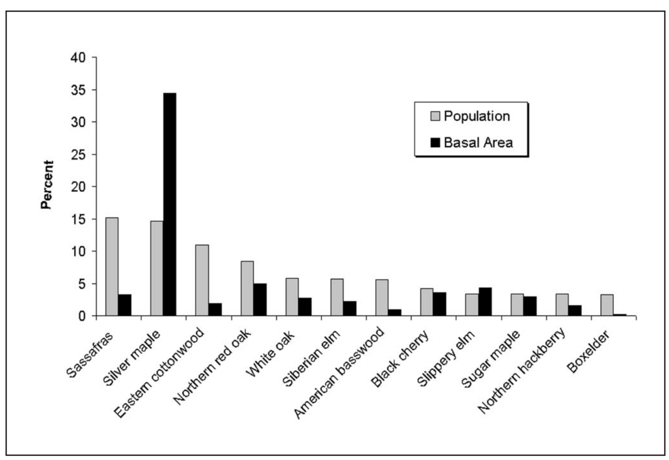
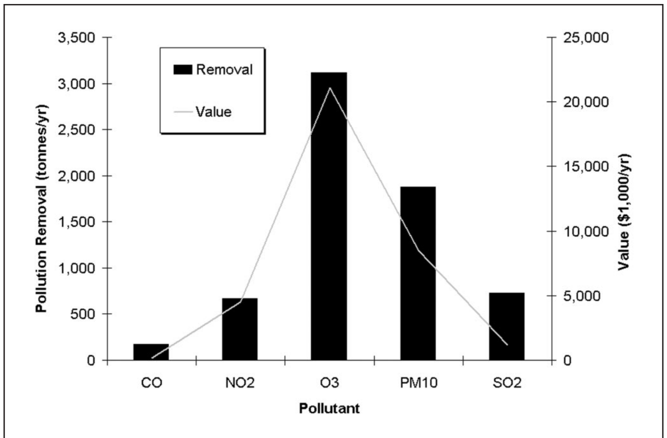


Figure 3.—*Estimated pollution removal (2000) by Indiana's urban forest. Removal value estimated using median externality values in the United States for each pollutant: nitrogen dioxide* (NO_2) *= $6,750 t*$^{-1}$*, particulate matter < 10 microns (PM10) = $4,500 t*$^{-1}$*, sulfur dioxide (SO2) = $1,650 t*$^{-1}$*, carbon dioxide (CO) = $950 t*$^{-1}$ *(Murray et al. 1994). Externality values for* O_3 *were set to equal those for* NO_2.



Urban trees in Indiana store an estimated 8.4 million metric tons of carbon ($170.2 million value). Of the species sampled, silver maple stores the most carbon (about 32 percent of all carbon stored). Urban trees sequester an estimated 280,000 metric tons of carbon annually ($5.7 million).

Urban trees in Indiana save homeowners an estimated $14.7 million annually by reducing electricity energy consumption. However, tree shade from branches increases costs by $20.8 million annually due to increased fuel usage to heat buildings in the winter. The net effect of the current structure is an annual cost of $6.1 million. Although costs go up, Indiana's urban forest reduces carbon emissions from power plants by nearly 23,600 metric tons. This disparity is due to the difference between cost and carbon production involving energy use in winter and summer. Because tree location around buildings and tree size are key determinants of energy effects, the small sample size combined with relatively few trees in energy effect positions means the results of this analysis are highly uncertain.

Exotic pests also can have a significant influence on Indiana's urban forest. The Asian longhorned beetle (ALB) bores into and kills a wide range of hardwood species (USDA Forest Service 2004a). The risk from ALB to Indiana's urban forest is a loss of $30.3 billion in structural value (57.8 percent of the population). The gypsy moth feeds on a variety of tree species and can cause widespread defoliation and mortality if outbreak conditions last for several years (USDA Forest Service 2004b). The risk from this pest in Indiana is a loss of $9.0 billion in structural value (22.7 percent of population). The risk from the emerald ash borer, which has killed thousands of ash trees in Michigan, Ohio and Indiana (USDA Forest Service 2004c), is $2.9 billion in structural value (1.9 percent of population).

The overall pilot test was based on 32 plots, which is a relatively small sample. Increased sample size with future measurements will increase confidence in the results.

Statewide Urban Street Tree Monitoring

Statewide Urban Street Tree Monitoring assesses street trees using plots established randomly in the public right-of-way in urban areas. Although they account for a small portion of the urban forest (approximately 5 to 10 percent), street trees are the resource that municipal foresters are responsible for and often are the most visible component of the urban forest. A monitoring system provides data on the nature and condition of the street tree population and can be used to detect new or exotic insects or pathogens. Like urban forest inventory plots, street tree plots are updated continually to provide data on changes in tree populations.

The statewide sample consists of 300 street tree plots. In the first year, all 300 plots are installed; this becomes the baseline sample. In subsequent years, a subsample of plots is revisited to allow for assessments of change. A State may choose to intensify the baseline sample. This intensification was done in Wisconsin in 2002 when 900 plots were installed by 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, in Maryland, plots were revisited using a rotating panel design to obtain an estimate of year-to-year change in condition. A panel consists of one-fifth of the 300 baseline plots along with a remeasurement 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 subplots, 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 subplot is 181.5 feet long and 10 feet wide (area equals the area of an urban forest inventory subplot). Instructions were provided for cul-de-sacs, dead-end roadways, and roads with median strips. Although not set permanently 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 as sample locations. Plot locations were provided to State personnel along with replacement locations if the original plots could not be accessed (e.g., plots with dangerous access or located in private or gated communities).

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

Street Tree Monitoring in Maryland and Massachusetts

An estimated 643,958 trees exist along Maryland's 14,139 miles of urban roadway (about 46 trees per mile). The 20,384 miles of urban roads in Massachusetts are lined with an estimated 1,184,776 trees (58 trees per mile). In Maryland, the street tree population comprises 67 different species, none making up more than 13 percent of the total population (table 1). Species diversity at the genus level shows 32 different genera, with more than 70 percent of the trees among only five genera (*Acer*, *Pyrus*, *Quercus*, *Prunus*, and *Platanus*). In Massachusetts, Norway maple clearly dominates, accounting for nearly 35 percent of the 66 species encountered (table 2). Massachusetts street trees are represented by 29 different genera, with more than half of all trees either *Acer* or *Quercus*.

The street population in both States is dominated by maples; nearly half of the trees in Massachusetts and 40 percent of the trees in Maryland are Norway, sugar, red, silver, or other maples. This distribution has implications for insect or disease infestations that could cause significant losses in street trees. An example is the recently introduced ALB, which attacks and kills at least six species of maple. Other potentially significant pests or diseases are the gypsy moth, which could have a significant impact on oaks, the emerald ash borer, and sudden oak death.

Available planting space was determined by factoring an accepted planting space (50 feet) between trees, knowing the proportion of roadways that lack street trees, and considering trees whose crowns overlap the public right-of-way and essentially function as street trees. In Maryland, an estimated 23 plantable spaces exist per mile of urban roadway, and 20 such spaces exist per mile in Massachusetts. Planting potential spaces would nearly double the number of street trees in Maryland but increase

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

Species	Percent of total	Mean diameter at breast height (d.b.h.) (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
Honeylocust	3	12
Sweetgum	2	8

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

Species	Percent of total	Mean d.b.h. (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

street trees only about 30 percent in Massachusetts. However, this estimate of potential planting space includes hardscape such as driveways, sidewalks, and other impervious surfaces that could limit tree planting.

Distribution of tree size as reflected by diameter class indicates that street tree populations in Maryland are relatively well distributed; the largest proportion of trees is in the 5- to 15-inch diameter classes. In Massachusetts, larger trees (15 inches and larger in diameter) account for about half of the total, indicating a somewhat older or maturing street tree population. Large street trees are often aesthetically pleasing, but frequently require additional management (e.g., pruning due to interference with sidewalks or overhead wires, or for public safety). Compared to street trees in Maryland, those in Massachusetts had a higher incidence of conflicts involving sidewalks (28 versus 18 percent) and overhead wires (25 versus 18 percent). In Maryland, 64 percent of the trees did not meet the minimum threshold for recording damage compared to 71 percent in Massachusetts. In Maryland, the most common damage recorded was open wounds (16 percent of damage recorded); conks and signs of advanced decay were the most common in Massachusetts (17 percent). Street tree monitoring, particularly in the long term, can provide useful information for sustaining populations, maximizing benefits, and minimizing liability.

Conclusion

National monitoring of urban forests can provide critical information for improving urban forest health, management, and benefits derived from this valuable resource. Although the information obtained from UFHM plots can be used immediately in management and planning, increased value will be derived after the plots have been remeasured. Long-term tree and forest monitoring in urban areas provides essential information on rates of change as well as a means for detecting and monitoring the spread and range of numerous tree health-related factors (e.g., spread and damage associated with the introduction of exotic pests). Knowing how the urban forest is changing can aid in developing more effective policies for protecting, sustaining, and otherwise enhancing our urban forests for future generations.

Acknowledgments

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