National Forest Health Monitoring Program

Monitoring Urban Forests in Indiana: Pilot Study 2002

Part 2: Statewide Estimates Using the UFORE Model

United States Department of Agriculture

Forest Service

Northeastern Area
State and Private Forestry
Newtown Square, PA

NA–FR–01–07

July 2007

NATIONAL FOREST HEALTH MONITORING PROGRAM

Monitoring Urban Forests in Indiana: Pilot Study 2002

Part 2: Statewide Estimates Using the UFORE Model

U.S. Department of Agriculture
Forest Service

Northeastern Area State and Private Forestry
11 Campus Boulevard, Suite 200
Newtown Square, PA 19073

NA–FR–01–07

July 2007

www.na.fs.fed.us

Preface

Trees in cities can improve environmental quality and human health. Unfortunately, little is known about the urban forest resource and what and how it contributes to local, regional, and national societies and economies. To better understand the urban forest resource and its value, the Forest Service, U.S. Department of Agriculture, Forest Health Monitoring Program initiated a pilot program to assess urban forests in several States. State urban forest functions and values were analyzed using the Urban Forest Effects (UFORE) Model (www.ufore.org, www.itreetools.org). Results from this report should be viewed as a demonstration of the value of collecting and analyzing urban forest data. These data can be used to advance understanding of urban forests and their management to improve human health and environmental quality in urban areas.

This report highlights the findings from the first statewide urban forest health monitoring pilot study conducted in the State of Indiana in 2002. Other pilots were subsequently established in Wisconsin, New Jersey, Tennessee, and Colorado. The report on Indiana's urban forests is in two parts. Part 1 summarizes analysis of the field methods and data collected on the urban nonforest plots of one panel in Indiana (Lake and others 2006). This report (Part 2) expands these field data to statewide urban forest estimates with the addition of data from Forest Inventory and Analysis forest plots within the urban boundary.

Authors

David J. Nowak,[1] Anne Buckelew Cumming,[2] Daniel B. Twardus,[3] Robert Hoehn,[4] and Manfred Mielke[5]

[1]Research Forester, Forest Service, Syracuse, NY
[2]Forester, Forest Service, Morgantown, WV
[3]Forest Health Group Leader, Forest Service, Morgantown, WV
[4]Research Forester, Forest Service, Syracuse, NY
[5]Forest Health Specialist, Forest Service, St. Paul, MN

Acknowledgments

In addition to the authors, Forest Service personnel involved in compiling this report included Jeffrey Walton and Daniel Crane of the Northern Research Station in Syracuse, NY, and the Information Management Analysis staff in the Morgantown, WV, Field Office.

We thank the following groups within the Forest Service for their support and funding of this project: the Forest Health Monitoring Program, Forest Inventory and Analysis, Northeastern Area State and Private Forestry, Northern and Southern Research Stations, and the Urban and Community Forestry Program. We also thank Robert Mangold, Borys Tkacz, Bill Smith, Dave Alerich, Bill Burkman, Mark Buscaino, and Ken Stolte. Thoughtful edits on the manuscript were provided by Chris Woodall, Phil Marshall, Keith Cline, and Jim Steinman.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The goal of the 2002 Indiana statewide urban forest health monitoring pilot study was to test the application of established methods of collecting forest plot data to urban areas and to illustrate what types of information could be derived from the data to aid urban forest management and planning. This report, based on a limited number of plots, is a demonstration of information that can be derived from these urban forest health monitoring field plots. Though the information in this report can be used now to aid in management and planning, increased value can be derived after the plots have been remeasured. 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 (e.g., spread and damage associated with the introduction of exotic pests).

The pilot test was based on 32 plots (one "panel"), which is a relatively small sample size, and the information given in this report should be considered preliminary. All trees within the urban boundary (both forest and nonforest lands) were measured using Forest Service Forest Health Monitoring protocols modified for urban areas and analyzed using the Forest Service UFORE (Urban Forest Effects) Model to quantify and describe the benefits of Indiana's urban forest (table 1).

Highlights of Indiana's Urban Forest

- Estimated number of trees in Indiana's urban areas: 92.7 million
- Percentage of Indiana's urban trees less than 3 inches in diameter: 53.6 percent
- Air pollution removed each year: 7,230 tons (savings = $35.4 million in mechanical removal costs)
- Carbon storage (total): 9.4 million tons (savings = $174 million in marginal social costs of carbon dioxide emissions)
- Carbon sequestration (annual): 313,000 tons (savings = $5.8 million in marginal social costs of carbon dioxide emissions)
- Effects of urban trees on building energy use (annual): savings of $2.3 million
- Total structural or compensatory value of Indiana's urban trees: $43.6 billion
- Percentage of Indiana's urban tree population at risk of mortality from invasive insects:
    - Asian longhorned beetle: 58.4 percent (valued at $29.1 billion)
    - Gypsy moth: 22.9 percent (valued at $4.0 billion)
    - Emerald ash borer: 2.3 percent (valued at $3.3 billion)

Table 1. Summary of Indiana's urban forest.

	Total urban	Urban nonforest	Urban FIA forest
Area (acres)	1,194,486	995,366	199,120
Estimated number of trees	92,725,000	43,642,000	49,083,000
Total biomass (tons of carbon)	9,428,000	6,035,000	3,393,000
Most common species (percent)	Sassafras (15.1) Silver maple (14.6) Eastern cottonwood (10.9) Northern red oak (8.4) White oak (5.8) Siberian elm (5.7) American basswood (5.6) Black cherry (4.3) Slippery elm (3.4) Sugar maple (3.4)	Silver maple (31.1) Eastern cottonwood (23.2) Siberian elm (12.1) Boxelder (6.8) Crabapple (3.2) Norway spruce (3.2) Eastern hemlock (2.6) Red mulberry (2.6) White ash (2.1) American elm (1.6) Red maple (1.6)	Sassafras (28.6) Northern red oak (15.8) White oak (11.0) American basswood (10.5) Black cherry (7.1) Northern hackberry (6.3) Slippery elm (5.9) Sugar maple (5.9) Tulip tree (1.6) White mulberry (1.6)

Definitions

Urban—Urban area in Indiana was delimited using the 1990 U.S. Census Bureau definition of urban. Urban areas consisted of (1) urbanized areas with a human population density of at least 1,000 people per square mile and (2) urban places defined as the urban portion of places with 2,500 people or more outside of the urbanized areas. In 2000, the census definition of urban changed; however, this study uses the 1990 definition because the study began prior to the definition change.

Urban FIA forest—An area within the urban boundary of at least 1 acre in size, at least 120 feet wide, at least 10 percent stocked with trees, and with an understory undisturbed by another nonforest land use. This definition of forest is used by the Forest Service Forest Inventory and Analysis (FIA) Program.

Urban forest—All trees within the urban boundary (both forest and nonforest lands).

Urban nonforest—The area within an urban boundary that does not meet the definition of urban FIA forest.

Urban Forest Effects (UFORE) Model—Developed by the Forest Service Northern Research Station, this model uses field data in conjunction with air pollution and meteorological inputs to quantify urban forest structure (species composition, tree density, tree health, leaf area, and biomass); environmental services (air pollution removal, carbon storage and sequestration, and effects of trees on energy use); and potential pest impacts.

INTRODUCTION

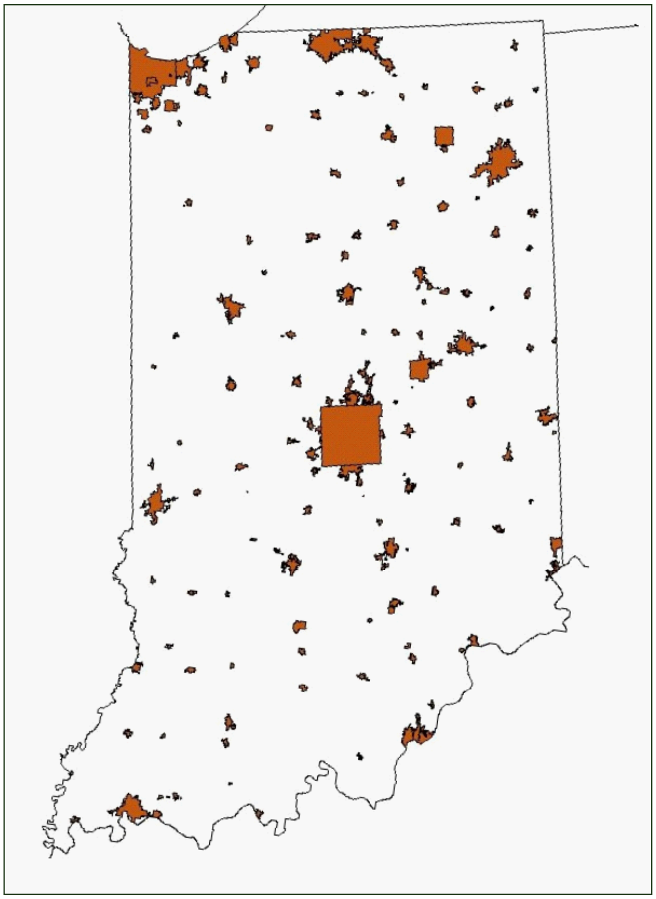
Urban forests provide a multitude of benefits to society, and millions of dollars are spent annually to maintain them, yet relatively little is known about this important resource. In an attempt to learn more about this resource and to aid in management and planning, a pilot test to apply a national forest health monitoring protocol was conducted. Based on standard Forest Service Forest Health Monitoring and Forest Inventory and Analysis field sampling protocols, the national plot inventory grid was used to sample urban areas within the State of Indiana.

Data from 32 field plots located throughout urban areas in Indiana were analyzed using the Forest Service Urban Forest Effects (UFORE) Model to quantify the State's urban forest structure, health, benefits, and values (Nowak and Crane 2000). These plots were located in a variety of land uses and were not limited to "street trees." This report details the findings of the analysis. The numbers in this report should not be viewed as definitive due to the small sample size. The pilot was developed to test the feasibility of various field data collection and reporting procedures, including UFORE analysis. This report reviews the types of information about urban forests that can be obtained and disseminated across the Nation at both the State and national scale if a full nationwide program of urban forest health monitoring is implemented.

A long-term urban forest health monitoring program can provide not only information on the structure, health, functions, and values of the urban forest that are critical to improving management and planning at the State, regional, and national level, but other essential information for sustaining urban forest productivity and health. Such a program can provide a means of detecting and monitoring the spread and impact of numerous insects and diseases that can, and are, affecting urban forests across the Nation (e.g., Asian longhorned beetle, emerald ash borer, and sudden oak death). In addition, long-term monitoring data will provide critical information on rates of change in the urban forest (e.g., Is the urban forest declining and at what rate? Which species perform the best in a region over the long term?). By knowing how the urban forest is changing, better policies can be developed to protect, sustain, and enhance urban forest health and benefits for future generations.

URBAN LAND, FOREST EXTENT, AND POPULATION

The 1990 census-defined urban land area in Indiana was estimated at 5.2 percent of the total land area (map 1). Nineteen percent of the State was classified as forest land during the FIA inventory that occurred closest to the 1990 census (4.4 million acres in 1986) (Hansen 1987). This amount of forest land remained stable between 1986 and 2000 (Schmidt and others 2002). In 2000, the U.S. Census Bureau modified its definition of urban, which resulted in an overall reduction of urban land area in the United States as an artifact of the definition (U.S. Census Bureau 2003). Based on the 2000 census definition of urban, the amount of urban land in Indiana was re-estimated to be 4.9 percent of the total land area in 1990 compared with 5.2 percent (1990 definition). Using the 2000 census estimates as a standard measure, urban land in Indiana increased from 4.9 percent in 1990 to 6.1 percent in 2000, ranking Indiana 14th in the United States for amount of urban land (Nowak and others 2005). Forecasts predict that urban land in the State will grow to 16.7 percent by 2050 (Nowak and Walton 2005). Urban land area is, of course, influenced by human population, which was 5.5 million in 1990 and increased 8.8 percent by 2000. Indiana's population is projected to continue to increase over the next three decades, with overall State population growth of 12 percent between 2000 and 2030 (U.S. Census Bureau 2006).



Map 1. Urban land in Indiana in 1990 (using the 1990 census definitions of urban).

METHODS

The Forest Service FIA Program annually assesses the Nation's forest resource on a statewide basis. Detailed tree measurements are collected on forest plots defined by the FIA Program as areas at least 1 acre in size, at least 120 feet wide, and at least 10 percent forested. Forested plots must also have an understory that is undisturbed by another land use (U.S. Department of Agriculture, Forest Service 2003). In 2001, the Forest Service Forest Health Monitoring Program initiated an assessment of urban forest conditions. This assessment collected tree information from plots established within delimited urban boundaries. Urban areas were classified based on the 1990 census and consisted of (1) urbanized areas with a population density of at least 1,000 people per square mile and (2) urban places defined as the urban portion of places with 2,500 people or more outside of the urbanized areas. Plots were measured regardless of whether the plot met the FIA definition of forest. Plots not meeting the FIA definition of forest are referred to as "urban nonforest."

FIA plots are measured on a panel system in which approximately one-fifth of all the plots within a State are measured in a given year. This pilot study utilized only one panel of plots (forest and nonforest) that fell within urban areas of Indiana. At total of 30 FIA plots landed within the urban nonforest area. Four of these plots were inaccessible and not measured. Thus, 26 permanent urban nonforest field plots were established and measured during the summer of 2002 (Lake and others 2006). These plots were combined with six urban FIA forest plots (already measured by FIA) (table 2). Within each urban nonforest plot, all trees greater than 1 inch in diameter at breast height (d.b.h., measured at 4.5 feet) were measured on four 1/24-acre subplots (figure 1). Within each urban FIA forest plot, all trees greater than 5 inches d.b.h. were measured on four 1/24-acre subplots, and trees 1 to 5 inches d.b.h. were measured on four 1/300-acre microplots.

Table 2. Urban FIA plots in Indiana, 2002.

Plot status	Number of plots
Urban nonforest	26
Urban FIA forest	6
Census-defined water	0
Denied access or problem plot	4
Total plots measured	32

For each urban nonforest plot, urban forest health monitoring data collection protocols were used for tree measurements. Urban forest health monitoring variables included species, diameter, height, height to live crown, crown dimensions, foliage transparency, tree damage, distance and direction of tree to buildings, ground cover, impervious surface in plot, condition class, and ownership. For existing urban FIA forested plots, standard data collected by FIA crews were used for analysis, and these data were combined with the additional urban nonforest plot data to assess the entire State urban forest.

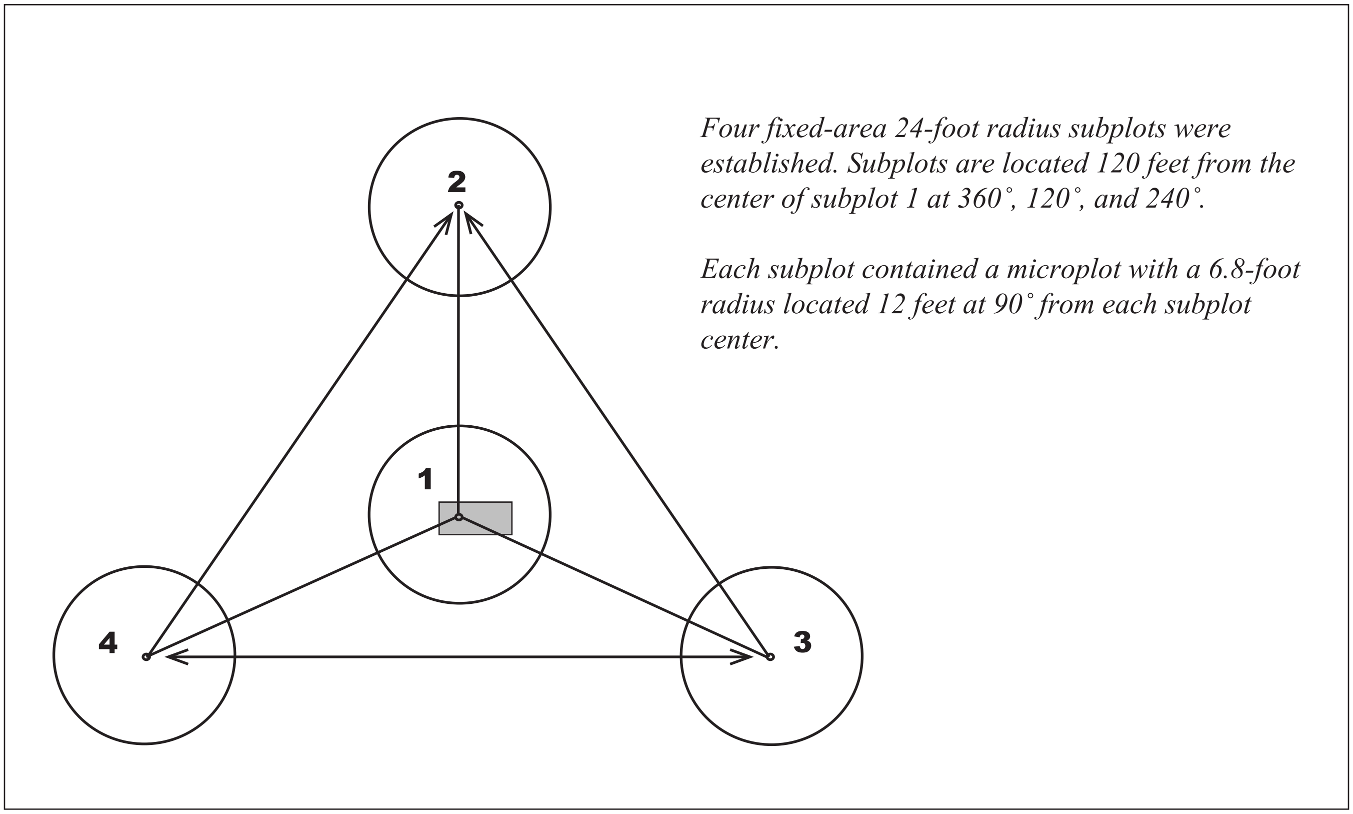


Figure 1. FIA plot configuration.

RESULTS

Structure and Composition

A total of 264 trees were sampled in the one panel surveyed in Indiana (table 3). Most plots were considered urban nonforest. There was an estimated average of 77.6 trees per acre and a total population of 92.7 million trees on all urban land in Indiana. Of these trees, approximatedly 49.1 million were in urban FIA forest areas and the remaining 43.6 were in other urban nonforest areas (table 1). A total of 35 species were sampled, the most common of which were sassafrass (15.1 percent), silver maple (14.6 percent), and eastern cottonwood (10.9 percent). However, sassafras was only found in urban FIA forested areas, and silver maple and eastern cottonwood were only found in urban nonforest areas. In urban FIA forest areas, sassafras (28.6 percent), northern red oak (15.8 percent), and white oak (11.0 percent) dominated; on urban nonforest lands, silver maple (31.1 percent), eastern cottonwood (23.2 percent), and Siberian elm (12.1 percent) were most common. Overall tree cover in the urban forest was estimated at 20 percent.

Most of the trees in the urban forest were small, with diameters less than 3 inches (53.6 percent) (figure 2). This "inverse-J" distribution of trees is a common occurrence in both naturally regenerating systems and in areas where new trees only occur through planting. In forest settings, many seedlings survive to sapling size, fewer survive to pole size, and the fewest grow to larger sizes, mainly due to limited resources (sun, nutrients, and water) and the influence of natural stressors (herbivory and competition, among others). In managed settings, trees are usually planted when they are manageable sizes (2- to 3-inch caliper) and large enough to withstand human stresses such as lawn mowers and vandals. Similar to natural settings, a small number of urban trees survive to larger sizes due to natural and the added anthropogenic stressors.

The species that dominated in terms of basal area in the whole urban forest is silver maple. In urban FIA forest areas, northern red oak, sassafras, and white ash dominated in terms of basal area, while in urban

Table 3. Summary of plot-level data.

	Total	Urban nonforest	Urban FIA forest
Number of living trees sampled	264	190	74
Average basal area (ft^2/acre)	24.6	20.2	46.7
Number of species	35	26	20
Estimated number of trees per acre	77.6	43.8	246.5

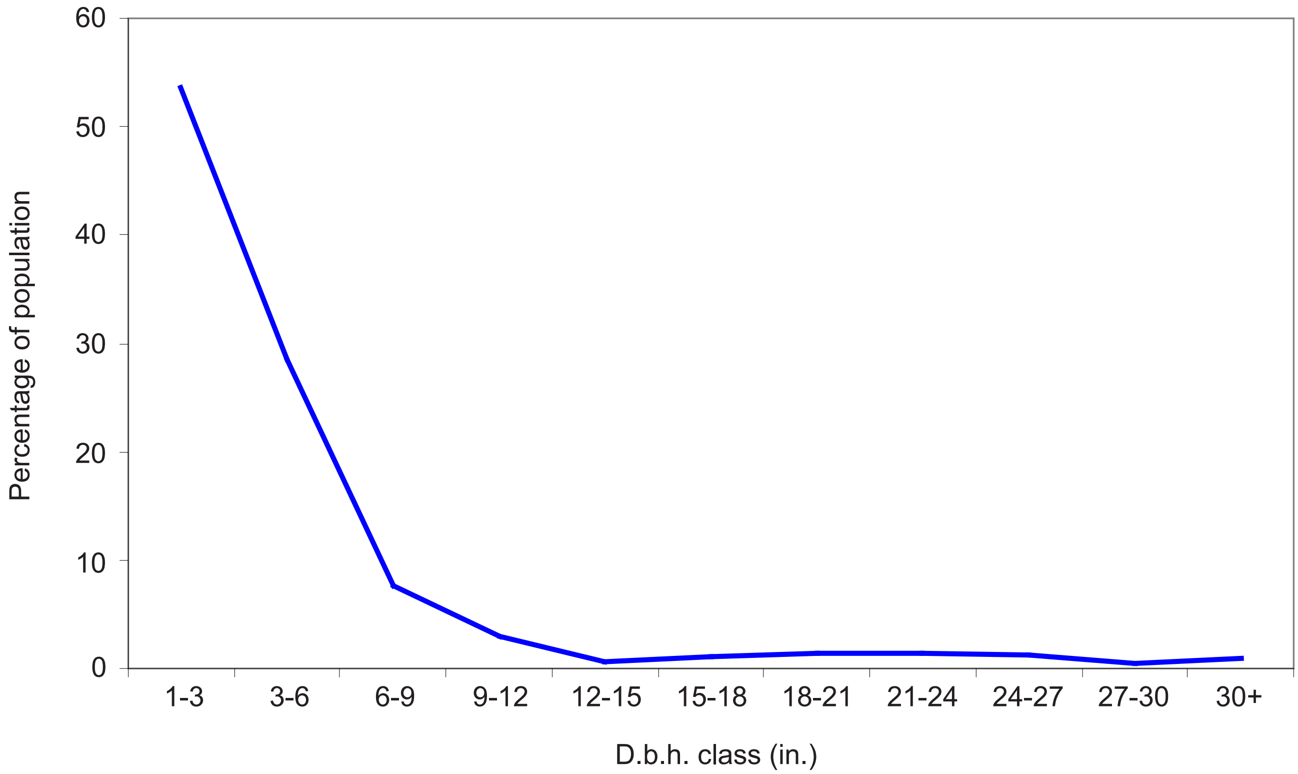


Figure 2. D.b.h. distribution of urban trees in Indiana.

nonforest areas, silver maple, red maple, and black walnut had the greatest basal area. Sassafras, eastern cottonwood, American basswood, and boxelder maple trees comprised a relatively small amount of basal area.

Nonnative species comprised about 12 percent of the urban forest—about 2 percent in urban FIA forest stands and about 22 percent of the remaining urban nonforest lands. Most exotic species originated in Asia.

Ground Cover

Trees covered approximately 20 percent of Indiana's urban areas and shrubs covered about 8 percent. Dominant ground cover types included herbaceous cover (e.g., grass, gardens) (46 percent); impervious surfaces, including buildings (28 percent); and duff, mulch, and bare soil (23 percent). Ground cover in urban FIA forested stands was assumed to be dominated by duff since these data are not a standard variable collected by FIA. In urban nonforest areas, where ground cover was measured, herbaceous ground cover dominated. Approximately one-half of Indiana's urban area is classified as pervious areas not filled with trees. This type of information can be used in conjunction with other data (e.g., land use, ownership, and zoning) to estimate available areas for potential tree planting.

Biomass/Carbon Cycle

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tree tissue and reducing energy use in buildings, consequently reducing carbon dioxide emissions from fossil-fuel-based power plants (Abdollahi and others 2000).

The rate at which a tree removes carbon from the atmosphere is called carbon sequestration. The amount or weight of carbon accumulated by a tree over its entire lifetime is considered carbon storage. Trees can reduce the amount of carbon in the atmosphere by providing a net increase in tree biomass every year. When new growth sequesters more carbon than is released during decomposition of biomass (old leaves and twigs, for example), the forest acts as a carbon sink. Healthy trees and forests are considered a significant sink of carbon within the carbon cycle. The amount of carbon sequestered annually is typically greatest in large healthy trees.

Carbon storage by Indiana's urban forest was estimated to be 9.4 million tons (table 4). The species that were estimated to sequester the most carbon annually are silver maple (34.5 percent of the total annual sequestration), red maple (9.2 percent), and black walnut (5.4 percent). Sequestration estimates are based on estimates of growth, which are partially dependent upon tree condition. Because no condition data were obtained in FIA forest plots, tree conditions there were assumed to be "fair" (average dieback between 11 and 25 percent).

Annual carbon sequestration by urban trees is valued at $5.8 million. To estimate the monetary value associated with urban tree carbon storage and sequestration, carbon values were multiplied by $20.30 per metric ton of carbon, based on the estimated marginal social costs of carbon dioxide emissions (Fankhauser 1994).

Heating and Cooling

Trees affect energy use in buildings by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy use in the summer and either increase or decrease building energy use in the winter depending upon their location around the building. Tree effects on building energy use were based on field measurements of tree distance and direction to residential buildings, climate zone, and building vintage (McPherson and Simpson 1999).

In Indiana, interactions between trees and buildings were projected to save homeowners $2.3 million annually, with most of the savings that occurred during the summer offset by increased energy use in the winter (figure 3). Of the 43.6 million nonforest urban trees, approximately 25.9 million trees (59 percent) are

Table 4. Carbon storage, carbon sequestration, and carbon avoided, by weight (in tons) and associated value, for Indiana's urban forest.

	Total	Urban nonforest	Urban FIA forest
Carbon storage (total)	9,428,000 $173.7 million	6,035,000 $111.2 million	3,393,000 $62.5 million
Carbon sequestration (annual)	313,000 $5.8 million	197,000 $3.6 million	116,000 $2.1 million
Carbon avoided (annual)	26,000 $480,000	26,000 $480,000	N/A

Carbon storage—total amount of carbon accumulated in tree structures.
Carbon sequestration—amount of carbon accumulated in tree structures annually.
Carbon avoided—annual reduction in the amount of carbon emitted by power-generating facilities due to the effect of trees on heating and cooling energy demands of buildings.

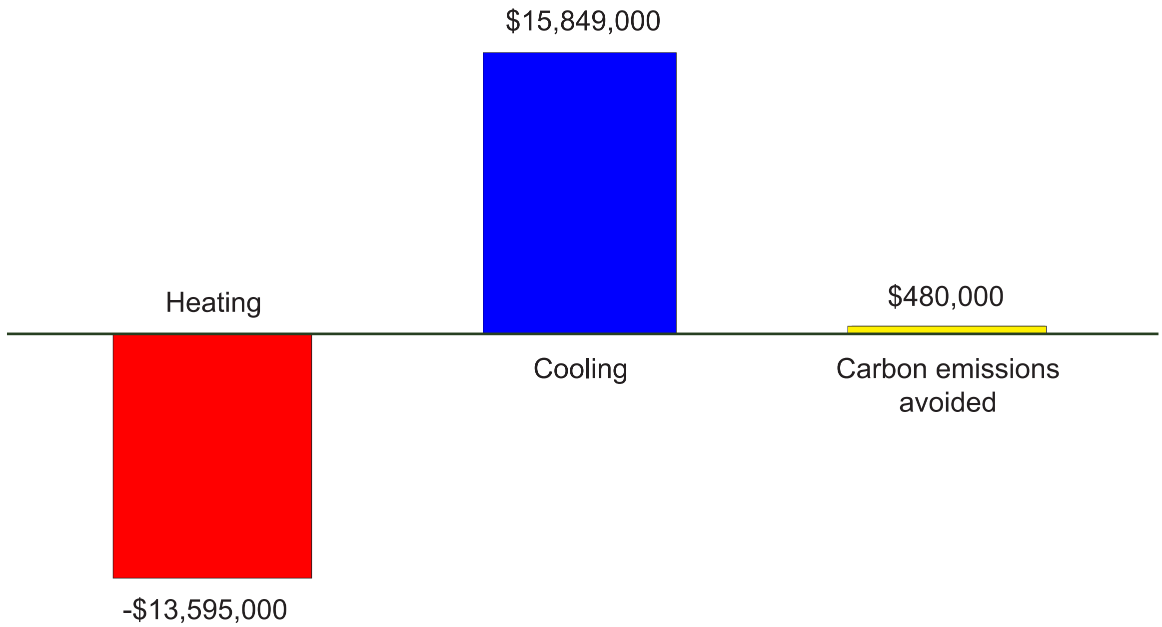


Figure 3. Estimated annual energy costs or savings and carbon emissions avoided due to nonforest urban trees in Indiana. Negative values indicate costs to building owners.

affecting energy use of residential buildings. Because of reduced building energy use, power plants will burn less fossil fuel and, therefore, release less carbon dioxide. Energy conservation due to trees reduced carbon emissions by about 26,000 tons per year in Indiana, with an estimated value of $480,000 per year.

The estimated net effect of the current urban forest structure is an annual energy savings of $2.3 million. However, the location of trees around buildings and tree size are key determinants of energy effects. The small sample size in this study, compounded with relatively few trees in energy-effective positions, means that the conclusions are uncertain.

Air Quality Improvement

Poor air quality is a common problem in urban areas that leads to health problems, ecosystem damage, and reduced visibility. The urban forest can improve air quality by reducing ambient air temperatures, removing pollutants directly from the air, and reducing energy use in buildings. However, trees emit volatile organic compounds (VOCs) that can contribute to ground-level ozone formation. Yet integrated studies have revealed that increasing tree cover will ultimately reduce ozone formation (Nowak 2005).

Pollution removal by Indiana's urban forest was estimated using hourly pollution data from all monitors in the State and weather data (Indianapolis) from the year 2000. Based on these inputs, the UFORE Model estimated that the urban forest in Indiana removes about 7,230 tons of pollution per year, with an associated annual value of about $35.4 million. The pollutant removal rate was greatest for ozone (O_3) followed by particulate matter less than 10 microns (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) (table 5).

Table 5. Annual pollution removal and value for Indiana's urban forest.

Pollutant	Amount removed by Indiana's urban forest (tons/year)	Value of removal ($1,000/year)
O_3	3,440	21,100
PM_{10}	2,070	8,460
NO_2	730	4,500
SO_2	800	1,210
CO	190	170

Value of the Urban Forest

Urban forests have a structural value based on the tree resource itself (e.g., the cost of having to replace the tree with a similar tree), and produce functional values annually based on the functions the tree performs. These annual values can be either positive (e.g., air pollution removal, reduced building energy use) or negative (volatile organic compound emissions, increased building energy use) depending upon species and tree location. In North America, the most widely used method for estimating the compensatory or structural value of trees was developed by the Council of Tree and Landscape Appraisers (CTLA 2000). Compensatory values represent compensation to owners for the loss of an individual tree. Compensatory values can be used for estimating compensation for tree losses, justifying and managing resources, and setting policies related to the management of urban trees. The CTLA compensatory value calculations used in this analysis are based on four tree and site characteristics: tree trunk area (cross-sectional area at 1.37 m above the ground), species, condition, and location (Nowak and others 2002).

The structural value of Indiana's urban forest was approximately $43.4 billion. Other functional values of the urban forest included carbon storage ($174 million), annual carbon sequestration ($5.8 million), annual pollution removal ($35.4 million), and annual building energy reduction ($2.3 million) (table 6). These values tend to increase with increased size and number of healthy trees.

Table 6. Monetary value of Indiana's urban forest by benefit category.

Benefit	Value
Structural or replacement costs	$43.4 billion
Carbon storage	$174 million
Carbon sequestration	$5.8 million/year
Pollution removal	$35.4 million/year
Energy reduction	$2.3 million/year
Avoided carbon emissions	$480,000/year

Potential Economic Impacts of Pests on the Urban Forest

Based on tree species distribution, the urban forest is at risk to various pests that could potentially impact its health and sustainability. The effects of three exotic pests—Asian longhorned beetle, gypsy moth, and emerald ash borer—were analyzed using the UFORE Model.

The Asian longhorned beetle is an insect that bores into and kills a wide range of hardwood species (U.S. Department of Agriculture, Forest Service 2002). The risk of the Asian longhorned beetle to Indiana's urban forest is a loss of $29.1 billion in structural value or 58.4 percent of all urban trees in the State. 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 (Liebhold 2003). This pest already exists in the northeastern region of Indiana (Purdue University Extension 2006). The risk of this pest is a loss of $4.0 billion in structural value (22.9 percent of the urban forest). Finally, the emerald ash borer can kill any species of ash tree and has been detected in Michigan, Ohio, Indiana, and Maryland (McCullough and Katovich 2004). The potential risk to urban forests in Indiana from this borer is $3.3 billion or 2.3 percent of the urban forest population (table 7).

Table 7. Total replacement value of host trees and percentage of the Indiana urban tree population at risk from three important insect pests.

Insect pest	Total replacement value of host trees	Percentage of urban tree population at risk
Asian longhorned beetle	$29.1 billion	58.4
Gypsy moth	$4.0 billion	22.9
Emerald ash borer	$3.3 billion	2.3

CONCLUSIONS

Our efforts to explore the feasibility of a statewide urban forest monitoring project through data collection of one panel of plots in Indiana illustrate that a long-term urban forest health monitoring program is practical with some minor modifications of standard methods. Part 1 of this report (Lake and others 2006) elaborated further on specific considerations and modifications to field methods. This report concentrates on the data products available from collection of statewide urban forest monitoring information.

Based on the UFORE Model, an urban forest health monitoring program can generate statewide data that address urban forest structure, ecosystem services and values, and potential risk from native and invasive insects. If this program is implemented similarly to the current Forest Inventory and Analysis Program, information about the status of forests in urban areas and how those forests change over time can be captured. Valuable information, such as how much of the urban forest is potentially at risk to destructive insects or devastating diseases, will help improve State and national management decisions and policies related to urban forests.

Data can be collected on trees in urban areas using existing FIA procedures to monitor the status, conditions, and trends of the urban forest resource at the State, regional, and national level. This monitoring will meet the needs of many programs by assessing the following:

1. Magnitude, composition, and condition of the urban forest resource to aid in management and planning.

2. Changes and threats to the sustainability of urban forests (species and cover changes, invasive species, pest outbreaks).

3. Ecosystem services and values (air pollution removal, carbon storage and sequestration, building energy conservation).

4. Basic data (species composition, leaf area, leaf biomass, leaf area index, tree biomass) needed for incorporation of urban vegetation within environmental regulations and assessments, such as State Implementation Plans (SIPs) of the Clean Air Act, Total Maximum Daily Loads and Stormwater Program for Municipal Separate Storm Sewer Systems of the Clean Water Act, and the Kyoto Protocols aimed at reducing greenhouse gases.

5. Biomass and economics of wood utilization in urban areas (board foot volume, waste wood management).

6. Cover and leaf area to aid in understanding the impact of urban tree canopies on dispersion of atmospheric pollutants or chemical reagents.

7. Long-term change in the urban forest to:
   a. Understand and manage factors that alter urban forests,
   b. Monitor and evaluate the effectiveness of Federal and State urban forest program accomplishments, and
   c. Identify critical resource needs and direct program funding to meet those needs as directed by Congress.

In summary, implementation of a national urban forest health monitoring program would strengthen the Forest Service's ability to survey, monitor, manage, and protect forest land where almost 80 percent of the human population lives, works, and recreates. By providing data that describe urban forest structure, function, and condition, the Forest Service, in partnership with State agencies, nonprofit groups, and educational institutions, will be meeting the congressional directives outlined in the Cooperative Forestry Assistance Act and the Healthy Forests Restoration Act.

The opportunity cost of not implementing a national urban forest health monitoring program is tremendous. Understanding the role of urban forests with respect to carbon storage, air and water quality, and the spread of invasive pests and diseases is imperative to sustaining livable communities for urban citizens. Without being able to quantify and qualify urban forests at the State and national level, resource managers and other stakeholder groups will be unable to fully utilize this resource for public benefit. Responsible stewardship and management of natural resources can only be accomplished with complete knowledge of the structure and condition of the resource. The ability to predict future condition, calculate risk from invasive species, and identify areas for agency leadership is essential to ensure healthy, productive, and vibrant forests for all of our Nation's communities.

REFERENCES

Abdollahi, K.K.; Ning, Z.H.; Appeaning, A., eds. 2000. Global climate change and the urban forest. Baton Rouge, LA: Franklin Press and GCRCC. 77 p.

Council of Tree and Landscape Appraisers [CTLA]. 2000. Guide for plant appraisal. 9th ed. Champaign, IL: International Society of Arboriculture. 143 p.

Fankhauser, S. 1994. The social costs of greenhouse gas emissions: an expected value approach. The Energy Journal. 15(2): 157–184.

Hansen, M.H. 1987. Forest area in Indiana, 1986. Res. Note NC–341. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Experiment Station. 5 p.

Lake, M.; Marshall, P.; Mielke, M.; Cumming, A.B.; Twardus, D.B. 2006. Monitoring urban forests in Indiana: Pilot study 2002. Part 1: Analysis of field methods and data collection. NA–FR–06–06. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 22 p.

Liebhold, A. 2003. Gypsy moth in North America. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northern Research Station. www.fs.fed.us/ne/morgantown/4557/gmoth. (14 June 2007).

McCullough, D.G.; Katovich, S.A. 2004. Pest alert: emerald ash borer. NA–PR–02–04. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 2 p. http://www.na.fs.fed.us/spfo/pubs/pest_al/eab/eab04.htm. (14 June 2007).

McPherson, E.G.; Simpson, J.R. 1999. Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW–171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 237 p. www.treesearch.fs.fed.us/pubs/6779. (14 June 2007).

Nowak, D.J. 2005. The effects of urban trees on air quality. Syracuse, NY: U.S. Department of Agriculture, Forest Service, Northern Research Station. 4 p. www.fs.fed.us/ne/syracuse/gif/trees.pdf. (14 June 2007).

Nowak, D.J.; Crane, D.E. 2000. The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and function. In: Hansen, M.; Burk, T., eds. Proceedings of the IUFRO Conference: Integrated tools for natural resource inventories in the 21st century: an international conference on the inventory and monitoring of forested ecosystems; 1998 August 16-19; Boise, ID. Gen. Tech. Rep. NC–212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 714–720.

Nowak, D.J.; Crane, D.E.; Dwyer, J.F. 2002. Compensatory value of urban trees in the United States. Journal of Arboriculture. 28(4): 194–199.

Nowak, D.J.; Walton, J.T. 2005. Projected urban growth (2000–2050) and its estimated impact on the U.S. forest resource. Journal of Forestry. 103(8): 383–389.

Nowak, D.J.; Walton, J.T.; Dwyer, J.F.; Kaya, L.G.; Myeong, S. 2005. The increasing influence of urban environments on U.S. forest management. Journal of Forestry. 103(8): 377–382.

Purdue University Extension. 2006. Indiana gypsy moth information from Purdue Extension. http://www.entm.purdue.edu/GM/GMIN.htm. (14 June 2007).

Schmidt, T.L.; Mielke, M.E.; Marshall, P.T. 2002. Indiana's forest resource in 2000. Resource Bull. NC–206.
St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 25 p.

U.S. Census Bureau. 2003. Differences between the 1990 census and Census 2000 urbanized area criteria. http://www.census.gov/geo/www/ua/uac2k_90.html. (14 June 2007).

U.S. Census Bureau. 2006. Table 1: Interim projections: Ranking of Census 2000 and projected 2030 State population and change: 2000 to 2030. http://www.census.gov/population/projections/PressTab1.xls. (14 June 2007).

U.S. Department of Agriculture, Forest Service. 2002. Pest alert: Asian longhorned beetle (*Anoplophora glabripennis*): a new introduction. NA–PR–01–99GEN. Newtown Square, PA: Northeastern Area State and Private Forestry. 2 p. http://www.na.fs.fed.us/spfo/pubs/pest_al/alb/alb04.htm. (14 June 2007).

U.S. Department of Agriculture, Forest Service. 2003. Forest inventory and analysis national core field guide. Vol. 1: Field data collection procedures for phase 2 plots. Version 1.7. St. Paul, MN: North Central Research Station. 203 p.