National Forest Health Monitoring Program

Wisconsin Street Tree Assessment 2002–2003

United States
Department of Agriculture

Forest Service

Northeastern Area
State and Private Forestry

NA–FR–02–08

December 2008

Photo by Future Neenah

Trees create a more inviting environment in downtown Neenah, WI.

(Cover photo credit: Wisconsin Department of Natural Resources)

National Forest Health Monitoring Program

Wisconsin Street Tree Assessment 2002–2003

Anne Buckelew Cumming
Daniel B. Twardus
Robert Hoehn
David J. Nowak
Manfred Mielke
Richard Rideout
Helen Butalla
Patricia Lebow

U.S. Department of Agriculture

Forest Service

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

NA–FR–02–08

December 2008

www.na.fs.fed.us

Authors

Anne Buckelew Cumming, Forester, Northeastern Area, State and Private Forestry, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505

Daniel B. Twardus, Forest Health Group Leader, Northeastern Area, State and Private Forestry, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505

Robert Hoehn, Biological Science Technician, Northern Research Station, USDA Forest Service, State University of New York College of Environmental Science and Forestry, 5 Moon Library, Syracuse, NY 13210

David J. Nowak, Research Forester, Northern Research Station, USDA Forest Service, State University of New York College of Environmental Science and Forestry, 5 Moon Library, Syracuse, NY 13210

Manfred Mielke, Plant Pathologist, Northeastern Area, State and Private Forestry, USDA Forest Service, 1992 Folwell Avenue, St. Paul, MN 55108

Richard Rideout, State Urban Forestry Coordinator, Wisconsin Department of Natural Resources, P.O. Box 7921, Madison, WI 53707

Helen Butalla, Information Technology Specialist, Northeastern Area, State and Private Forestry, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505

Patricia Lebow, Mathematical Statistician, Forest Products Laboratory, USDA Forest Service, 1 Gifford Pinchot Drive, Madison, WI 53726

Acknowledgments

In addition to the authors, personnel involved in compiling this report were: Bill Smith, Jeffrey Walton, Daniel Crane, and the Creative and Web Services Staff, Northeastern Area State and Private Forestry (USDA Forest Service) and the Wisconsin Department of Natural Resources.

We thank the following groups and individuals for their support and funding of this project: Wisconsin Department of Natural Resources Forestry Division; NSR Land Management, Inc.; and the Forest Health Monitoring Program, Urban and Community Forestry Program, Northeastern Area State and Private Forestry, Northern Research Station, North Central Research Station, Southern Research Station, Robert Mangold, and Borys Tkacz (USDA Forest Service).

TABLE OF CONTENTS

TABLES AND FIGURES

SUMMARY

A pilot study to assess the structure, function, and health of Wisconsin's street trees was initiated in 2002. Almost 900 plots were established in Wisconsin's urban areas. Table 1 provides an overview of plot-level data, population estimates, and a calculated monetary value for Wisconsin's street trees.

Wisconsin has mid-sized street trees, dominated by Norway maple (30 percent), green ash (15 percent), honey locust (8 percent), and littleleaf linden (7 percent). Field assessments of crown dieback indicated robust and healthy trees in 2002. Damage was observed on only 16 percent of trees, and the most frequently observed types of damage were cracks or seams, open wounds, and conks on the trunk.

The structural and functional value of Wisconsin's street trees approaches $1.8 billion. Carbon storage and sequestration ($7.5 million), replacement value ($1.8 billion), and pollution removal ($1.7 million/year) are important assets to the citizens of Wisconsin.

Emerging threats to Wisconsin's street trees include the Asian longhorned beetle, which could impact 82 percent of the roadside trees, emerald ash borer (20 percent), and gypsy moth (15 percent).

Table 1. Plot-level data, Wisconsin street trees, 2002-2003.

Variables	Value
Number of plots	891
Miles of urban roadway	16,073
Number of living trees sampled	2,865
Average d.b.h., inches (cm)	12.8 (32.5)
Number of trees per mile	63
Population estimate - live	1,018,000
Population estimate - dead	2,364
Number of species sampled	87
Number of genera sampled	36
Number of families sampled	19
Monetary (structural) value	$1,771,000

INTRODUCTION

Street trees grow along roadways within the public right-of-way. They are an important part of the urban forest due to their visibility to motorists and pedestrians, even if their numbers represent a small fraction of trees in urban areas. Little data are available that describe this resource at a large, statewide scale. In 2000, the Forest Service, U.S. Department of Agriculture, began a series of pilot studies to examine the structure and function of street trees throughout a State. Maryland and Massachusetts were the first two States included in the pilot (Cumming and others 2006). In 2002, the Forest Service initiated a pilot study in the State of Wisconsin to sample and monitor street trees in urban areas throughout the State.

Street trees, a subpopulation of the urban forest, were chosen for these projects because:

- Their proximity to commercial districts puts them at high risk to invasive pests.
- Their proximity to nonpoint source air pollution generated by cars and trucks makes them important for improving air quality.
- Their proximity to stormwater runoff pathways makes them an important component in stormwater management and water quality in urban areas.
- They are the most visible element of the urban forest.
- Their proximity to roads, sidewalks, and parking lot surfaces makes them a key moderator of temperatures.
- They are frequently managed by public agencies.

These statewide pilots are the first of their kind. In Wisconsin, 891 street-side plots were established throughout urban areas. Data were collected to describe the structure and characteristics of street trees and to estimate their functions and values statewide. The pilot study will establish baseline data, with the intent to remeasure the plots over time. These remeasurements will allow us to learn more about changes in the structure and function of the street tree component of the urban forest and what causes them.

From a historical perspective, major cities in both Europe and the United States had incorporated trees into street and avenue designs by the mid-1800s (Lawrence 1997). Pests and diseases, such as gypsy moth, brown-tail moth, chestnut blight, and Dutch elm disease, necessitated a systematic approach to care for public street trees, although the management focus was still the individual tree (Koch 2000).

Although modern arboriculture has been used to manage street trees in the United States since the 1960s, few studies have looked beyond municipal boundaries to assess street tree health. Several studies have chosen multiple cities for comparisons, e.g., inventories (Bassett and Lawrence 1975), street tree policies (Hager and others 1980), pruning and removal needs (Nowak 1990), and cost-benefit analysis (McPherson and others 2005). Only a handful of studies have looked at changes over time. For example, Nowak and others (2004) made projections about the urban tree population (street trees plus other land uses) and mortality in Baltimore, MD, via 2 years of sampling; and Dawson and Khawaja (1985) looked at changes in species composition in two Urbana, IL, neighborhoods over 50 years. Roman (2006) provided an overview of street tree mortality studies and concluded that statistically analyzed and scientifically reported data related to street tree longevity, mortality, and causes of death and disease are lacking. The intent of this series of pilot studies was to test the methods and implementation of a large-scale street tree study, establish baseline data, and illustrate the types of data analyses and uses.

METHODS

The protocols used to sample street trees in Wisconsin were based upon methods developed and used in Maryland and Massachusetts (Cumming and others 2001, 2006). In general, all roadways within U.S. Census Bureau-defined urban areas were considered the statistical "population" to be sampled. Census data from 1990 (U.S. Census Bureau 2008a) were used to develop boundaries of urban areas (figure 1). An urban area was defined as the area occupied by the union of three Census-defined designations: (1) urbanized area – has a population of 50,000 or more and a minimum of 384 people per square kilometer, (2) place – contains some urbanized areas within its boundary, and (3) urban place – has at least 2,500 people located outside an urbanized area (Dwyer and others 2000).

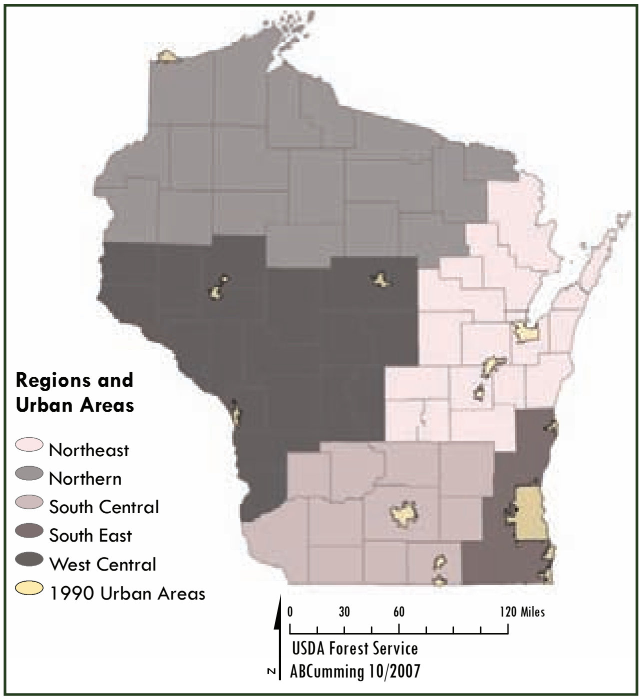

Figure 1. Regions and urban areas of Wisconsin, 1990.

Segments of road (U.S. Census Bureau 2008b) were randomly chosen and plots were located in the right-of-way along both sides of the road. The subplot configuration was used to parallel the subplot system used by the Forest Inventory and Analysis (FIA) and Forest Health Monitoring (FHM) Programs, and consisted of four 1/24-acre (0.016 ha) subplots for a total of one 1/6-acre (0.06 ha) plot. Unlike FIA sampling, where plots are located on all owner and land use types, the street tree samples are located within the public domain and do not require prior property owner permission. Each subplot was 181.5 feet (55.32 m) long, 10 feet (3.05 m) wide, and had a random starting location. Crews were trained to accommodate cul-de-sacs, dead-end roadways, and roadways with median strips. While not permanently set with a monument marker, plot locations were identified by distance and azimuth to landmarks.

The statewide sample for Wisconsin consisted of 891 plots, a triple intensification of designs used previously in Maryland and Massachusetts. The plots were installed and sampled during the summers of 2002 and 2003. Summer field work was necessitated by the need for in-leaf crown evaluations.

DATA COLLECTION

All trees 1 inch (2.54 cm) in diameter at breast height (d.b.h.) and greater were tallied. Data included tree species, diameter, height, crown conditions, and occurrence of damage. Ground cover was estimated. Tree conflicts with sidewalks or overhead electric utilities were recorded.

Tree condition was evaluated using protocols established by the National Forest Health Monitoring Program (U.S. Department of Agriculture, Forest Service 1998). Tree crowns were assessed along with any damage visible on the tree. Crown condition was described by measuring dieback, transparency, and density. Damage signs and symptoms were prioritized and recorded based on location in the following order: roots, lower bole, upper bole, crown stem, branches, buds and shoots, and foliage.

Plot Density and Intensification

To evaluate various design alternatives that could be used in future surveys by reducing the sampling intensity either at the plot and/or subplot level, a “bootstrap simulation” was carried out using the current survey data (similar to Manly 1992). Three plot intensity levels (3×=890 plots, 2×=600 plots, and 1×=300 plots) were considered, as well as three subplot measurement possibilities (4, 2, or 1 subplots per plot).

For standard errors within 10 percent of the estimate, results of the “bootstrap simulation” indicate that size of the population, diameters, crown width, and tree heights can all be estimated with 1× (300 plots) and 1 subplot per plot. Estimates of the number of species, however, vary dramatically among the sampling intensities from an estimated 73 species (66-79, 95 percent confidence interval) at the 3×, four-subplot intensity to an estimated 30 species (22-38, 95 percent confidence interval) at the 1×, one-subplot intensity. This dramatic change in the estimated number of species across the sampling intensities is most likely due to the large number of single species occurring within the sample. Therefore, to quantify the street tree population in basic mensurational terms, the 1× (300 plots) with 1 subplot appears to be sufficient, while characterizing the population in terms of composition requires the 3×, four subplot-sampling frame. Appendix A contains further details of the “bootstrap simulation.”

LAND USE

Each plot was given a land use designation. Land use definitions were based on Anderson and others (1976/2001). Residential lands were characterized by single and multifamily housing units predominating around the plot location. Anderson describes residential areas as having relatively uniform size and spacing of structures, linear driveways, and lawn areas, as compared to commercial zones where buildings are more likely to be of different sizes and lots have larger driveways and parking areas. Industrial areas were designated as areas where an array of manufacturing activities would occur and characteristically have large buildings, parking lots, and shipping facilities. Raw materials may or may not be stored on site based on the type of manufacturing or industry. Land uses not identified in the above descriptions were considered "other."

Plots were characterized by one of these four land uses and by the ownership of the road (municipal, county, State, or Federal). Over 90 percent of the trees sampled were in a residential land use and on a municipal road (table 2). Appendix B lists the 10 most frequent species by land use.

Since plots were placed in areas defined as urban, based on human population, the distribution of plots throughout the State followed that pattern. Most plots were in the southeast and west-central areas of the State (table 3), and over 85 percent of the sampled trees were in three regions (southeast, west central, and south central; figure 1).

RESULTS

Based on the 1990 U.S. Census Bureau's urban definition, there were 16,073 miles of roadway in urban areas. Almost half of the plots (435) had trees, and a total of 2,865 live trees were sampled. The estimated urban street tree population for the whole State of Wisconsin was calculated to be 1,018,000 and was based on the average area of the right-of-way along urban roads. An estimated 934,000 of these trees occur in residential areas. See appendix C for a list of all species sampled, their estimated population, and mean height, d.b.h., and dieback.

Table 2. Number of plots and live trees by road ownership and land use, Wisconsin, 2002-2003.

Road ownership	Residential		Commercial		Industrial		Other		Total	
	Plots	Trees	Plots	Trees	Plots	Trees	Plots	Trees	Plots	Trees
Federal	1	0	8	8	0	0	0	0	9	8
State	4	4	12	16	1	0	3	1	20	21
County	10	0	5	2	0	0	0	0	15	2
Municipal	706	2,623	102	122	25	45	8	27	841	2,817
N/A[a]	0	0	0	0	0	0	6	17	6	17
Total	721	2,627	127	148	26	45	17	45	891	2,865

[a] N/A: Plots where land use or road type were not available

Table 3. Number of street tree plots per region in Wisconsin, 2002-2003.

Region	Plots	Percent of plots	Trees sampled
Northeast	146	16.4	349
Northern	47	5.3	65
South Central	157	17.6	570
Southeast	330	37.0	1,351
West Central	211	23.7	530

GROUND COVER

The average right-of-way width encountered on the plots was 13.5 feet (4.1 m), ranging from 0 to more than 100 feet (30.5 m). Over 35 percent of plot areas were covered with an impervious material, such as asphalt or concrete, which does not allow water to percolate into the soil. The remaining area of the plots was mostly vegetation (grass, herbs, or trees) or bare soil. Tree cover on the plots was approximately 24 percent (table 4). Thirty-one percent of the plots sampled were influenced by shade from trees that were not in, but directly adjacent to, the plot.

STRUCTURE AND COMPOSITION

Tree Size

Tree size, often considered a proxy for age, is a useful metric for street tree managers. Because street trees are within the public right-of-way, proper management of these trees, especially large and mature trees, is essential to public safety. A stable street tree population is most dependent upon age (size) diversity, and inadequate tree replacement is a greater threat to future street tree population stability than is low species diversity (Richards 1983). The urban street trees in Wisconsin averaged 12.8 inches (32.5 cm) d.b.h. and would be considered well-established, "mid-sized" trees. Managers will be contending with many mature trees within the next 10 to 20 years, depending on species and site characteristics. Figure 2 shows the d.b.h. distribution within the 10 most common species.

Table 4. Extent of ground cover, Wisconsin street tree plots, 2002-2003.

Ground cover	Mean (percent)	Standard error
Impervious materials	35.5	0.9
Vegetation	60.4	0.9
Bare soil	4.1	0.3
Tree cover	23.7	1.2

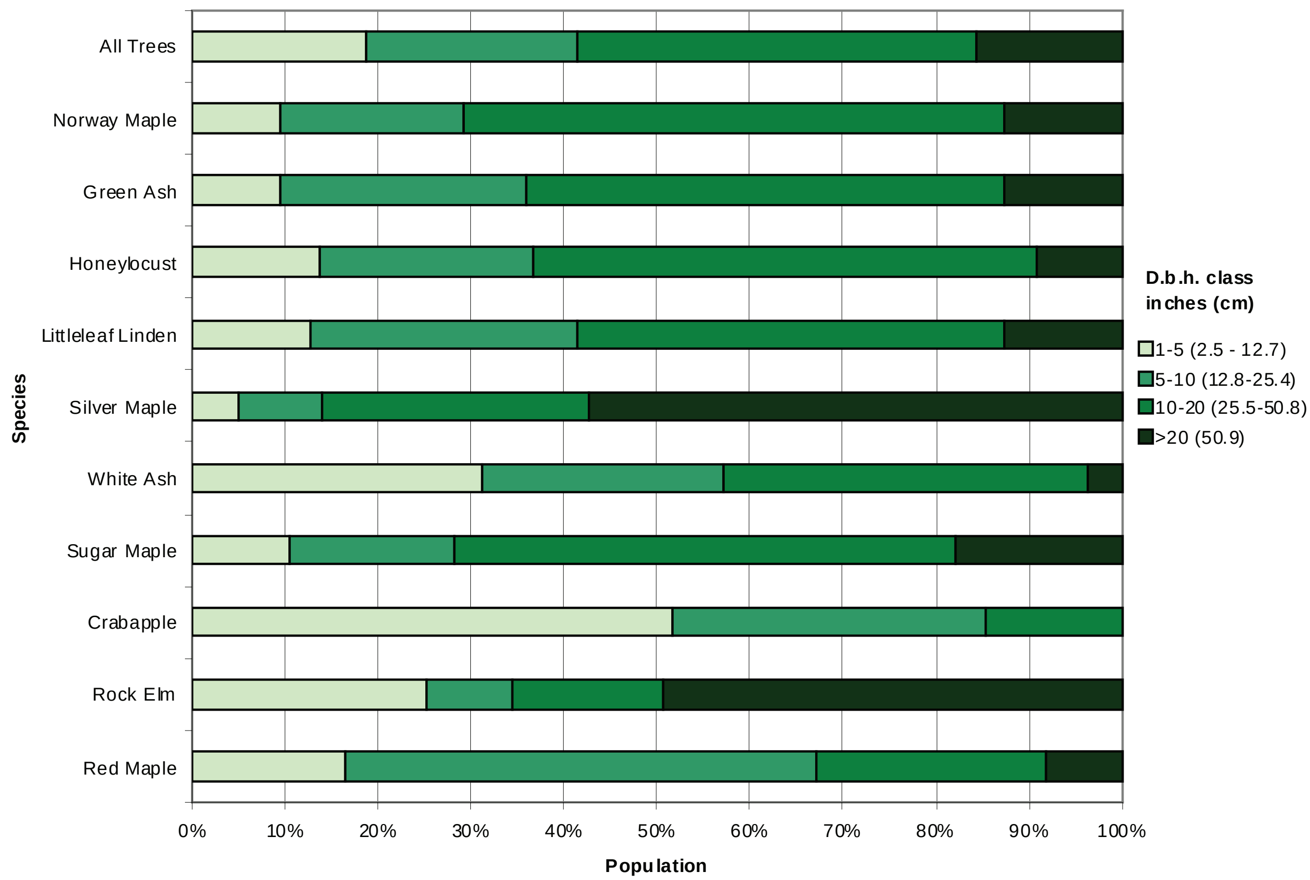

Figure 2. Diameter distribution within the 10 most common species, Wisconsin street trees, 2002-2003.

Species Frequency

The sampled street tree population consists of 88 species—87 identified species and an unknown category with four unidentified trees (table 5). This is considerably more than the mean of 53 species reported by McPherson and Rowntree (1989) in their nationwide survey of street tree populations in 22 U.S. cities. From an ecological perspective, a common perception is that species diversity contributes to the stability of the overall population (Odum 1971). Richards (1983) defines stability in a street tree population as a low probability that the number of functional trees will decline over the foreseeable future, to the extent that any decline disrupts the value of the street tree population. Another confounding aspect of street tree diversity is that in an attempt to increase diversity, a variety of species may be planted, some of which may not be as adaptable to the stressed environment of the streetscape. By not considering species requirements together with site conditions, there is an increased likelihood of premature tree decline or death (Richards 1983).

Diversity of the street tree population can be described based upon the number of species (richness) and the relative abundance of each species (evenness). The street tree population would be considered highly diverse if many near-equally abundant species are present. While we sampled 88 different species (high species richness), two dominated—*Acer platanoides* (Norway maple) and *Fraxinus pennsylvanica* (green ash)—representing 46 percent of the trees (uneven abundance). Thus, the Wisconsin street tree population cannot be considered to have high diversity and consequently is more susceptible to catastrophic impacts such as the damaging effects of a pest. Raupp and others (2006) discuss the catastrophic impacts of Dutch elm disease as a result of the heavy use of elm as a street tree. It is difficult, however, to predict the likelihood of an exotic pest introduction. It may be more costly, in the long term, to replace species well adapted to the streetscape with unproven species (Richards 1983). Nevertheless, Wisconsin street tree populations are at risk from the introduced emerald ash borer (at this writing in Illinois, Indiana, Maryland, Michigan, Missouri, Ohio, Pennsylvania, Virginia, West Virginia, and Wisconsin) and the Asian longhorned beetle (Massachusetts, New York, New Jersey, and believed eradicated in Illinois).

Genera and Family Frequency

Acer was the most common genus, representing 43.7 percent of all trees sampled. *Fraxinus* and *Gleditsia* comprised 19.7 and 8.4 percent of the sample, respectively. The 10 most frequently occurring genera represented 93.5 percent of all trees (table 6). At the family level, Aceraceae was the most common. Oleaceae and Fagaceae were the other families that contained more than 10 percent of trees sampled. A total of 19 different families were represented. The 10 most common plant families represented 98.0 percent of all trees sampled (table 7).

Table 5. Species Composition – Percentages of the 10 most frequent species along urban roadways in Wisconsin, 2002 – 2003.

Species	Common name	Percent of sample	Cumulative (%)
Acer platanoides	Norway maple	30.5	30.5
Fraxinus pennsylvanica	Green ash	15.2	45.7
Gleditsia triacanthos	Honeylocust	8.4	54.1
Tilia cordata	Littleleaf linden	6.6	60.7
Acer saccharinum	Silver maple	6.3	67.0
Fraxinus americana	White ash	3.9	70.9
Acer saccharum	Sugar maple	3.7	74.6
Malus sp.	Crabapple	3.2	77.8
Ulmus thomasii	Rock elm	2.3	80.1
Acer rubrum	Red maple	2.1	82.2
All other (78 species)		17.8	100.0

Santamour (1990) recommended that urban forests could be protected from pest outbreaks if no more than 10 percent of a single species, 20 percent of a single genus, or 30 percent of a single family were represented. The "10-20-30 percent rule" relates specifically to the possibility of a pest outbreak including exotic pests (Santamour 1990). Recognizing that some insects and diseases have more than one host species within a genus or family, Santamour includes limits on genus and family representation in his guide.

Ball and others (2007) characterized street tree populations in several South Dakota communities as having high, medium, or low stability based on the genera composition. Street tree populations that were considered highly stable had genera that were no more than 10 percent of the fully stocked population. When Ball and others's methods are applied to Wisconsin street trees, we found that the urban roads were 60 percent stocked and that the stability of the population, based on genera, would be rated as "low." The "low" rating is a result of the heavy representation of *Acer* and *Fraxinus*. Low stability can be described in two ways: (1) as at least two genera each comprising more than 10 percent of the fully stocked street tree population or (2) as a single genus comprising more than 25 percent (Ball and others 2007). Based on full stocking (50-foot stem spacing), *Acer* represented 25.3 percent and *Fraxinus* 11 percent of the estimated population.

The Wisconsin street tree population exceeds Santamour's guide and earned a "low" rating based on the methods of Ball and others (2007). With 20 percent of the population at serious risk to emerald ash borer infestation and destruction, and another 43 percent of the population consisting of just one genus (*Acer*), future plantings and management should include species other than ash or maple.

POTENTIAL ECONOMIC IMPACTS OF PESTS

Based on its species distribution, the Wisconsin urban forest is at risk from several pests that could impact its health and sustainability (table 8). The impacts of three exotic pests and one disease—Asian longhorned beetle (*Anoplophora glabripennis*), gypsy moth (*Lymantria dispar*), emerald ash borer (*Agrilus planipennis*), and Dutch elm disease (*Ophiostoma novo-ulmi*)—were analyzed using the UFORE Model (Nowak and Crane 2000).

Table 6. Genera Frequency – Frequency (percent) of 10 most common genera of all trees sampled on urban streets of Wisconsin, 2002 - 2003.

Genus	Total (%)	Cumulative (%)
Acer	43.7	43.7
Fraxinus	19.7	63.4
Gleditsia	8.4	71.8
Tilia	7.3	79.1
Ulmus	5.3	84.4
Malus	3.2	87.6
Quercus	2.6	90.2
Celtis	1.2	91.4
Populus	1.1	92.5
Prunus	1.0	93.5
Other 25 genera	6.5	100

Table 7. Family Frequency – Frequency (percent) of plant family of all trees sampled, Wisconsin, 2002-2003.

Family	Total (%)	Cumulative %
Aceraceae	43.7	43.7
Oleaceae	19.7	63.4
Fagaceae	11.2	74.6
Tiliaceae	7.3	82.0
Ulmaceae	6.5	88.5
Rosaceae	4.9	93.4
Betulaceae	1.9	95.3
Pinaceae	1.6	96.9
Juglandaceae	0.7	97.6
Cupressaceae	0.4	98.0
Other nine families	2.0	100.0

Table 8. Pest Risk to Urban Roadside Trees – Monetary structural replacement value ($US) and percent of total population of host tree species at risk to a disease and three important insect pests: Dutch elm disease, Asian longhorned beetle, emerald ash borer, and gypsy moth, Wisconsin 2002-2003.

Pest or disease	Replacement value of host trees (million $US)	Percent of urban street trees in Wisconsin
Asian longhorned beetle	1,512	82.1
Emerald ash borer	338	19.5
Gypsy moth	227	15.0
Dutch elm disease	111	4.0

The Asian longhorned beetle (ALB) kills a wide range of hardwood species (U.S. Department of Agriculture, Forest Service 2002). The risk to Wisconsin's urban forest from ALB is a loss of $1.5 billion in structural value (replacement value) or 82.1 percent of all urban street 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 outbreaks last several years (Liebhold 2003). This pest already exists in the eastern region of the State, and the risk from gypsy moth damage is a loss of $227 million in replacement value (15 percent of the urban forest population). The emerald ash borer can kill many species of ash trees and has been detected in Illinois, Indiana, Maryland, Michigan, Missouri, Ohio, Pennsylvania, Virginia, West Virginia, Wisconsin, and Ontario, Canada (Michigan State University 2007). The potential urban risk from this borer in Wisconsin is $338 million or 19.5 percent of the urban forest tree population. Dutch elm disease, a problem in Wisconsin since at least 1957, has caused the death and removal of thousands of American elms. Madison, WI, alone lost 36,000 elms between 1957 and 1996. The disease spreads through root grafts (making streets lined with elm highly vulnerable) and by the native elm bark beetle. Elms comprise 4 percent of the Wisconsin streetscape.

UTILITY AND SIDEWALK CONFLICTS

Overhead utility wires and sidewalks are unique site features that affect the growth and success of street trees. Electric utilities and municipalities spend significant time and money to manage trees or repair damage caused by trees. For example, We Energies, serving an area over 23,000 square miles (59,565 km^2) with electric and gas in Wisconsin and Michigan's Upper Peninsula, spent approximately $22 million in 2008 to trim trees adjacent to electric utilities (Saul Lopez, We Energies, Personal Communication, May 29, 2008). Fourteen percent of urban street trees in Wisconsin had conflicts with overhead wires. Trees in commercial districts and in the northern and south-central regions had above-average occurrences. Sidewalks were less problematic, with only about 3 percent of trees affecting hardscape material (table 9).

Table 9. Utility Conflicts with Urban Roadside Trees – Percent of trees with utility conflicts (overhead wires and sidewalks), Wisconsin, 2002-2003.

Category	Wire conflict (%)	Sidewalk conflict (%)
All Trees	14.0	3.1
Commercial	10.1	0.0
Industrial	31.1	0.0
Residential	14.2	3.5
Northeast Region	13.2	2.9
Northern Region	26.1	0.0
South Central Region	26.1	1.8
Southeast Region	10.3	4.7
West Central Region	10.6	1.3

URBAN FOREST HEALTH

CROWN INDICATORS OF FOREST HEALTH

Crown dieback and density can be used as indicators of tree health. Large, dense crowns are often indicative of vigorously growing trees, while small, sparsely foliated crowns with little or no growth are possibly declining. Two measurements of crown health were used to estimate tree condition: dieback and density.

Crown dieback is defined as recent mortality of small branches and twigs in the upper and outer portion of the tree crown. Trees with crown dieback greater than 25 percent may be in decline, for both hardwoods and conifers. Further, hardwoods with more than 30 percent dieback and softwoods with more than 25 percent dieback are most likely to die within 1 year (Steinman 1998).

Crown density is an estimate of the crown condition of each tree relative to its potential and is determined by observing the percentage of light blocked by branches and foliage. Reduced crown density reflects gaps in the crown that may have been caused by declining tree health. Density estimates that are less than 30 percent for both hardwoods and conifers generally indicate that a tree is in poor health (Steinman 1998).

Average crown results for dieback and density for all trees in the survey are shown in table 10. Seventy-three percent of all live trees in the survey had less than 5 percent crown dieback. Of trees with observable dieback, only about 2 percent exceeded the thresholds of concern. Species with the highest average dieback include *Quercus ellipsoides* (6 percent), *Ulmus americana* (5 percent), and *Q. velutina* (1.6 percent). About 1 percent of the observed ash had dieback that exceeded thresholds of concern (i.e., greater than 25 percent; figure 3). Results indicate that crown densities are well above critical thresholds, with 98 percent of all live trees having crown densities above the thresholds defined by Steinman (1998).

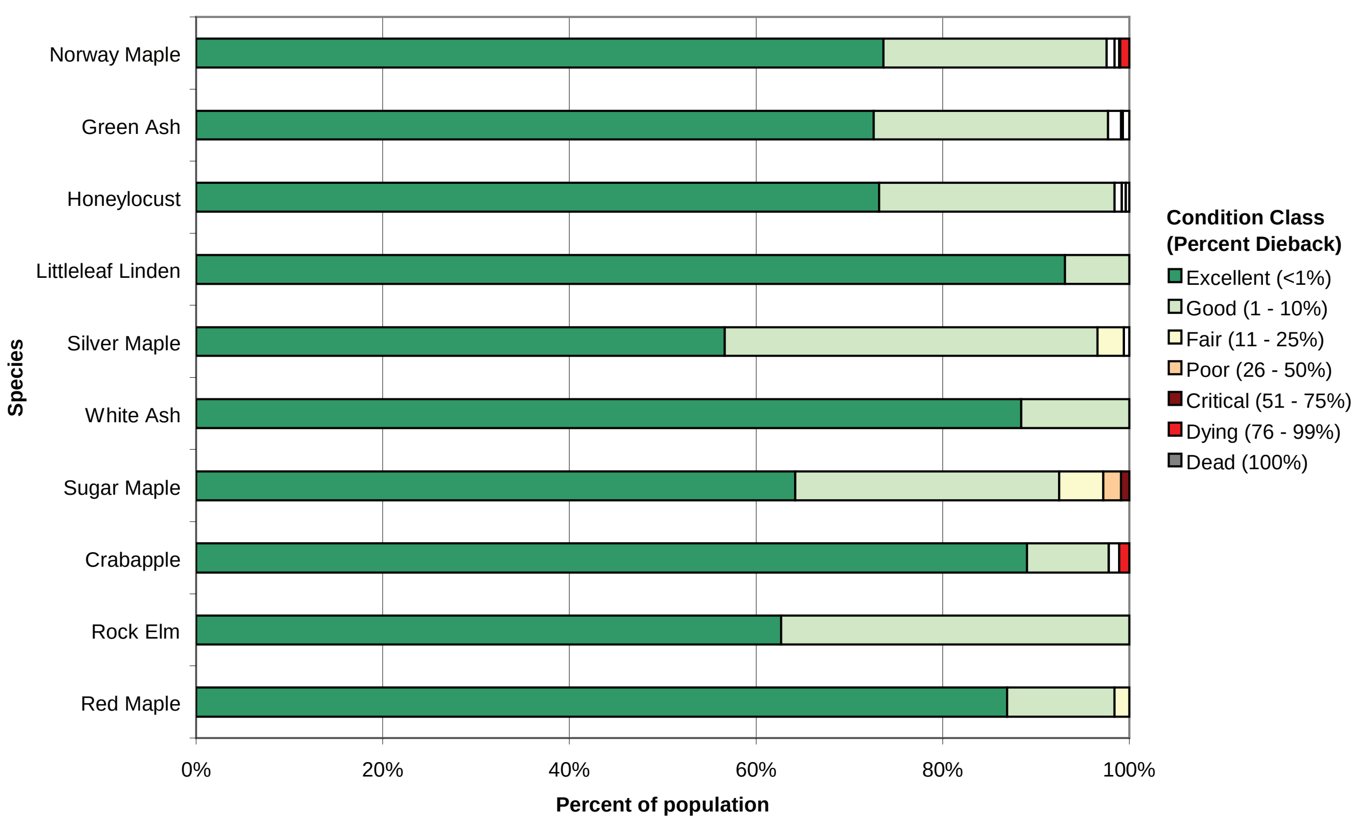

Figure 3. Dieback condition class for the 10 most common species, Wisconsin street trees, 2002- 2003.

Table 10. Crown Measurements – Wisconsin street trees, 2002 – 2003.

Crown measure	Average	Standard error
Crown diameter	25.22 ft (7.7 m)	0.6
Crown dieback	2.51% [a]	0.2
Crown density	73.3% [b]	0.9

[a] Crown dieback values less than 25 percent indicate good health
[b] Crown density values greater than 30 percent indicate good health

DAMAGE INDICATORS OF FOREST HEALTH

Signs of damage were recorded for all trees 1 inch (2.54 cm) d.b.h. and greater and were recorded based upon the location of the damage. Damage at the root level or tree bole can be more significant in terms of tree health, as compared with damage in branches or the upper bole. Some of the damage indicators had thresholds below which damage was not recorded; these are detailed in the Forest Health Monitoring Methods Guide (U.S. Department of Agriculture, Forest Service 1998).

Signs of damage used in this assessment included these:

- Cankers and galls – may be caused by various agents, but most commonly fungi.
- Conks – fruiting bodies of fungi that are often signs of hidden decay.
- Open wounds – areas where the bark has been removed and the inner wood is exposed to decay.
- Resinosis – resin or sap exuding from the tree bole or branches.
- Cracks and seams – separations of the bark caused by wounds, such as lightning strikes.
- Broken bole or roots – breaks, or other physical damage, that may indicate hidden decay.
- Brooms on roots or bole – clustering of foliage about a common point that may indicate the presence of disease.
- Vines in the crown – vines, such as ivy or grape, that can reduce tree foliage and damage twigs and branches.
- Loss of apical dominance – death of a tree's main terminal caused by insects, disease, or frost.
- Broken or dead branches – may indicate long-term tree decline problems due to disease or insect defoliation over several years.
- Excessive branching or brooms within the crown – exaggerated branching or clustering of twigs, branches, or both, possibly resulting from disease or environmental changes.
- Damaged buds, foliage, or shoots – damage is most commonly due to insect feeding or the presence of disease, but can also be caused by frost or the misapplication of chemicals.
- Discoloration of foliage – color change may be indicative of general tree decline resulting from disease or environmental problems.

Up to three sites of damage could be recorded for each tree. They were recorded in order, starting at the base of the tree, as Damage 1, 2, and 3. "Damage 1" was usually considered the most potentially threatening to the tree. Table 11 shows the frequency of observed damage for all live trees. While 84 percent of all live trees had no observed damage, the predominant types of damage in the remaining 16 percent were cracks and seams, open wounds, and conks. Of the 467 trees with one site of damage, 54 had a second site that was

Table 11. Types of Tree Damage – Most common damage types found on Wisconsin's urban street trees, 2002-2003.

Types of damage	Live trees with damage (percent)
Cracks and seams	5.7
Open wounds	4.7
Signs of advanced decay, conks	3.7
Damaged buds, foliage, or shoots	0.4
Canker, gall	0.3
Resinosis or gummosis	0.2
Vines in crown	0.2
Loss of apical dominance	0.2
Broken or dead branches	0.2
Other	0.4
Total	**16.0**

predominantly cracks and seams, and conks. Of the 54 trees with two sites of damage, 5 had a third damage observed (predominantly conks). Cracks and seams, open wounds, and conks comprise 88 percent of all damage recorded.

Cracks and seams are defined as separations along the radial plane of a tree's stem or trunk. When cracks extend to the bark, they are sometimes called frost cracks. Although cracks are not initiated by frost or freezing temperatures, frost can be a major factor in their continued development. Cracks are most often caused by basal wounds or sprout stubs and expand when temperatures drop rapidly. Sinclair and Lyon (2005) describe how "woundwood" (a callus-derived tissue that forms at the edge of a wound and eventually covers it) forms along cracks and may develop into external seams. Trunk cracks have also been reported to be caused by the force of the wind on the tree crown (Sinclair and Lyon 2005).

Open wounds can result from human-caused mechanical injury such as vandalism, improper pruning, lawnmowers, or vehicles and lead to fungal infection and wood decay. Conks, the fruiting bodies of fungi, are indications of decay present within the wood. Table 12 shows the 10 most common tree species, observed damage to those species, and the most common types of damage recorded as Damage 1 and Damage 2. Norway, red, and sugar maple have the highest incidence of damage, and within those species, cracks and seams, open wounds, and conks predominate. The reason for the abundant frequency of cracks and seams in Wisconsin's street tree population, particularly on Norway maple, is unknown and should be investigated. The occurrence of cracks in tree trunks has been documented previously for sugar maple (Burns and Honkala 1990), Norway maple (Gilman and Watson 1993, Bartlett Tree Research Laboratory 1999) and others (Sinclair and

Table 12. Tree Damage by Species – Ten most common species and frequency of damage, Wisconsin street trees, 2002-2003.

Species	**Common name**	**Damage**			
		Frequency		**Types**	
		Percent	Damaged/ Total sampled	Damage 1	Damage 2
Acer platanoides	Norway maple	29	258/877	Cracks and seams	Cracks and seams
Acer rubrum	Red maple	23	14/61	Conks	Conks Cracks and seams
Acer saccharum	Sugar maple	22	23/106	Conks	Open wounds Cracks and seams
Acer saccharinum	Silver maple	16	28/179	Open wounds	Open wounds Cracks and seams
Fraxinus pennsylvanica	Green ash	12	46/434	Open wounds	Conks Open wounds Cracks and seams
Ulmus thomasii	Rock elm	10	7/67	Open wounds	None
Tilia cordata	Littleleaf linden	8	16/189	Conks, Cracks and seams	Conks Cracks and seams
Fraxinus americana	White ash	7	9/122	Conks	None
Malus sp.	Crabapple	6	5/90	Conks	Open wounds
Gleditsia triacanthos	Honeylocust	3	8/242	Cracks and seams	None

Lyon 2005). Cracks can lead to decay with visible symptoms such as conks. The observed conks, though not identified as part of this survey, could be caused by white trunk rot fungi, such as *Phellinus igniarius*, which is common to hardwoods. Sugar and red maple are particularly susceptible. Conks, such as those caused by *P. igniarius*, are usually associated with advanced decay that weakens the tree. Open wounds, like those recorded on silver maple and rock elm, can lead to white trunk rot infections.

BENEFITS OF WISCONSIN'S URBAN STREET TREES

Urban street trees provide a variety of benefits that contribute to improved air and water quality, and aesthetics, as well as human quality of life to those who live, work, and travel in urban areas. Data collected from the urban street trees in Wisconsin were analyzed using the Urban Forest Effects Model (UFORE, Nowak and Crane 2000) and benefits from these trees were quantitatively described in terms of structural and functional values. Structural value is the cost associated with replacing a tree with another of similar size, while functional value is an expression of the services a tree provides to the environment, such as the amount of carbon removed from the atmosphere and stored by trees and the value of air quality improvement due to pollutant removal by trees. Table 13 shows the benefits provided by Wisconsin's street trees expressed in US dollars. These values tend to increase with increased size and numbers of healthy trees.

STRUCTURAL VALUE

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). 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/or setting policies related to the management of urban trees. CTLA compensatory value calculations are based on tree and site characteristics, specifically: tree trunk area (cross-sectional area at 1.37 m above the ground), species, condition, and location.

CARBON SEQUESTRATION AND STORAGE

Trees capture atmospheric carbon in the form of carbon dioxide through the process of photosynthesis. The tree uses the products of photosynthesis for structural and physiological purposes, i.e., wood, leaves, fruit, roots, and the energy to support them. The term carbon sequestration, as used in this study, refers to the annual removal of carbon from the environment by trees. Similarly, carbon storage is the amount or weight of carbon currently accumulated by urban street trees.

Trees occurring along urban roadways in Wisconsin had stored 325,000 metric tons (t) of carbon, with a sequestration rate of 9,500 t per year in 2002. Using a carbon cost per metric ton based on the estimated marginal social costs of carbon dioxide emissions (Fankhauser 1994), the value of carbon stored exceeds $7 million.

AIR QUALITY IMPROVEMENT

Poor air quality is a common problem in urban areas and leads to human 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. Trees emit volatile organic compounds (VOCs), however, that can contribute to ground-level ozone formation. Yet, integrated studies have revealed that increasing tree cover will ultimately reduce ozone formation (Nowak and others 2000).

The amount and rate of pollution removed by Wisconsin's street trees was estimated using hourly pollution data from all the monitors in the State and weather data (Milwaukee) from the year 2000. Based on these inputs, the UFORE Model estimated that the street trees in Wisconsin remove about 297 metric tons of pollution per year, with an associated annual value of about $1.7 million (table 14).

Table 13. Value and extent of Wisconsin's urban street trees.

Benefit	Value (Million $US)	Extent
Structural / rreplacement costs	$1,771.0	1,018,000 street trees
Carbon storage (metric tons, t)	$7.3	325,000
Carbon sequestration (t/yr)	$0.2	9,500
Pollution removal (t/yr)	$1.7	300

Table 14. Amount (metric tons) and value of pollution removed annually by Wisconsin's urban street trees, 2002-2003.

Pollutant	Amount removed by Wisconsin's urban street trees (t/yr)	Value of removal
Ozone	160.34	$1,082,610
Particulate matter less than 10 microns (PM_{10})	72.20	$325,499
Nitrogen dioxide (NO_2)	35.63	$240,590
Sulfur dioxide (SO_2)	25.22	$41,695
Carbon monoxide (CO)	3.29	$3,152

LITERATURE CITED

Anderson, J.R.; Hardy, E.E.; Roach, J.T.; Witmer, R.E. 1976 [2001 conversion to digital]. A land use and land cover classification system for use with remote senor data. Geologic Survey Professional Paper 964. As revision of the land use classification system as presented in USGS Circular 671. U.S. Government Printing Office, Washington, DC. http://landcover.usgs.gov/pdf/anderson.pdf (November 1, 2007).

Ball, J.; Mason, S.; Kiesz, A.; McCormick, D.; Brown, C. 2007. Assessing the hazard of emerald ash borer and other exotic stressors to community forests. Journal of Aboriculture and Urban Forestry. 33(5): 350–359.

Bartlett Tree Research Laboratory. 1999. Norway maple. Plant Health Care Program Fact Sheet PHC–37. Charlotte, NC: Bartlett Tree Research Laboratory. http://www.bartlett.com/post/tree/PHC_37_Norway_Maple_.pdf. (November 1, 2007).

Bassett, J.R.; Lawrence, W.C. 1975. Status of street tree inventories in the US. Journal of Arboriculture. 1: 48–52.

Burns, R.M.; Honkala, B.H., tech. coords. 1990. Silvics of North America: 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture. 877 p. http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/acer/saccharum.htm. (May 21, 2008).

Council of Tree and Landscape Appraisers [CTLA]. 2000. Guide for plant appraisal. International Society of Arboriculture, Savoy, IL.

Cumming, A.B.; Galvin, M.F.; Rabaglia, R.J.; Cumming, J.R.; Twardus, D.B. 2001. Forest health monitoring protocols applied to roadside trees in Maryland. Journal of Arboriculture. 27(3): 126–138.

Cumming, A.B.; Smith, W.; Twardus, D.B. 2006. Pilot project: monitoring street trees in Maryland and Massachusetts. NA–FR–01–06. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry.

Dawson, J.O.; Khawaja, M. 1985. Change in street-tree composition of two Urbana, IL, neighborhoods after fifty years: 1932–1982. Journal of Arboriculture. 11(11): 344–348.

Dwyer, J.F.; Nowak, D.J.; Noble, M.H.; Sisinni, S.M. 2000. Connecting people with ecosystems in the 21st century: an assessment of our Nation's urban forests. Gen. Tech. Rep. PNW–GTR–490. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 483 p.

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

Gilman, E.F.; Watson, D.G. 1993. *Acer platanoides*, Norway maple. Fact Sheet ST–28. Gainsville: Florida Cooperative Extension Service, Environmental Horticulture Department, University of Florida. http://hort.ufl.edu/trees/ACEPLAA.pdf. (September 15, 2008).

Hager, B.C.; Cannon, W.N.; Worley, D.P. 1980. Street tree policies in Ohio towns. Journal of Arboriculture. 6(7): 185–191.

Koch, J. 2000. The origin of urban forestry. In: Kuser, J.E., ed. Handbook of urban and community forestry in the Northeast. New York: Kluwer Academic: 1–10.

Lawrence, H.W. 1997. From private allee to public shade tree: historic roots of the urban forest. Arnoldia Summer 1997. A publication of the Arnold Arboretum; Cambridge, MA: Harvard University: 3–10.

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. (September 15, 2008).

Manly, B.F.J. 1992. Bootstrapping for determining sample sizes in biological studies. Journal of Experimental Marine Biology and Ecology. 158: 189–196.

McPherson, E.G.; Rowntree, R.A. 1989. Using structural measures to compare twenty-two U.S. street tree populations. Landscape Journal. 8: 13–23.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Maco, S.E.; Xiao, Q. 2005. Municipal forest benefits and costs in five US cities. Journal of Forestry. 103(8): 411–416.

Michigan State University. 2007. Emerald ash borer multistate, multiagency information Web site. Michigan Department of Agriculture and U.S. Department of Agriculture, Forest Service. http://www.emeraldashborer.info/index.cfm. (November 2, 2007).

Nowak, D.J. 1990. Street tree pruning and removal needs. Journal of Arboriculture. 16(12): 309–315.

Nowak, D.J.; Civerolo, K.L.; Rao, S.T.; Sistla, G.; Luley, C.J.; Crane, D.E. 2000. A modeling study of the impact of urban trees on ozone. Atmospheric Environment. 34: 1610–1613.

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. Integrating tools for natural resource inventories in the 21st century. Proceedings of the IUFRO Conference. GTR–NC–212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 714–720.

Nowak, D.J.; Kuroda, M.; Crane, D.E. 2004. Tree mortality rates and tree population projections in Baltimore, MD USA. Urban Forestry Urban Greening. 2: 139–147.

Odum, E.O. 1971. Fundamentals of ecology. W.B. Saunders Co. 754 p.

Raupp, M.J.; Cumming, A.B.; Raupp, E.C. 2006. Street tree diversity in North America and its potential for loss to exotic borers. Journal of Arboriculture and Urban Forestry. 32(6): 297–304.

Richards, N.A. 1983. Diversity and stability in a street tree population. Urban Ecology. 7: 159–171.

Roman, L. 2006. Trends in street tree survival, Philadelphia, PA. Philadelphia: University of Pennsylvania. Master of Environmental Studies Capstone Project. ScholarlyCommons@Penn. http://repository.upenn.edu/cgi/viewcontent.cgi?article=1003&context=mes_capstones. (October 26, 2007).

Santamour, F.S. 1990. Trees for urban planting diversity, uniformity and common sense. Proceedings, 7th Conference of the Metropolitan Tree Improvement Alliance (METRIA). 7: 57–65.

SAS Institute, Inc. 2004. SAS/STAT® 9.1 User's Guide. Cary, NC: SAS Publishing: 5136 p.

Sinclair, W.A.; Lyon, H.H. 2005. Diseases of trees and shrubs. Ithaca, NY: Comstock Publishing Associates. 659 p.

Steinman, J. 1998. Tracking the health of trees over time on forest health monitoring plots. In: Hansen, M.; Burk, T., eds. Integrating tools for natural resource inventories in the 21st century. Proceedings of the IUFRO Conference. GTR–NC–212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 334–339.

U.S. Census Bureau. 2008a. Census '90. http://www.census.gov/main/www/cen1990.html. (September 8, 2008).

U.S. Census Bureau. 2008b. 1995 Census test geographic products, TIGER line files. http://www.census.gov/population/www/censusdata/95-test/geoinfo.html. (September 8, 2008).

U.S. Department of Agriculture, Forest Service. 1998. Forest Health Monitoring 1998 field methods guide. National Forest Health Monitoring Program. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service.

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: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. www.na.fs.fed.us/spfo/pubs/pest_al/alb/index.htm. [Date accessed unknown].

APPENDIX A

PLOT DENSITY AND INTENSIFICATION

A statistical analysis to evaluate various design alternatives was completed using the triple-intensity Wisconsin street tree data collected in this study. The analysis considered the original survey data as the population being sampled. This population was sampled with replacement 999 times for a total of 1,000 (the original plus the 999 new datasets) "pilot" studies from which designs were evaluated, with each design following the sampling procedure that would be hypothetically used in a future survey. Nine design combinations were evaluated, based on the sampling intensity at the plot level (3×=890 plots, 2×=600 plots, and 1×=300 plots) and the sampling at the subplot level (four, two, or one subplots per plot). For each design the randomly selected plots (without replacement) were selected using SAS's SURVEYSELECT procedure (SAS Institute 2004) and, for designs with fewer subplots, were followed with a random selection of subplots. The designs with two subplots restricted the random selection to a pair of matching subplots (one each from each side of the road).

The survey statistics were obtained using SAS's SURVEYFREQ and SURVEYMEANS procedures (SAS Institute 2004). Table A-1 summarizes the results. The first column of data are from the observed results (obtained from slightly different methods than the main text to simplify simulation evaluations in SAS, but not invalidate results). The second and remaining columns are means of the variables of interest, the standard errors, and the percent standard error from the bootstrap simulation. The numbers in the parentheses are the 95 percent bootstrap confidence interval for the percent standard error obtained from the 2.5^{th} and 97.5^{th} percentiles of the simulated surveys. No adjustments for bias were made for these estimates or the intervals (this has the most obvious problem for the estimate of number of species in the 3 by 4 design).

Table A-1. Plot density and intensification.

Variable of interest	**Observed results** Survey estimate SE SE% No. trees (nt)	**Simulated results by intensity level** (variable mean, SE, SE%, and 95% confidence interval in parentheses)[b]								
Number of plots		3x	3x	3x	2x	2x	2x	1x	1x	1x
Number of subplots		4	2	1	4	2	1	4	2	1
Number of species[a] **(%SE 2.5th and 97.5th percentile)**	88	73 (66, 79)	63 (55, 70)	49 (41, 57)	65 (58, 72)	55 (47, 63)	42 (34, 50)	52 (43, 60)	41 (34, 49)	30 (22, 38)
Size of population of live trees (millions)	1.016 0.034 3.38% nt=2,865	1.013 0.034 3.38% (3.09, 3.66)	1.014 0.033 3.26% (2.97, 3.57)	1.014 0.036 3.55% (2.87, 4.42)	1.016 0.042 4.12% (3.73, 4.55)	1.013 0.040 3.98% (3.56, 4.48)	1.012 0.044 4.32% (3.41, 5.70)	1.016 0.059 5.83% (5.07, 6.72)	1.014 0.057 5.62% (4.82, 6.61)	1.013 0.062 6.07% (4.52, 8.80)
D.b.h. **(all trees)**	12.79 0.31 2.42% nt=2,874	12.80 0.31 2.41% (2.06, 2.80)	12.80 0.34 2.67% (2.28, 3.12)	12.79 0.44 3.48% (2.84, 4.34)	12.79 0.38 2.94% (2.47, 3.56)	12.79 0.42 3.25% (2.69, 3.95)	12.79 0.54 4.24% (3.38, 5.58)	12.80 0.53 4.14% (3.21, 5.42)	12.80 0.58 4.57% (3.58, 5.86)	12.80 0.75 5.90% (4.44, 8.56)
Crown **(domain=live)**	25.69 0.54 2.09% nt=2,865	25.70 0.54 2.09% (1.77, 2.44)	25.71 0.59 2.30% (1.96, 2.69)	25.69 0.76 2.98% (2.38, 3.74)	25.68 0.65 2.54% (2.11, 3.08)	25.69 0.72 2.80% (2.30, 3.40)	25.72 0.93 3.63% (2.82, 4.82)	25.70 0.91 3.57% (2.76, 4.64)	25.71 1.01 3.94% (3.06, 5.11)	25.71 1.29 5.07% (3.61, 7.38)
Height **(domain=live)**	34.08 0.59 1.72% nt=2,865	34.07 0.59 1.72% (1.55, 1.89)	34.08 0.65 1.89% (1.69, 2.13)	34.06 0.82 2.40% (2.07, 2.84)	34.05 0.71 2.10% (1.86, 2.36)	34.05 0.79 2.31% (2.01, 2.68)	34.05 1.00 2.93% (2.44, 3.58)	34.06 1.01 2.96% (2.48, 3.50)	34.04 1.11 3.27% (2.70, 3.98)	34.09 1.40 4.10% (3.22, 5.39)

[a] Includes an "Unknown" category

[b] Number of species includes variable mean and 95% confidence interval only

APPENDIX B.

Species composition by land use.

	Land use		
	Residential	**Commercial**	**Industrial**
Number of trees sampled	2,672	148	45
Most frequent species (% within land use)	*Acer platanoides* (29.6) *Fraxinus pennsylvanica* (15.4) *Gleditsia triacanthos* (8.2) *Acer saccharinum* (6.8) *Tilia cordata* (6.6) *Fraxinus americana* (4.1) *Acer saccharum* (4.0) *Malus* sp. (3.2) *Ulmus thomasii* (2.6) *Acer rubrum* (2.2)	*Acer platanoides* (31.8) *Fraxinus pennsylvanica* (14.9) *Gleditsia triacanthos* (8.2) *Tilia cordata* (6.1) *Prunus pensylvanica* (5.4) *Prunus* sp. (3.4) *Pinus sylvestris* (3.4) *Ginkgo biloba* (2.7) *Ulmus rubra* (2.7) *Malus* sp. (2.7)	*Acer platanoides* (84.4) *Tilia americana* (4.4) *Gleditsia triacanthos* (4.4) *Acer rubrum* (4.4) *Fraxinus pennsylvanica* (2.2)
Number of species	86	28	5
Average d.b.h. (inches)	13.2	8.7	7.0

APPENDIX C.

Wisconsin Tree Species Data Listed by Population Estimates.

Scientific name	Common name	Sample size	Population estimate	Population (%)	Mean height (ft)	Mean d.b.h. (in)	Diameter class in inches (%)								Mean die-back (%; SE)
							1-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	
Acer platanoides	Norway Maple	877	310,600	30.5	33.1	13.5	4	9.1	10.9	17.2	18.8	16.8	13.5	4.8	2.1 (0.3)
Fraxinus pennsylvanica	Green Ash	438	154,791	15.2	37.1	12.8	4.1	9.1	17.4	17.6	18.3	13.7	11.6	4.1	2.5 (0.5)
Gleditsia triacanthos	Honeylocust	242	85,542	8.4	35.4	12.2	7.9	7.9	14.5	17.8	17.8	16.9	13.2	3.7	2.3 (0.6)
Tilia cordata	Littleleaf Linden	189	67,212	6.6	34.1	12.4	10.1	9	11.1	23.3	16.4	12.7	7.9	4.8	0.4 (0.2)
Acer saccharinum	Silver Maple	180	64,157	6.3	48.2	22.3	1.7	4.4	5.6	6.1	6.1	12.2	8.9	10	4.0 (0.7)
Fraxinus americana	White Ash	112	39,716	3.9	33.1	9.7	20.5	12.5	17	16.1	10.7	13.4	6.2	0.9	0.8 (0.2)
Acer saccharum	Sugar Maple	106	37,679	3.7	37.7	14.3	5.7	4.7	16	11.3	16	19.8	9.4	8.5	4.8 (1.1)
Malus species	Crabapple	91	32,588	3.2	15.7	5.9	30.8	31.9	18.7	6.6	11	1.1	0	0	2.1 (1.2)
Ulmus thomasii	Rock Elm	67	23,422	2.3	41.3	17.6	14.9	13.4	4.5	7.5	4.5	3	4.5	9	2.8 (0.5)
Acer rubrum	Red Maple	61	21,386	2.1	33.5	9.3	13.1	11.5	39.3	13.1	11.5	1.6	3.3	1.6	1.1 (0.5)
Celtis occidentalis	Northern Hackberry	34	12,220	1.2	32.1	11.8	14.7	5.9	20.6	14.7	5.9	23.5	8.8	0	1.5 (0.9)
Ulmus pumila	Siberian Elm	33	11,202	1.1	31.5	13.0	18.2	9.1	18.2	6.1	6.1	18.2	6.1	3	4.7 (1.0)
Ulmus rubra	Slippery Elm	28	10,184	1	28.5	11.0	39.3	10.7	14.3	3.6	3.6	0	3.6	0	3.6 (1.7)
Quercus rubra	Northern Red Oak	24	8,147	0.8	38.4	11.4	33.3	20.8	8.3	0	0	4.2	0	12.5	5.2 (1.3)
Tilia americana	American Basswood	22	8,147	0.8	29.8	10.1	36.4	18.2	9.1	0	0	13.6	4.5	9.1	2.3 (1.9)
Ulmus americana	American Elm	23	8,147	0.8	37.7	10.3	13	34.8	17.4	13	4.3	0	0	8.7	11.3 (5.1)
Fraxinus excelsior	European Ash	16	6,110	0.6	31.2	13.9	12.5	6.3	0	0	37.5	18.8	12.5	12.5	5.6 (3.0)

(continued)

Wisconsin Tree Species Data Listed by Population Estimates (continued).

Scientific name	Common name	Sample size	Population estimate	Population (%)	Mean height (ft)	Mean d.b.h. (in)	Diameter class in inches (%)								Mean die-back (%; SE)
							1-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	
Acer negundo	Boxelder	14	5,092	0.5	30.5	10.5	7.1	42.9	7.1	14.3	0	14.3	0	0	1.1 (0.8)
Quercus alba	White Oak	15	5,092	0.5	35.8	12.3	33.3	20	6.7	0	0	0	20	0	5.3 (0.9)
Quercus ellipsoidalis	Northern Pin Oak	15	5,092	0.5	28.2	9.7	13.3	33.3	0	6.7	20	20	0	0	7.3 (6.4)
Syringa reticulata	Japanese Tree Lilac	13	5,092	0.5	14.8	3.9	53.8	46.2	0	0	0	0	0	0	3.8 (1.8)
Acer ginnala	Amur Maple	12	4,073	0.4	12.8	3.0	58.3	41.7	0	0	0	0	0	0	1.3 (0.8)
Populus deltoides	Eastern Cottonwood	12	4,073	0.4	46.2	16.3	0	0	0	33.3	16.7	25	0	16.7	0.0 (0)
Betula papyrifera	Paper Birch	9	3,055	0.3	32.5	6.2	22.2	22.2	44.4	0	11.1	0	0	0	3.3 (1.7)
Carya ovata	Shagbark Hickory	9	3,055	0.3	36.1	10.1	0	33.3	33.3	0	11.1	0	0	22.2	0.0 (0)
Crataegus spatulata	Littlehip Hawthorn	9	3,055	0.3	17.1	4.4	33.3	44.4	22.2	0	0	0	0	0	0.0 (0)
Juglans nigra	Black Walnut	8	3,055	0.3	28.2	10.9	25	0	12.5	25	12.5	12.5	0	0	1.9 (1.0)
Picea glauca	White Spruce	8	3,055	0.3	30.2	7.8	37.5	0	25	12.5	12.5	12.5	0	0	1.9 (0.8)
Picea pungens	Blue Spruce	8	3,055	0.3	22.0	7.3	37.5	12.5	12.5	12.5	0	25	0	0	0.0 (0)
Pinus strobus	Eastern White Pine	8	3,055	0.3	47.2	16.5	12.5	0	0	0	37.5	0	37.5	0	2.5 (2.0)
Pinus sylvestris	Scotch Pine	8	3,055	0.3	20.3	12.4	12.5	12.5	0	12.5	37.5	0	25	0	5.0 (1.6)
Populus tremuloides	Quaking Aspen	10	3,055	0.3	26.9	4.7	50	20	20	10	0	0	0	0	1.0 (0.5)
Prunus pensylvanica	Pin Cherry	9	3,055	0.3	13.4	2.4	77.8	22.2	0	0	0	0	0	0	5.0 (0.8)
Prunus serotina	Black Cherry	8	3,055	0.3	24.9	7.9	12.5	50	0	25	0	0	0	12.5	0.6 (0.6)
Quercus velutina	Black Oak	10	3,055	0.3	32,5	15.0	0	30	0	20	10	0	10	20	6.5 (1.9)

(continued)

Wisconsin Tree Species Data Listed by Population Estimates (continued).

Scientific name	Common name	Sample size	Population estimate	Population (%)	Mean height (ft)	Mean d.b.h. (in)	Diameter class in inches (%)								Mean die-back (%; SE)
							1-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	
Syringa sp.	Lilac	8	3,055	0.3	12.1	2.6	50	50	0	0	0	0	0	0	1.9 (0.9)
Thuja occidentalis	Northern White Cedar	10	3,055	0.3	17.1	5.4	10	50	40	0	0	0	0	0	1.0 (1.0)
Catalpa speciosa	Northern Catalpa	7	2,037	0.2	34.4	19.8	0	0	0	28.6	0	14.3	0	14.3	5.7 (3.2)
Ginkgo biloba	Ginkgo	6	2,037	0.2	18.7	5.7	66.7	0	0	16.7	0	16.7	0	0	0.0 (0)
Ostrya virginiana	Eastern Hophornbeam	6	2,037	0.2	20.7	6.7	16.7	16.7	33.3	33.3	0	0	0	0	4.2 (0)
Picea abies	Norway Spruce	5	2,037	0.2	51.2	21.5	0	0	0	0	20	0	40	0	11.0 (0)
Pinus resinosa	Red Pine	6	2,037	0.2	24.9	10.0	0	16.7	16.7	33.3	33.3	0	0	0	3.3 (1.4)
Prunus sp.	Ornamental Cherry	5	2,037	0.2	19.7	3.4	20	80	0	0	0	0	0	0	16.0 (0)
Prunus virginiana	Common Chokecherry	5	2,037	0.2	18.0	5.3	0	80	20	0	0	0	0	0	3.0 (3.4)
Quercus marcrocarpa	Bur Oak	6	2,037	0.2	36.7	22.9	16.7	16.7	0	0	0	0	16.7	0	9.2 (7.5)
Robinia pseudoacacia	Black Locust	5	2,037	0.2	45.3	15.6	0	0	20	0	0	60	20	0	5.0 (0)
Salix discolor	Pussy Willow	6	2,037	0.2	18.7	5.3	0	66.7	33.3	0	0	0	0	0	4.2 (0)
Acer campestre	Hedge Maple	2	1,018	0.1	16.4	5.5	0	50	50	0	0	0	0	0	0.0 (0)
Acer x freemanii	Freeman Maple	4	1,018	0.1	51.2	14.6	0	0	25	0	50	0	25	0	0.0 (0)
Aesculus hippocastanum	Horsechestnut	2	1,018	0.1	32.5	17.2	0	0	0	0	50	0	50	0	0.0 (0)
Alnus glutinosa	European Alder	2	1,018	0.1	12.1	3.5	50	50	0	0	0	0	0	0	5.0 (0)
Amelanchier arborea	Downy Serviceberry	2	1,018	0.1	16.1	3.5	50	50	0	0	0	0	0	0	0.0 (0)

(continued)

Wisconsin Tree Species Data Listed by Population Estimates (continued).

Scientific name	Common name	Sample size	Population estimate	Population (%)	Mean height (ft)	Mean d.b.h. (in)	Diameter class in inches (%)								Mean die-back (%; SE)
							1-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	
Amelanchier sanguinea	Roundleaf Serviceberry	2	1,018	0.1	18.0	2.3	100	0	0	0	0	0	0	0	2.5 (0)
Betula pendula	European White Birch	2	1,018	0.1	31.5	6.5	0	50	50	0	0	0	0	0	0.0 (0)
Carya cordiformis	Bitternut Hickory	3	1,018	0.1	25.3	6.0	33.3	0	33.3	33.3	0	0	0	0	0.0 (0)
Crataegus phaenopyrum	Washington Hawthorn	2	1,018	0.1	14.1	4.8	0	100	0	0	0	0	0	0	0.0 (0)
Crataegus sp.	Carriere Hawthorn	2	1,018	0.1	32.1	9.1	0	0	0	100	0	0	0	0	0.0 (0)
Fagus grandifolia	American Beech	2	1,018	0.1	41.3	14.5	0	0	50	0	0	0	50	0	0.0 (0)
Gynmocladus dioicus	Kentucky Coffeetree	2	1,018	0.1	34.1	12.2	0	0	50	0	0	50	0	0	0.0 (0)
Morus sp.	Mulberry	2	1,018	0.1	36.1	19.3	0	0	0	0	50	0	0	0	0.0 (0)
Pinus banksiana	Jack Pine	3	1,018	0.1	15.4	3.4	66.7	33.3	0	0	0	0	0	0	3.3 (1.6)
Populus alba	White Poplar	2	1,018	0.1	64.0	31.1	0	0	0	0	0	0	0	0	0.0 (0)
Populus grandidentata	Bigtooth Aspen	2	1,018	0.1	17.1	1.3	100	0	0	0	0	0	0	0	0.0 (0)
Populus nigra	Lombardy Poplar	3	1,018	0.1	43.3	14.7	0	33.3	0	0	0	0	66.7	0	17.8 (10.4)
Prunus avium	Sweet Cherry	3	1,018	0.1	36.7	14.1	0	0	0	0	66.7	33.3	0	0	3.3 (0)
Quercus sp.	Oak	2	1,018	0.1	9.5	1.5	100	0	0	0	0	0	0	0	32.5 (0)
Rhus typhina	Staghorn Sumac	2	1,018	0.1	13.1	4.7	0	100	0	0	0	0	0	0	10.0 (0)
Salix sp.	Willow	2	1,018	0.1	13.4	4.1	0	100	0	0	0	0	0	0	0.0 (0)
Sorbus L.	Mountain Ash	2	1,018	0.1	15.1	5.3	50	0	0	50	0	0	0	0	0.0 (0)
Syringa vulgaris	Common Lilac	2	1,018	0.1	11.2	2.7	50	50	0	0	0	0	0	0	5.0 (0)

(continued)

Wisconsin Tree Species Data Listed by Population Estimates.

Scientific name	Common name	Sample size	Population estimate	Population (%)	Mean height (ft)	Mean d.b.h. (in)	Diameter class in inches (%)								Mean die-back (%; SE)
							1-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	
Ulmus sp.	Elm	2	1,018	0.1	20.0	1.4	100	0	0	0	0	0	0	0	0.0 (0)
Unknown unknown	Unknown	4	1,018	0.1	32.1	19.3	0	0	50	0	0	0	0	0	5.0 (3.5)
Morus alba	White Mulberry	1	346	0.034	17.1	7.2	0	0	100	0	0	0	0	0	0.0 (0)
Acer pseudoplatanus	Sycamore Maple	1	0	0	29.8	12.8	0	0	0	0	100	0	0	0	30.0 (0)
Betula lenta	Black Birch	1	0	0	23.9	5.3	0	100	0	0	0	0	0	0	0.0 (0)
Carpinus betulus	European Hornbeam	1	0	0	23.9	16.8	0	0	0	0	0	100	0	0	0.0 (0)
Carpinus caroliniana	American Hornbeam	1	0	0	14.1	4.5	0	100	0	0	0	0	0	0	0.0 (0)
Fraxinus nigra	Black Ash	1	0	0	40.0	6.1	0	0	100	0	0	0	0	0	0.0 (0)
Fraxinus quadrangulata	Blue Ash	1	0	0	12.1	1.1	100	0	0	0	0	0	0	0	0.0 (0)
Juniperus virginiana	Eastern Red Cedar	1	0	0	9.8	1.3	100	0	0	0	0	0	0	0	0.0 (0)
Liriodendron tulipifera	Tulip Tree	1	0	0	32.1	12.3	0	0	0	0	100	0	0	0	0.0 (0)
Pinus sp.	Pine	1	0	0	47.9	20.5	0	0	0	0	0	0	100	0	5.0 (0)
Populus balsamifera	Balsam Poplar	1	0	0	47.9	7.1	0	0	100	0	0	0	0	0	20.0 (0)
Populus canadensis	Carolina Poplar	1	0	0	25.9	5.6	0	100	0	0	0	0	0	0	0.0 (0)
Populus canescens	Gray Poplar	1	0	0	54.1	17.1	0	0	0	0	0	100	0	0	0.0 (0)
Rhamnus sp.	European Buckthorn	1	0	0	20.0	4.4	0	100	0	0	0	0	0	0	0.0 (0)
Sambucus nigra	Elderberry	1	0	0	25.9	8.3	0	0	100	0	0	0	0	0	5.0 (0)
Thuja plicata	Western Redcedar	1	0	0	7.9	1.2	100	0	0	0	0	0	0	0	0.0 (0)

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

Cumming, Anne Buckelew; Twardus, Daniel B.; Hoehn, Robert; Nowak, David J.; Mielke, Manfred; Rideout, Richard; Butalla, Helen; Lebow, Patricia. 2008 Wisconsin street tree assessment 2002-2003. NA-FR-02-08. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 23p. 2008