URBAN FORESTS OF WISCONSIN, 2012

Wisconsin Department of Natural Resources
Forestry Division
Madison, WI

PUB-FR-615 2017
February 2017

WISCONSIN DEPT. OF NATURAL RESOURCES
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

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ACKNOWLEDGEMENTS

In addition to the authors, personnel involved in compiling this report included the following employees of the U.S. Forest Service, Northern Research Station: Dennis May, Peter Koehler, Mark Majewsky, Mark Hatfield and Cassandra Olson. We would also like to acknowledge the Lumberjack Resource Conservation and Development Council, Inc. for their work in collecting field data and providing information used in this report. We also thank Don Kissinger and Tricia Knoot of the Wisconsin Department of Natural Resources and John Stanovick of the U.S. Forest Service for their independent review.

We also thank the following groups of the Forest Service for their support and funding of this project: State and Private Forestry Landscape Scale Restoration grant program; Forest Health Monitoring Program; Forest Inventory and Analysis; Northeastern Area Urban and Community Forestry Program; and the Northern Research Station.

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ABSTRACT

Trees in cities can contribute significantly to human health and environmental quality. In 2002, there were an estimated 26.9 million trees (36.9 trees / acre) within non-forested urban areas in Wisconsin. In 2012, the non-forest urban areas were reassessed based on 185 field plots. Urban forest attributes changed between 2002 and 2012 due, in part, to the expansion of urban areas, but also tree planting and natural regeneration, tree growth and tree mortality. Based on the 2012 data, urban forest structure, functions, health, and values in non-forest urban areas in Wisconsin (i.e., hereafter referred to as urban forests) were analyzed using the i-Tree Eco model. In addition, changes in tree populations greater than 5 inches d.b.h. were assessed (2002-2012). Results reveal that urban forests in 2012 have an estimated 42.8 million trees (45.9 trees / acre). Trees are considered as any woody plant with a d.b.h. ≥ 1 inch. Most trees are found in residential areas (69.2 percent). The most common species are common lilac (*Syringa vulgaris*), Northern white cedar (*Thuja occidentalis*), and apple species (*Malus spp.*). Wisconsin's urban forest currently stores about 4.0 million tons of carbon valued at $507 million. In addition, these trees remove about 212 thousand tons of carbon per year ($26.8 million per year) and about 7,030 tons of air pollution per year ($47.7 million per year). Trees in non-forest urban Wisconsin are estimated to decrease annual residential energy costs by $78.9 million per year. The compensatory value is estimated at $19.3 billion. In Wisconsin, 64 percent of the trees were within maintained areas with residential land uses containing the highest proportion of maintained trees. Overall, 1.1 percent of trees were recorded as standing dead. Between 2002 and 2012, one species that had a statistically significant increase in trees greater than 5 inches was silver maple (*Acer saccharinum*). Species with statistically significant decreases were white ash (*Fraxinus americana*) and sugar maple (*Acer saccharum*). Strengths and weaknesses of the national urban forest inventory and analysis protocol were identified and recommendations for intensification are made. Information in this report can be used to advance the understanding and management of urban forests to improve human health and environmental quality in Wisconsin.

Keywords: Air pollution removal, carbon sequestration, ecosystem services, FIA, i-Tree, tree value, urban forestry.

HIGHLIGHTS

Value

- Urban vegetation, particularly trees, provides numerous benefits that can improve environmental quality and human health in and around urban areas.
- The structural value of Wisconsin's urban forests is valued at about $19.8 billion, including $507 million in carbon storage value.
- Urban forests in Wisconsin currently provide annual functional values greater than $150 million: $26.8 million in carbon sequestration, $47.7 million in pollution removal and $78.9 million in reduced building energy use.

Area

- There were a total of 933,000 acres of urban forests in Wisconsin.
- The land use that covered the largest area within the urban boundary of Wisconsin was residential at 432,000 acres.

Trees

- An estimated 42.8 million trees were found in urban areas of Wisconsin with 69.2 percent of them located on residential areas.
- A total of 65 species were encountered within urban areas of Wisconsin.
- The most common species in Wisconsin urban areas were common lilac (11.4 percent of the population), Northern white cedar (10.7 percent), and apple species (7.6 percent).
- Of the 42.8 million trees found in Wisconsin urban areas, 67.6 percent were < 6 inches d.b.h. One hundred percent of common lilac, winged burning bush, American plum, and common chokecherry were < 3 inches d.b.h.

Urban Forest Health

- In Wisconsin, American elm was the tree species with the highest average percent crown dieback.
- The most common damages on trees were tree bark inclusion.
- Potential risks of exotic pests include gypsy moth, emerald ash borer and pine shoot beetle, which can all be found in Wisconsin. Asian longhorned beetle poses a threat to more than a quarter of the tree population.

Protocol Evaluation

- A ten-year interval between data set samples created significant limitations on trend analysis.
- Traditional FIA sample density of one plot per 6,000 acres is insufficient to capture the high species diversity and low tree stem count in urban forests.

EXECUTIVE SUMMARY

Data from 185 field plots located within non-forest urban areas (U.S. Department of Commerce 2000 definition) of Wisconsin were measured in 2012. Land classified as forest based on the Forest Service Forest Inventory and Analysis (FIA) were excluded from the sample. Thus, this assessment analyzes non-forest urban areas in Wisconsin, hereafter referred to as “urban forests”. Trees within the urban boundary were sampled according to the U.S. Department of Agriculture (USDA) Forest Service, FIA and Forest Health Monitoring programs’ protocols. Data were analyzed using the Forest Service’s i-Tree Eco model to quantify and describe the benefits of Wisconsin’s urban forest. The data from this project updated values from a 2002 urban forest assessment in Wisconsin on ecosystem services and values provided by urban forests, and analyze change for species greater than 5 inches in diameter. This project also evaluated the sampling protocols’ value as a component of Wisconsin's developing statewide continuous urban forest assessment program.

In Wisconsin’s urban forest there are an estimated 42.8 million trees with 29.6 million in residential areas (69.2 percent of trees), 6.4 million within institutional / park areas (15.0 percent), 5.3 million on commercial / transportation lands (12.4 percent), 650,000 in wooded areas (1.5 percent), 560,000 on agricultural and other lands (1.3 percent) and 225,000 on wetland areas (0.5 percent) (Table 1). The most common species were common lilac (11.4 percent of the population), Northern white cedar (10.7 percent), apple species (7.6 percent), European buckthorn (5.9 percent) and Eastern red cedar (5.6 percent). Species that dominated in terms of leaf area were silver maple (10.6 percent), Norway maple (8.4 percent), Northern red oak (5.9 percent), green ash (5.4 percent) and Eastern red cedar (4.9 percent).

Table 1—Summary of urban forest populations estimates

			Three most common species					
Land use	**Area**	**Trees**	**1**		**2**		**3**	
	acres	*number*		%		%		%
Residential	431,600	29,610,000	Common lilac	16.4	Apple	10.7	European buckthorn	8.2
Institutional/Park	137,200	6,435,000	Winged burning bush	34.5	Scotch pine	11.1	Silver maple	9.9
Commercial/trans.	169,800	5,314,000	Northern white cedar	62.5	Eastern red cedar	14.6	Siberian elm	10.4
Partially Forested[a]	73,900	648,700	Green ash	19.0	Apple	14.3	Black locust	14.3
Agriculture / other	88,300	559,400	Norway maple	25.0	Green ash	18.7	White ash	18.7
Wetland	32,200	225,800	Green ash	71.4	Alder	28.6		
Total urban	932,900	42,800,000	Common lilac	11.4	Northern white cedar	10.7	Apple	7.6

1,2,3 = first-, second-, and third-most common tree within each land use or total urban area, respectively.
[a] plots with a portion of its area meeting the FIA definition of forest

Forest health data collected on crown conditions and occurrence of damage indicates that the urban forests of Wisconsin are healthy and vigorous with 1.1 percent of trees classified as dead. However, risks to the urban forest exist. The greatest potential risks from insect and diseases in

Wisconsin are from gypsy moth (5.8 million trees at risk; 13.6 percent of live tree population), emerald ash borer (3.2 million trees; 7.6 percent) and pine shoot beetle (2.7 million trees; 6.4 percent). The greatest risk from insects and diseases outside of Wisconsin come from Asian longhorned beetle (11.0 million trees; 26.0 percent), southern pine beetle (3.7 million trees; 8.7 percent), and sirex wood wasp (2.5 million trees; 5.9 percent).

The 42.8 million urban trees in Wisconsin have a compensatory value of $19.3 billion, provide an annual energy saving to residents of $78.9 million, remove $47.7 million worth of pollution from the air annually, and store 4.0 million tons of carbon valued at $507 million.

INTRODUCTION

Urban vegetation, particularly trees, provides numerous benefits that can improve environmental quality and human health in and around urban areas. Urban trees in particular make significant contributions to improve air and water quality, reduce energy used for heating and cooling buildings, cool air temperatures, reduce ultraviolet radiation, and many other environmental and social benefits (Nowak and Dwyer 2007). Structural data about these trees and forests (e.g., number of trees, species composition, tree size, health, and tree location) provide the basis to estimate numerous ecosystem services and values derived from these natural resources, and establish the foundation to improve management to enhance these services for future generations.

Urban forests are comprised of all trees (both within and outside forested stands) that occur within the U.S. Census Bureau definition of urban areas. Urban areas are defined as all territory, population, and housing units located within urbanized areas or urban clusters, which are based on population density (areas with core population density of 1,000 people per square mile), but includes surrounding areas with lesser population density (see U.S. Department of Commerce 2007 for definitions).

Urban forests provide a multitude of benefits to society, such as recreational opportunities, aesthetics, and cleaner air and water. Millions of dollars are spent annually to maintain them, yet relatively little is known about this important resource. Management of any natural resource requires knowledge of type, size, and quantity of the resource. Inventories and assessments to monitor composition, size, and health provide information about the current status of urban forests, and, if compiled periodically, information about how the forest changes over time.

In 2002, an assessment of Wisconsin's urban forest was conducted and found a total of 130.6 million trees—103.7 million in forests within urban areas and 26.9 million in non-forest urban areas (Cumming et al. 2007). In 2012, the urban forest was reassessed, but the study boundary was modified. The area changed as 1) urban area increased between 2002 and 2012, thus more urban land was included and 2) the 2012 study focused only on the urban plots that did not meet the traditional FIA definition of "forest." In the 2002 study, these urban forest plots were segregated out and referred to as "$UFIA^{+}$" to allow urban foresters to distinguish between "natural forest" land, referred to in the report as "$UFIA_f$", which they typically are not responsible for managing (i.e. urban woodlots) and the "urban forest" land which they traditionally do manage (i.e. street, park and yard trees).

This report details information on a) the extent and distribution of the urban forest, b) the characteristics of the urban tree population, c) the health of the urban trees, d) ecosystem services and values provided by the urban trees, e) change in tree populations for trees greater than 5 inches in diameter and f) an evaluation of the USDA Forest Service's Urban Forest Inventory and Analysis methodology for Wisconsin's statewide urban forest assessment program. Methods used in gathering these data are given in Appendix A.

RESULTS

Extent and Land Use Distribution of Wisconsin's Urban Forest

The 2000 census-defined urban land area used in this study is about 3.0 percent of the total land area of Wisconsin. This is an increase from 2.4 percent in 1990. Wisconsin ranked 26th in the coterminous United States for amount of urban land in 2000 and 26th in percent urban growth between 1990 and 2000 (Nowak et al. 2005). Forecasts predict urban land in the State will grow from 3.0 percent in 2000 to 8.3 percent of the land area by 2050, holding Wisconsin at 25th in the State ranking of percent urban land (Nowak and Walton 2005). Urban land area is, of course, influenced by the human population. State population was 4.89 million in 1990 and increased to 5.36 million in 2000 and 5.69 million in 2010 (U.S. Department of Commerce 1999; U.S. Department of Commerce 2000; U.S. Department of Commerce 2010). Wisconsin's population is projected to continue to increase between 2000 and 2030 by 14.7 percent or 0.79 million people to 6.15 million in 2030 (U.S. Department of Commerce 2013).

There were a total of 933 thousand acres of urban areas assessed in the 2012 study (Table 2). This land was selected for sampling based on the 2000 Census Urban Areas with sampling limited to only plots that were not fully forested as defined by FIA. Urban areas were classified by their principal land use in the field. The land uses designated for this study were residential, commercial/transportation, institutional/parks, agriculture/other, partially forested (i.e., plots with a portion of its area meeting the FIA definition of forest), and wetland. The distribution of urban land uses are residential (46.3 percent), followed by commercial/transportation (18.2 percent), institution/parks (14.7 percent), agriculture/other (9.5 percent), partially forested (7.9 percent), and wetland (3.4 percent) (Figure 1).

Table 2—Area of land within urban areas by land use, Wisconsin, 2012

Land use*	Area
	acres
Residential	432,000
Commercial/transportation	170,000
Institutional/parks	137,000
Agriculture/other	88,000
Partially forested	74,000
Wetland	32,000
Total Urban	933,000

*see Glossary for definitions

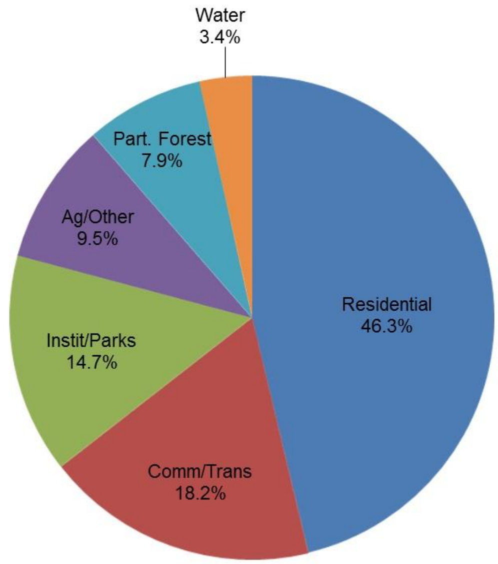

Figure 1—Land distribution based on urban plots, Wisconsin, 2012.

There are an estimated 42.8 million trees in Wisconsin's urban areas. Of these urban trees, about 29.6 million (69.2 percent) are found in the residential land use. There were a total of 597 live trees sampled. The average diameter at breast height (d.b.h.) was 5.4 inches, with a median d.b.h. of 2.9 inches. The average basal area (stem cross sectional area of a tree at 4.5 feet) was 16.4 square feet per acre. The average number of trees per acre in Wisconsin urban areas is 45.9 (Table 3). Tree density was highest on residential land (68.6 trees per acre), followed by institutional/parks (46.9 trees per acre), commercial/transportation (31.3 trees per acre), partially forested (8.8 trees per acre), wetland (7.0 trees per acre) and agriculture/other (6.3 trees per acre) (Figure 2). The average tree d.b.h. by land use was 10.4 inches on wetlands, 9.6 inches on partially forested, 7.9 inches on agriculture/other, 6.1 inches on institutions/parks, 5.6 inches on residential and 2.8 inches on commercial/transportation. Average basal area per acre by land use was 26.2 square feet per acre on residential, 18.8 square feet per acre on institutional/parks, 6.3 square feet per acre on partially forested, 5.3 square feet per acre on wetland, 3.4 square feet per acre on commercial/transportation and 2.6 square feet per acre on agriculture/other land.

Table 3—Forest and tree characteristics by land use type, Wisconsin, 2012

		Trees			D.b.h.	
Land use	**Urban land**	**Number**	**Density**	**Basal area**	**Avg**	**Median**
	percent	*millions*	*trees/acre*	*ft²/ac*	*inches*	
Residential	46.3	29.6	68.6	26.2	5.6	3.1
Commercial/transportation	18.2	5.3	31.3	3.4	2.8	1.6
Institutions/parks	14.7	6.4	46.9	18.8	6.1	4.6
Agriculture/other	9.5	0.56	6.3	2.6	7.9	7.7
Partially forested[a]	7.9	0.65	8.8	6.3	9.6	7.9
Wetland	3.4	0.23	7.0	5.3	10.4	10.5
Total urban	100.0	42.8	45.9	16.4	5.4	2.9

D.b.h. = Diameter at breast height
[a] plots with a portion of its area meeting the FIA definition of forest

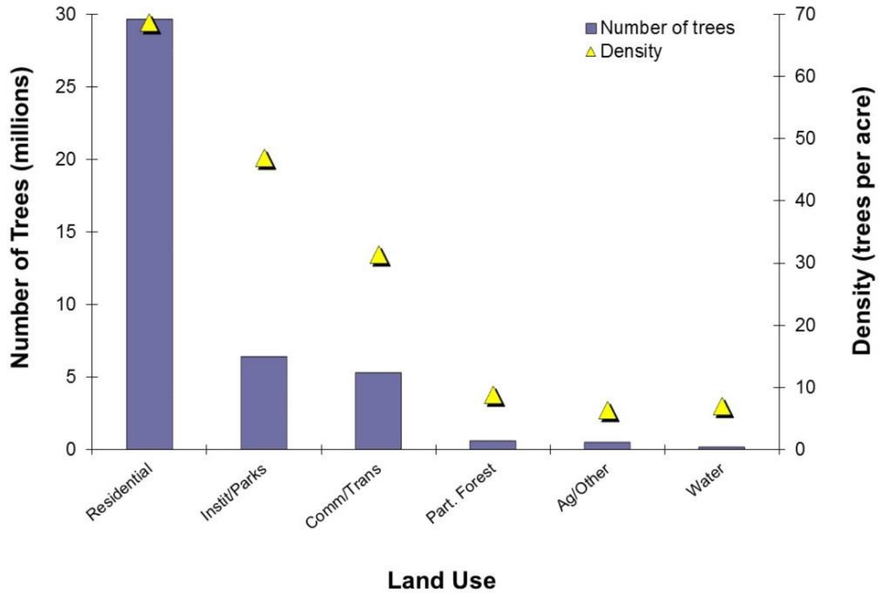

Figure 2—Tree population and density by land use type, Wisconsin, 2012.

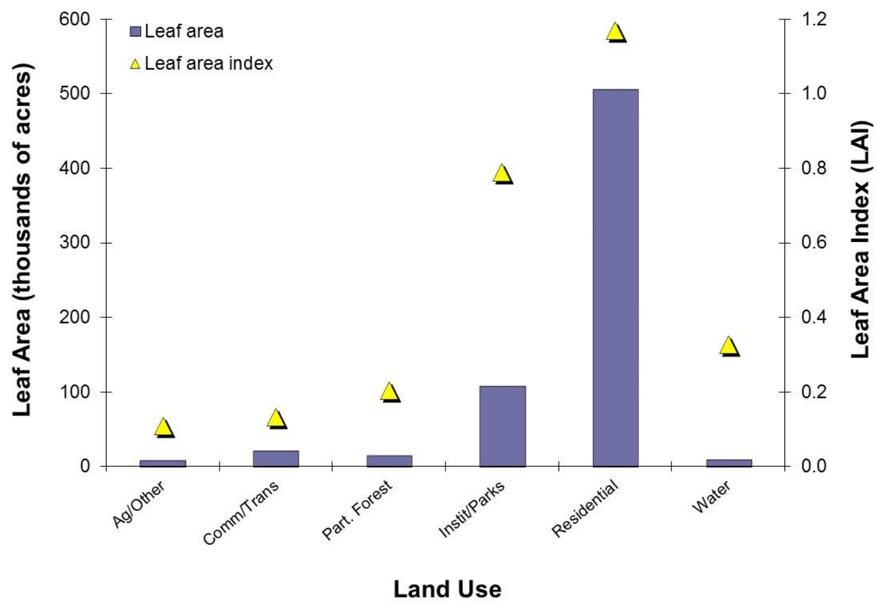

Figure 3—Total leaf area and leaf area index by land use, Wisconsin, 2012.

Total leaf area is greatest in residential land uses (75.3 percent of total tree leaf area) (Figure 3). Leaf area is a measure of leaf surface area (one side). Leaf area index (LAI) is a measure of the total leaf surface area (one side) divided by land area. As each land use has a different land area, LAI standardizes the canopy depth on an equal area basis. Higher LAIs indicate a greater leaf surface area per acre of land. The land use that has the highest LAI is residential (1.2) (Figure 3).

The Tree Population and Species Characteristics of Wisconsin's Urban Forest

Species Composition

The most common species observed in Wisconsin urban areas are common lilac (11.4 percent of the population), Northern white cedar (10.7 percent), and apple species (7.6 percent) (Figure 4-5). The 10 most frequent species account for 63.0 percent of the total urban tree population.

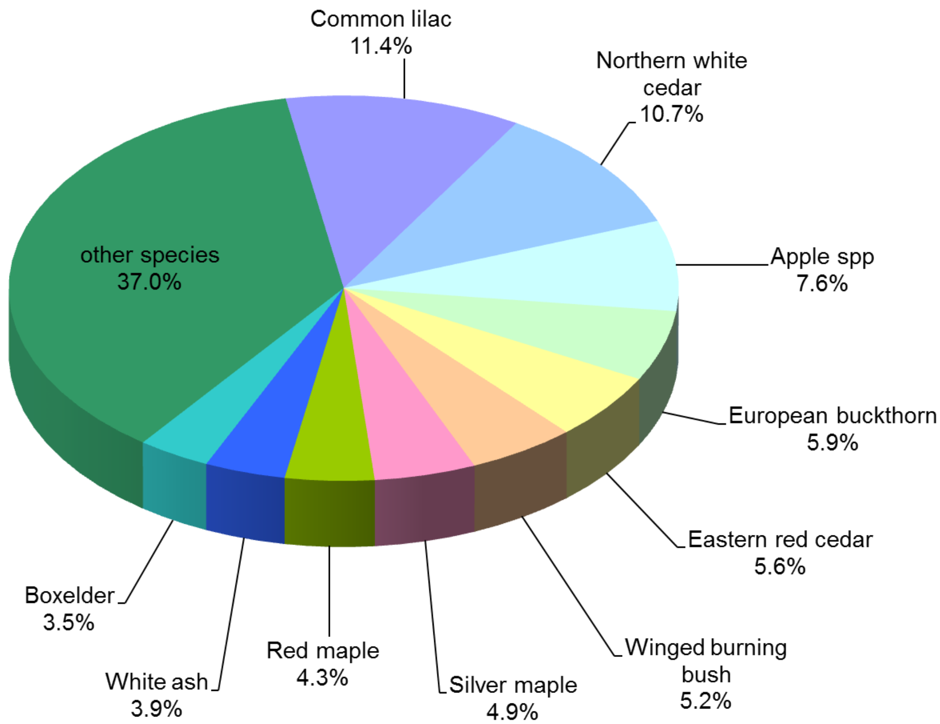

Figure 4—Urban tree species composition, Wisconsin, 2012.

The distribution of the top 10 species in urban areas varied by land use (Figure 6). The greatest proportion of many of the top 10 species is found in residential lands. For example, over 90 percent of all common lilac, apple species, European buckthorn, and red maple are found on residential lands. Also, various species tend to be more dominant in certain land uses (Figure 7). For example, Northern white cedar comprises 62.5 percent of the commercial/transportation tree population, while winged burning bush comprises 34.6 percent of institutional/parks land use. Species composition also varied by tree size. For trees < 5 inches d.b.h. (trees measured on microplots), the common species were common lilac (19.6 percent), Northern white cedar (17.6 percent), and European buckthorn (9.8 percent) (Figure 8). For trees > 5 inches d.b.h., the common species were green ash (8.1 percent), silver maple (7.7 percent), and apple species (6.5 percent) (Figure 9). A total of 65 species were encountered within Wisconsin's urban forests. The scientific names of the species sampled are found in Appendix B. Total species summary information is provided in Appendix C.

Species composition varies by land use. The most common species on residential lands were common lilac (16.4 percent), apple species (10.7 percent), and European buckthorn (8.2 percent)

(Figure 10). The most common species on institutional/park lands were winged burning bush (34.6 percent), Scotch pine (11.1 percent), and silver maple (9.9 percent) (Figure 11). The most common species on commercial/transportation lands were Northern white cedar (62.3 percent), Eastern red cedar (14.6 percent), and Siberian elm (10.4 percent) (Figure 12). The most common species on partially forested lands were green ash (19.1 percent), black locust (14.3 percent), and apple species (14.3 percent) (Figure 13). The most common species on wetland land use were green ash (71.4 percent) and alder (28.6 percent) (Figure 15). The most common species on agriculture/other lands were Norway maple (25.0 percent), white ash (18.8 percent), and green ash (18.8 percent) (Figure 15). Total species summary information by land use type is provided in Appendix D.

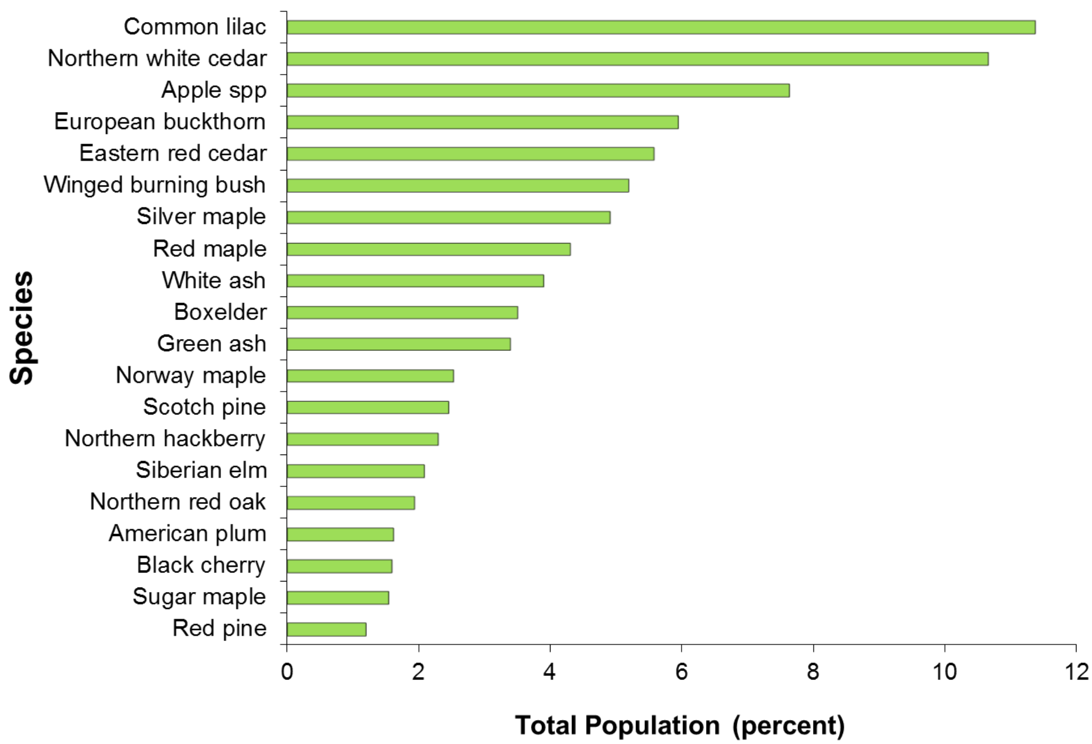

Figure 5—Percent of total urban tree population for 20 most common tree species, Wisconsin, 2012.

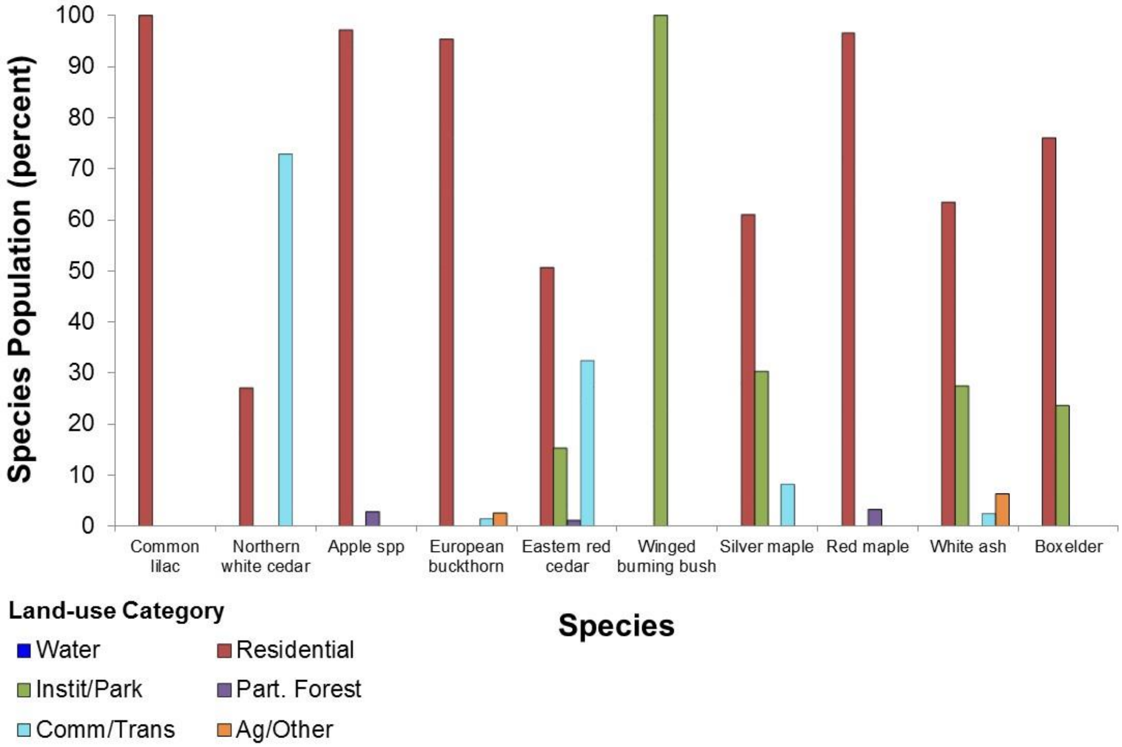

Figure 6—Distribution (percent of species population) of top 10 species by land use type, Wisconsin, 2012. For example, 100 percent of common lilac is found in residential areas.

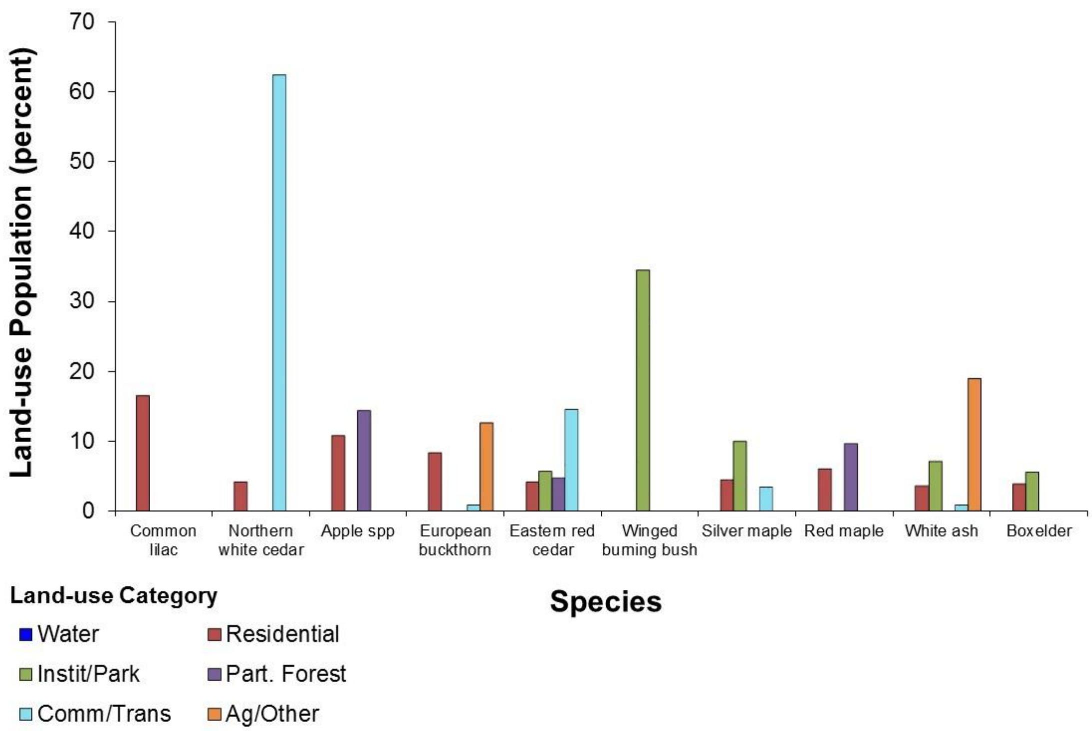

Figure 7—Percent of land use occupied by top 10 tree species, Wisconsin, 2012. For example, 62.5 percent of commercial/transportation trees are Northern white cedar.

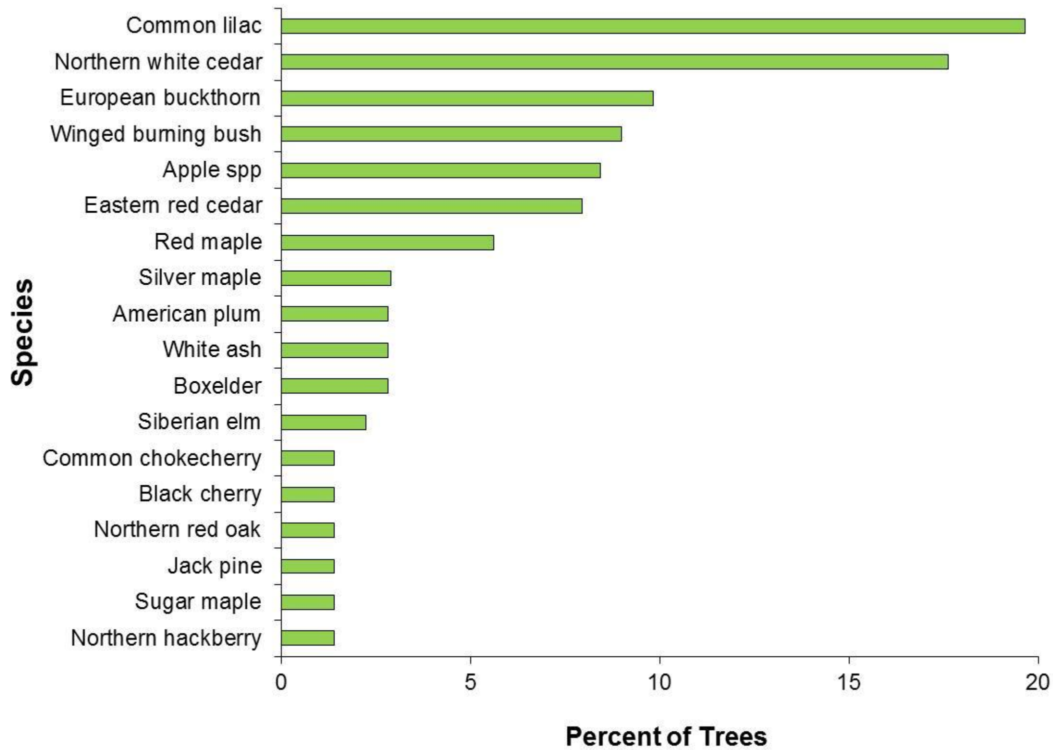

Figure 8—Percent of urban tree population < 5 inches diameter at breast height (d.b.h.) for the 18 species less than 5 inches d.b.h., Wisconsin, 2012.

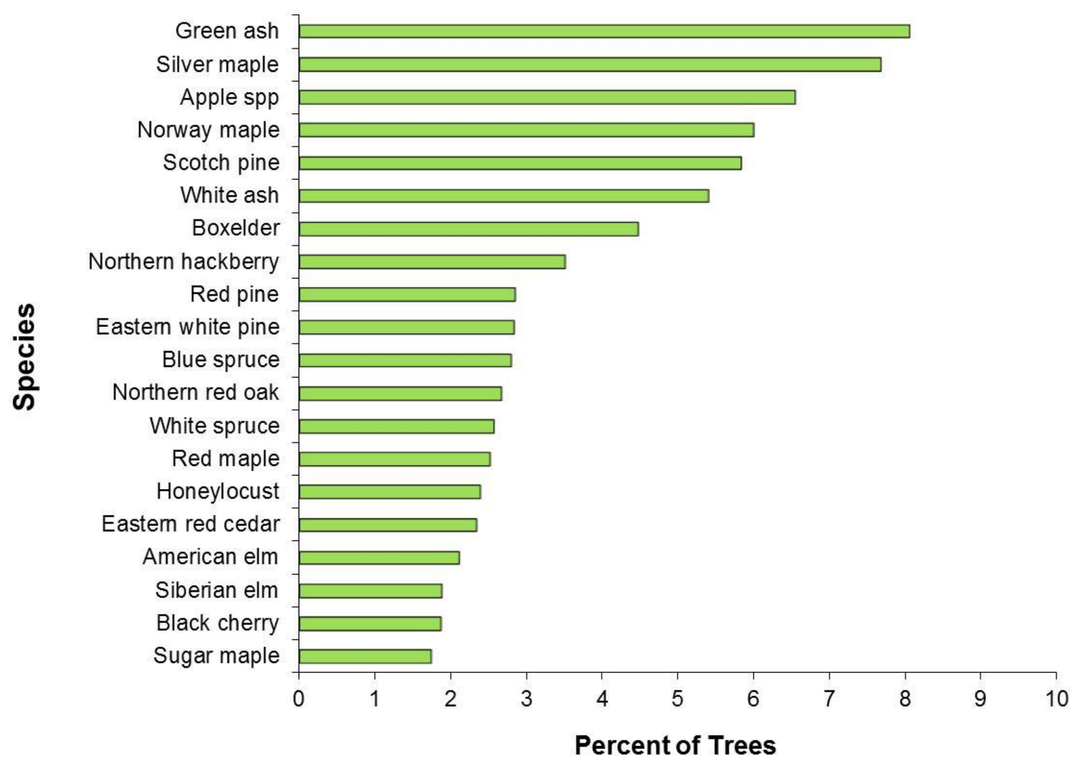

Figure 9—Percent of urban tree population > 5 inches diameter at breast height (d.b.h.) for 20 most common species greater than 5 inches d.b.h., Wisconsin, 2012.

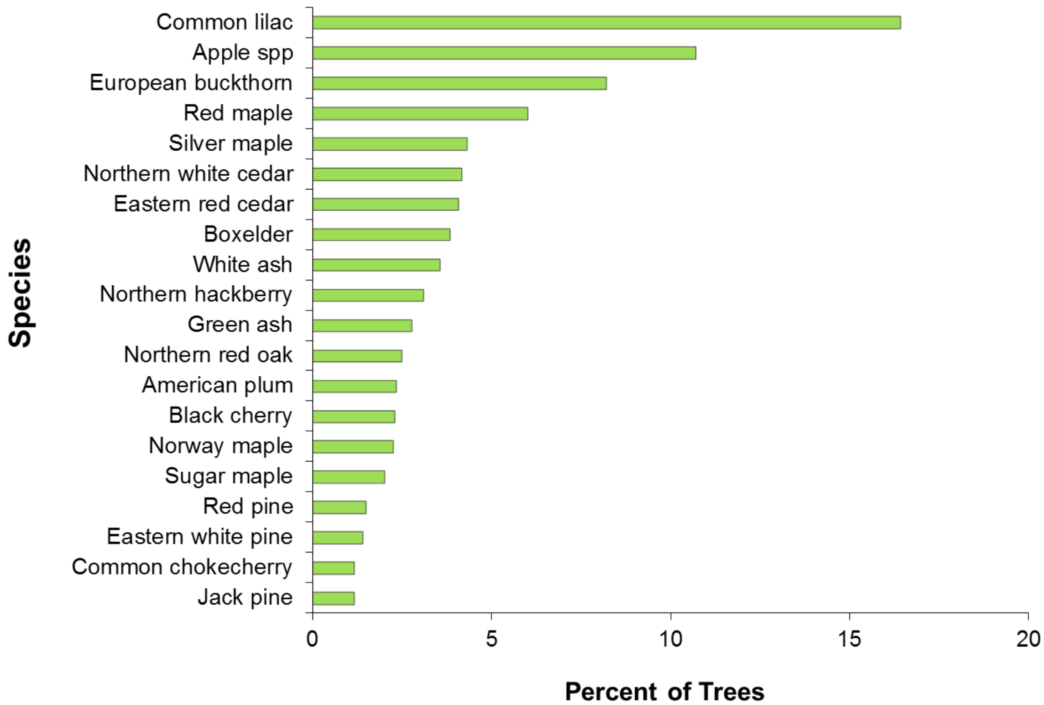

Figure 10—Percent of total tree population for 20 most common tree species in residential urban land use, Wisconsin, 2012.

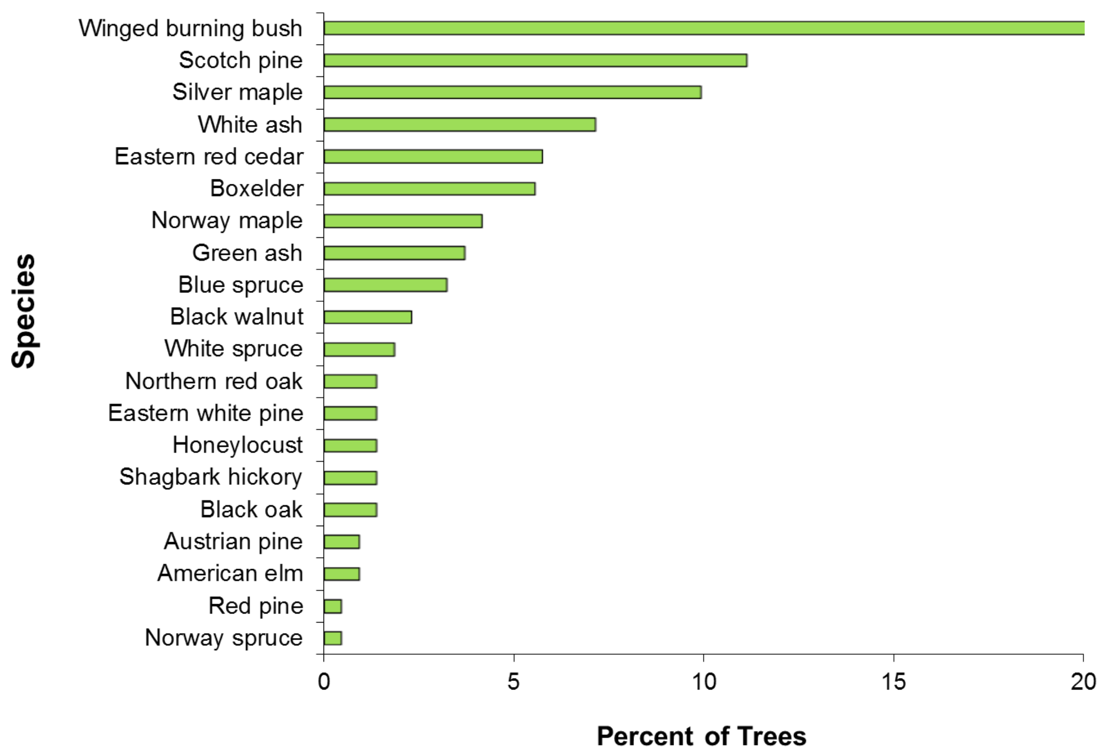

Figure 11—Percent of total tree population for 20 most common tree species in institution/parks land use, Wisconsin, 2012.

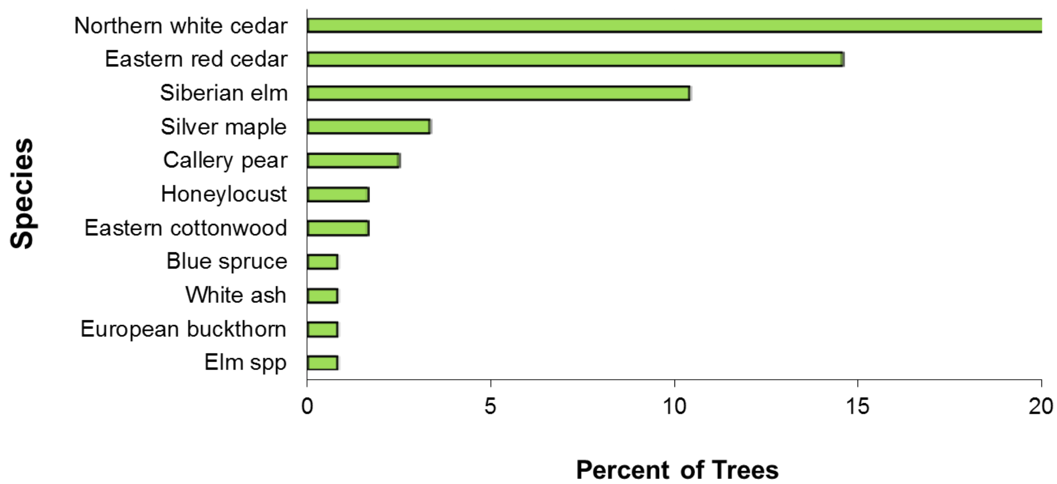

Figure 12—Percent of total tree population for 11 tree species in commercial/transportation land use, Wisconsin, 2012.

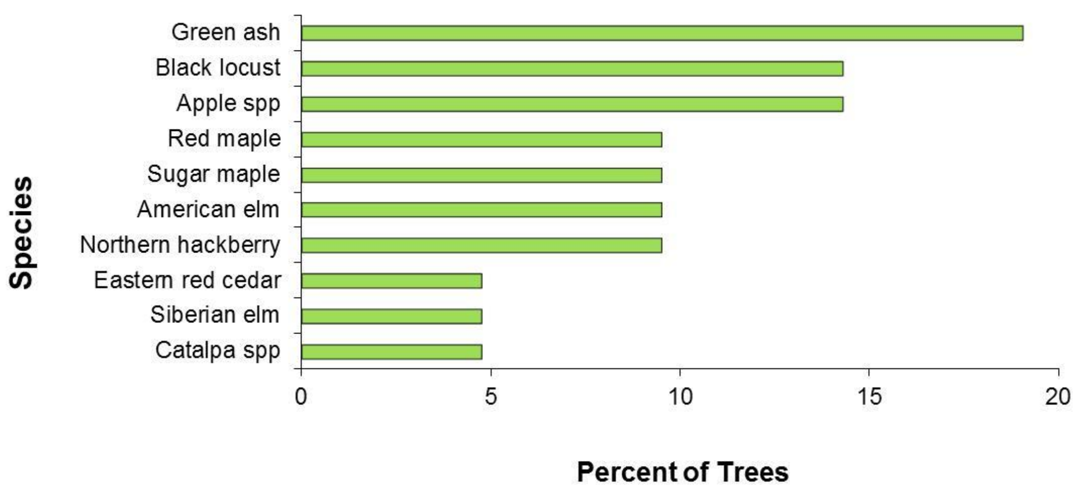

Figure 13—Percent of total tree population for 10 tree species in partially forested lands, Wisconsin, 2012.

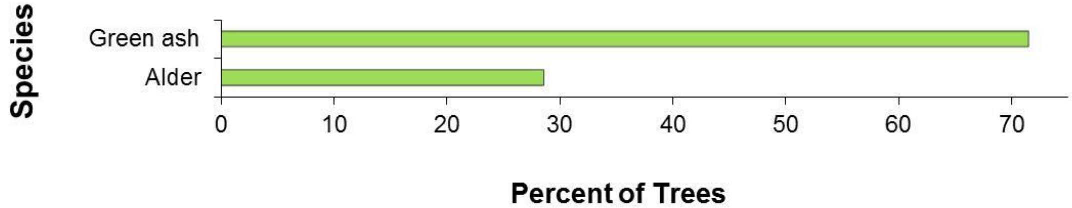

Figure 14—Percent of total tree population for 2 tree species in wetland land use, Wisconsin, 2012.

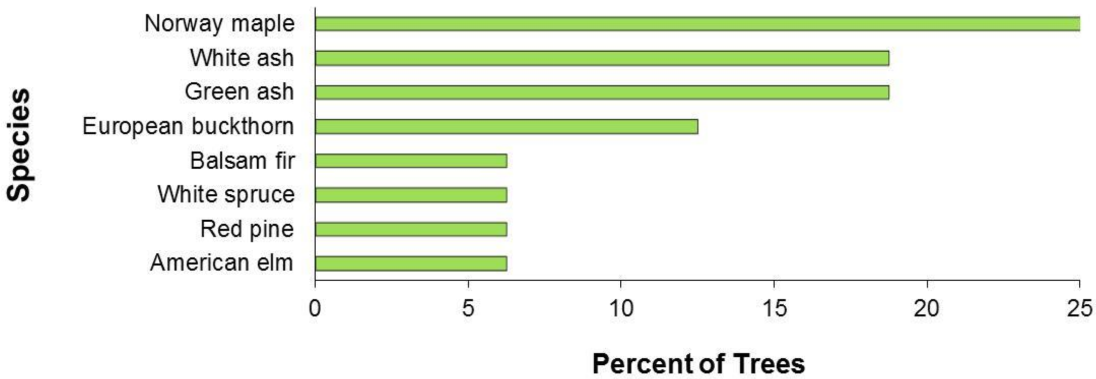

Figure 15—Percent of total tree population for 8 species in agriculture/other land use, Wisconsin, 2012.

Urban forests are a mix of native tree species that were planted, seeded in or existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but the increase in the number of exotic plants can also pose a risk to native plants if some of the exotics species are invasive plants that can potentially out-compete and displace native species. Nine tree species found in this survey are classified as invasive in Wisconsin (Wisconsin Department of Natural Resources 2015; Table 4). These species comprise about 20 percent of the population (8.4 million trees) and about 17 percent of the total leaf area. Species native to North America comprise 59.2 percent of trees in urban areas in Wisconsin, while 46.3 percent are native to Wisconsin specifically. Most of the exotic species identified originated from Europe (12.1 percent) (Figure 16).

Table 4—Invasive urban tree species, Wisconsin, 2012

Scientific name	Common name	% Population	% Leaf area	Number of Trees
Rhamnus cathartica	European buckthorn	5.9	2.4	2,545,755
Euonymus alata	Winged burning bush	5.2	0.2	2,223,535
Acer platanoides	Norway maple	2.5	8.4	1,082,477
Pinus sylvestris	Scotch pine	2.5	2.1	1,052,645
Ulmus pumila	Siberian elm	2.1	1.6	893,236
Morus alba	White mulberry	0.7	1.6	309,064
Pyrus calleryana	Callery pear	0.4	0.2	189,442
Robinia pseudoacacia	Black locust	0.2	0.4	92,667
Elaeagnus angustifolia	Russian olive	0.1	0.2	56,193
		19.6	17.1	8,445,014

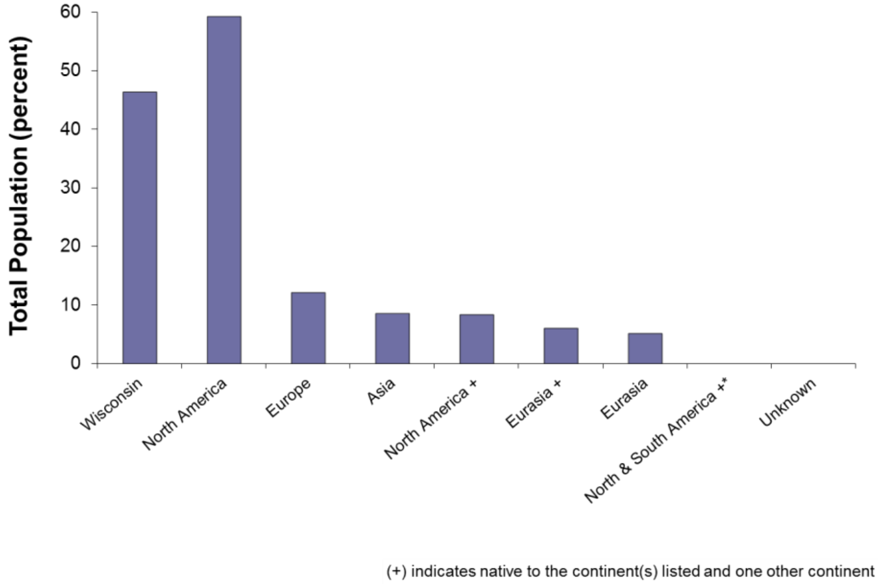

Figure 16—Native range distribution of urban trees in Wisconsin, 2012.

Tree Size Distribution

Tree stem diameter is used to estimate wood volume and mass. Unlike commercial forestry, where trees are harvested as a crop and volumes are used to estimate amount of timber products, urban wood volume can be translated into tons of carbon stored or carbon sequestered per year. As States and local units of government become more interested in environmental services provided by "green infrastructure," estimates of carbon storage and sequestration rates by trees will become increasingly more important.

That is not to say, however, that urban wood is not a commodity in its own right. Development of technologies, like portable saw mills, and increasing demand for specialty woods are making it more common for cities and local governments to market urban wood that is scheduled for removals as a timber or fuel product, rather than disposing as a wood waste or processing for mulch. In this case, knowledge of wood volumes for marketing plans and management is crucial (Bratkovich 2001). Thus, estimates of urban tree mass can provide information related to wood used for timber products or the amount of waste wood that may have to be disposed. In addition to basal area, tree leaf surface area is an important measure for determining the species effects on many ecosystem services (e.g., air temperature cooling, pollution removal), as many services are directly related to leaf surface area.

Tree diameter measurements are used by managers when creating plans for tree maintenance, removals and planting. When coupled with species information, size estimates can assist managers to determine long-term patterns of tree survival, selection and replacement (Cumming et al. 2001).

Species that dominate Wisconsin's urban land in terms of overall basal area are silver maple, Norway maple, and green ash (Table 5). Trees that dominate in terms of leaf surface area are silver maple (10.6 percent), Norway maple (8.4 percent), Northern red oak (5.9 percent), green ash (5.4 percent), and Eastern red cedar (4.9 percent) (Figure 17). Leaf area estimates are likely a better indication of ecosystem services derived from trees than basal area as the leaf area estimates are directly related to the parts of the trees where most of the services are derived. Species with percent leaf area much greater than percent total population tend to be relatively large, healthy trees on average. Species with percent of total population much greater than percent total leaf area tend to be relatively small and/or unhealthy trees on average. While most of the trees are found in the 1-3 inch diameter class, most of the leaf area is within the 6-9 inch diameter class (Figure 18).

Tree diameter distribution provides information related to tree size and approximate age distribution, which are important for understanding population dynamics. For example, for a sustainable population, more small trees are typically required than larger trees, as the smaller tree population eventually will fill the larger diameter population classes through time. However, some small-statured species (e.g., crabapple) will not attain a large diameter or stature. The diameter distribution for Wisconsin's urban forest displays the typical inverse-J shape distribution (Figure 19). On a per tree basis, larger trees can provide more services, such as air pollution removal and storm water mitigation, than smaller trees.

Of the 10 most common species, common lilac, Northern white cedar, Eastern red cedar, red maple and winged burning bush each have more than 75 percent of their trees in the 1-3 inch d.b.h. class (Figure 20). The three species with the largest average diameters were black willow (28.8 in.), weeping willow (22.0 in.) and Eastern cottonwood (21.6 in.). Diameter distribution patterns among the land use classes are given in Figure 21. Detailed statistics (e.g., average d.b.h. and basal area) on urban trees can be found in Appendix B. Detailed tree statistics by land use type are given in Appendix D.

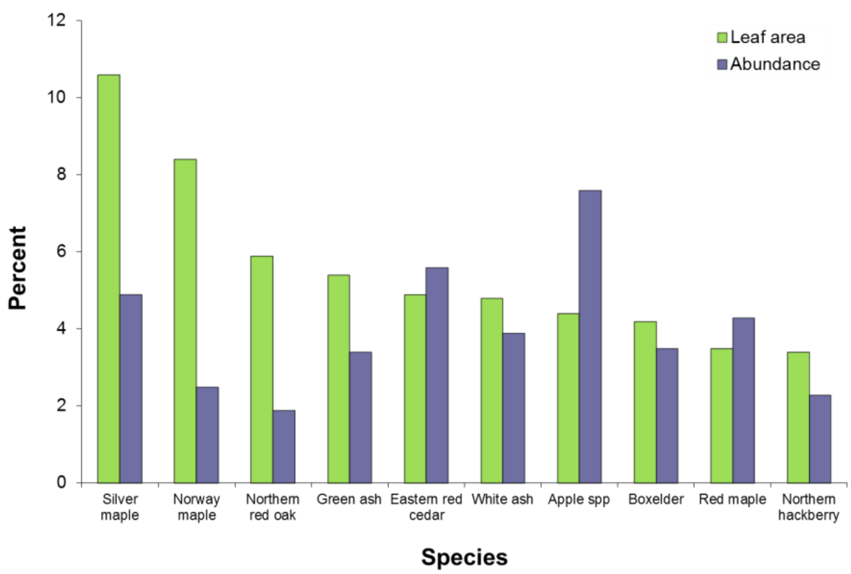

Figure 17—Percent of total tree population (abundance) and total leaf area for 10 most dominant species in terms of leaf area, Wisconsin, 2012.

Table 5—Top 20 urban tree species in terms of basal area, Wisconsin, 2012.

Species	Population	Basal area		D.b.h. Avg	D.b.h. Median
	percent	*ft²/ac*	*percent*	*inches*	
Silver maple	4.9	1.79	10.9	9.1	5.0
Norway maple	2.5	1.32	8.1	13.1	13.5
Green ash	3.4	1.04	6.3	9.3	7.8
Northern red oak	1.9	1.03	6.3	11.2	8.7
Eastern white pine	1.2	0.89	5.4	15.9	15.5
White ash	3.9	0.65	4.0	6.2	4.4
Eastern cottonwood	0.4	0.60	3.7	21.6	13.9
Honeylocust	1.0	0.60	3.6	13.9	13.3
Scotch pine	2.5	0.59	3.6	9.2	9.2
Boxelder	3.5	0.48	2.9	5.8	5.2
Black willow	0.2	0.46	2.8	28.8	23.5
American elm	0.9	0.44	2.7	10.9	7.4
Red maple	4.3	0.43	2.6	4.1	2.3
Apple spp	7.6	0.40	2.5	3.7	2.9
Red pine	1.2	0.37	2.2	10.0	9.9
White oak	0.5	0.36	2.2	14.4	10.0
Blue spruce	1.2	0.34	2.1	9.9	9.8
White spruce	1.1	0.33	2.0	9.7	8.0
Northern white cedar	10.7	0.28	1.7	2.1	1.6
Norway spruce	0.5	0.27	1.7	14.3	12.5

D.b.h. = Diameter at breast height.

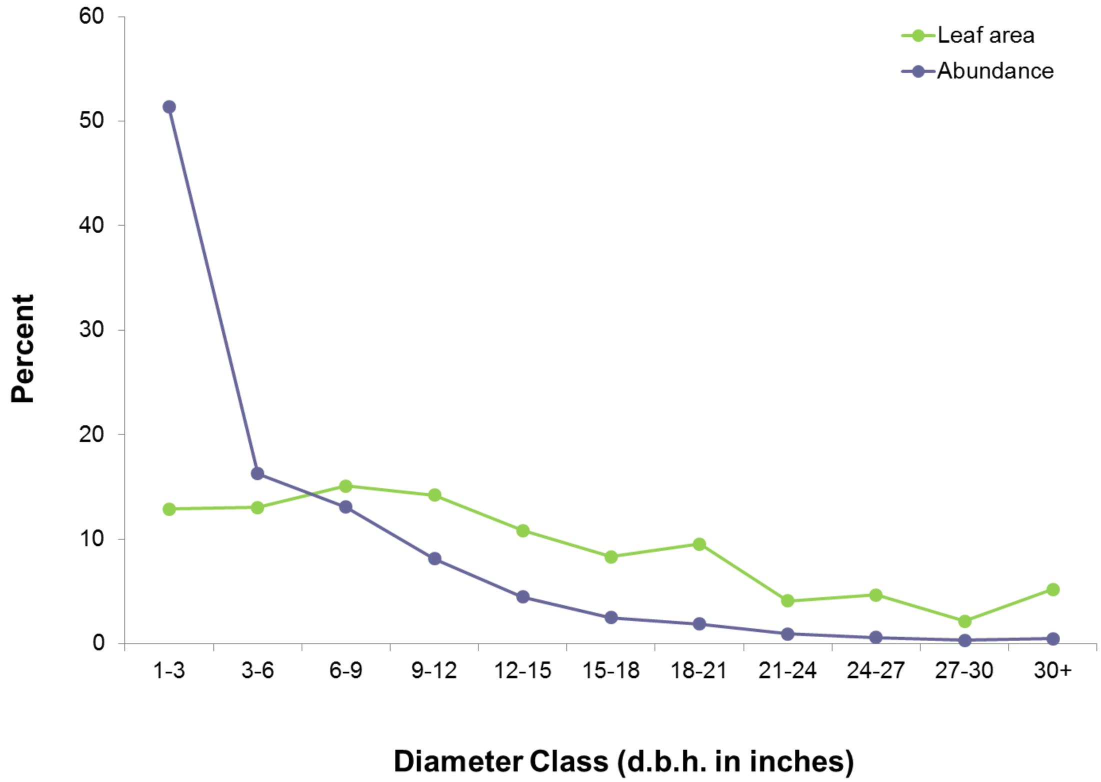

Figure 18—Comparison of proportion of tree abundance with leaf area by diameter class, Wisconsin, 2012.

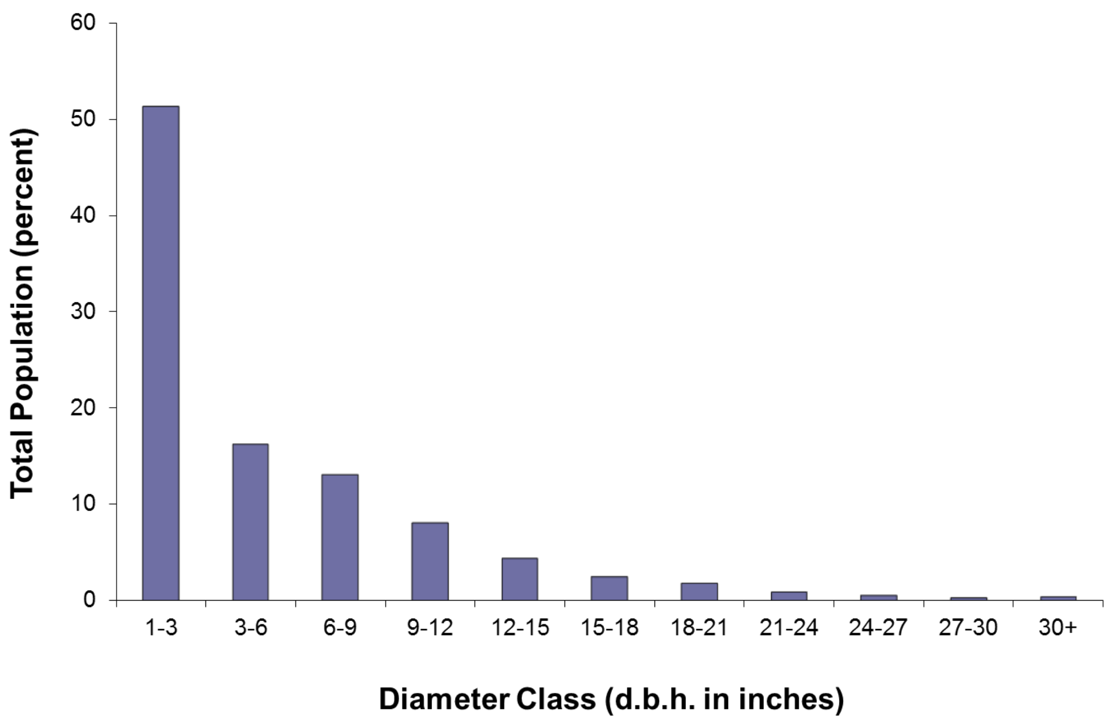

Figure 19—Proportion of urban tree population by diameter class, Wisconsin, 2012.

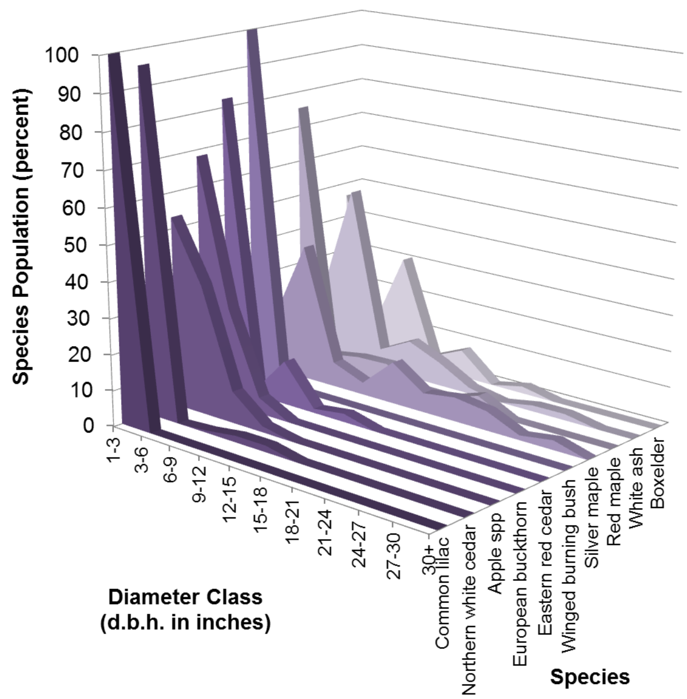

Figure 20—Proportion of top 10 species populations by diameter class, Wisconsin, 2012.

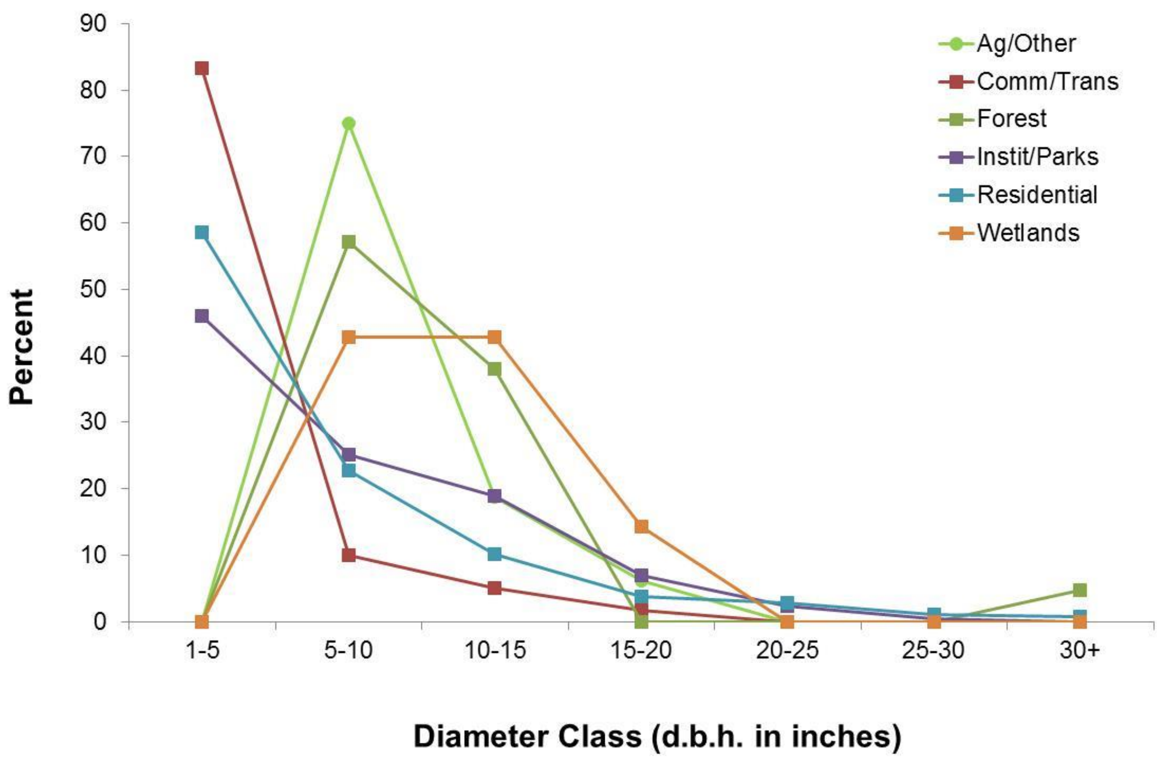

Figure 21—Diameter distribution by land use class, Wisconsin, 2012.

Tree and Ground Cover

Tree cover in urban areas in Wisconsin was interpreted using Google Earth imagery circa 2012. Five hundred points were randomly located within the urban areas of Wisconsin and interpreted as either tree/shrub cover, impervious surfaces (concrete, asphalt, etc.), water, or other. Urban tree/shrub cover in Wisconsin is estimated at 29.4 percent (standard error – 2.0 percent). Based on field crew estimates of tree and shrub cover, it is estimated that trees cover is 20.8 percent and shrub cover is 5.8 percent. However, the field plots only estimated non-forested urban areas, whereas the photo-interpreted estimates are for the entire urban area.

The ground cover in urban Wisconsin is dominated by herbaceous (grass and other nonwoody plants) cover (65.9 percent) (Figure 22). Herbaceous cover is also most common in all land uses except wetland. The wetland land use is dominated by water (61.5 percent).

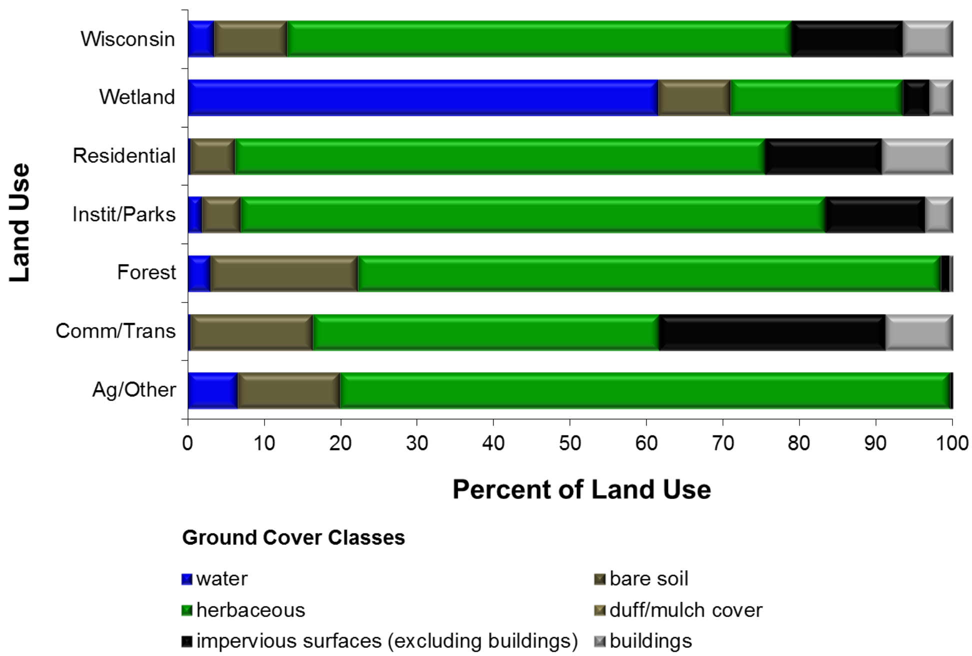

Figure 22—Ground cover distribution by land use type and for entire urban area, Wisconsin, 2012.

Trees in Maintained and Nonmaintained Urban Areas

Each tree was classified as to whether it was found in a maintained or nonmaintained area. Maintained areas are defined as those which are regularly impacted by mowing, weeding, herbicide applications, etc. Trees found in a maintained area do not imply each tree had maintenance. Examples of maintained areas include lawns, rights-of-way, and parks. Of the 65 tree species sampled on urban lands in Wisconsin, 58 species were classified as being found in maintained areas. Overall, 64 percent of the trees (27.4 million) were classified as growing in maintained areas (Table 6).

Most of the maintained trees (69.5 percent) were found on residential land (Table 6). Most of the sampled species (61.5 percent) had at least 80 percent of their sampled trees in maintained areas (Table 7). The proportion of species in maintained areas can be highly uncertain with low sample sizes (e.g., n < 10). Of the maintained tree population, the most common species were apple (10.3 percent of the total maintained tree population), winged burning bush (8.1 percent), and Eastern red cedar (8.0 percent) (Table 8).

Table 6—Number and percent of maintained trees by species within land use classes, Wisconsin, 2012

Land use	Species	Total trees		Maintained trees		
		number	*SE*	*number*	*SE*	*%*
Ag/Other	American elm	34,962	34,962	0	0	0.0
	Balsam fir	34,962	34,962	34,962	34,962	100.0
	European buckthorn	69,924	69,923	0	0	0.0
	Green ash	104,886	76,063	69,924	69,923	66.7
	Norway maple	139,848	139,846	139,848	139,846	100.0
	Red pine	34,962	34,962	0	0	0.0
	White ash	104,886	104,885	0	0	0.0
	White spruce	34,962	34,962	34,962	34,962	100.0
	Total	**559,394**	**250,165**	**279,697**	**184,116**	**50.0**
Comm/Trans	Blue spruce	44,416	44,416	0	0	0.0
	Callery pear	133,249	133,247	133,249	133,247	100.0
	Eastern cottonwood	88,833	88,832	88,833	88,832	100.0
	Eastern red cedar	775,365	582,186	597,699	555,062	77.1
	Elm spp	44,416	44,416	0	0	0.0
	European buckthorn	44,416	44,416	44,416	44,416	100.0
	Honeylocust	88,833	61,369	44,416	44,416	50.0
	Northern white cedar	3,319,696	3,319,693	0	0	0.0
	Siberian elm	553,283	553,282	553,283	553,282	100.0
	Silver maple	177,665	177,663	177,665	177,663	100.0
	White ash	44,416	44,416	44,416	44,416	100.0
	Total	**5,314,587**	**3,374,548**	**1,683,977**	**816,206**	**31.7**
Forest	American elm	61,778	42,202	0	0	0.0
	Black locust	92,667	92,665	92,667	92,665	100.0
	Catalpa spp	30,889	30,888	0	0	0.0
	Eastern red cedar	30,889	30,888	0	0	0.0
	Green ash	123,556	123,554	123,556	123,554	100.0
	Apple spp	92,667	92,665	0	0	0.0
	Northern hackberry	61,778	61,777	0	0	0.0
	Red maple	61,778	61,777	0	0	0.0
	Siberian elm	30,889	30,888	0	0	0.0
	Sugar maple	61,778	61,777	0	0	0.0
	Total	**648,667**	**273,381**	**216,222**	**216,219**	**33.3**
Instit/Park	American elm	59,624	41,372	59,624	41,372	100.0
	Austrian pine	59,624	59,623	0	0	0.0
	Black oak	89,436	89,434	89,436	89,434	100.0
	Black walnut	149,059	105,633	149,059	105,633	100.0
	Blue spruce	208,683	133,197	29,812	29,811	14.3
	Boxelder	357,742	228,913	357,742	228,913	100.0

continued

Land use	Species	Total trees		Maintained trees		
		number	*SE*	*number*	*SE*	*%*
Instit/Park cont.	Eastern red cedar	370,589	370,589	370,589	370,589	100.0
	Eastern white pine	89,436	89,434	89,436	89,434	100.0
	Green ash	238,495	112,426	149,059	75,024	62.5
	Honeylocust	89,436	65,665	89,436	65,665	100.0
	Jack pine	29,812	29,811	29,812	29,811	100.0
	Mountain ash spp	29,812	29,811	29,812	29,811	100.0
	Northern red oak	89,436	89,434	89,436	89,434	100.0
	Norway maple	268,307	136,130	268,307	136,130	100.0
	Norway spruce	29,812	29,811	0	0	0.0
	Red pine	29,812	29,811	29,812	29,811	100.0
	Scotch pine	715,484	715,472	715,484	715,472	100.0
	Shagbark hickory	89,436	89,434	89,436	89,434	100.0
	Silver maple	638,896	428,388	638,896	428,388	100.0
	White ash	460,025	376,362	460,025	376,362	100.0
	White spruce	119,247	82,743	0	0	0.0
	Winged burning bush	2,223,535	2,223,532	2,223,535	2,223,532	100.0
	Total	**6,435,735**	**2,586,443**	**5,958,746**	**2,583,183**	**92.6**
Residential	American basswood	56,193	39,524	28,097	28,096	50.0
	American beech	56,193	56,192	56,193	56,192	100.0
	American elm	224,774	147,662	224,774	147,662	100.0
	American plum	694,690	694,689	694,690	694,689	100.0
	Ash spp	112,387	88,567	112,387	88,567	100.0
	Bigtooth aspen	28,097	28,096	28,097	28,096	100.0
	Bitternut hickory	56,193	39,524	0	0	0.0
	Black cherry	684,506	374,422	196,677	82,293	28.7
	Black oak	56,193	56,192	56,193	56,192	100.0
	Black willow	84,290	84,289	84,290	84,289	100.0
	Blue spruce	252,871	126,802	224,774	124,187	88.9
	Boxelder	1,144,238	716,916	1,088,044	716,151	95.1
	Bur oak	28,097	28,096	28,097	28,096	100.0
	Callery pear	56,193	56,192	0	0	0.0
	Common chokecherry	347,345	347,344	0	0	0.0
	Common lilac	4,862,830	3,161,046	0	0	0.0
	Common pear	28,097	28,096	28,097	28,096	100.0
	Downy hawthorn	28,097	28,096	28,097	28,096	100.0
	Eastern cottonwood	84,290	62,560	84,290	62,560	100.0
	Eastern hophornbeam	84,290	62,560	56,193	56,192	66.7
	Eastern red cedar	1,210,615	791,568	1,210,615	791,568	100.0
	Eastern white pine	421,451	219,968	309,064	191,015	73.3
	European buckthorn	2,431,415	1,501,405	1,389,380	1,094,926	57.1
	Green ash	824,990	390,574	768,796	389,210	93.2
	Honeylocust	252,871	106,266	140,484	61,488	55.6
	Jack pine	347,345	347,344	347,345	347,344	100.0
	Littleleaf linden	56,193	56,192	56,193	56,192	100.0
	Apple spp	3,172,114	2,463,501	2,824,769	2,442,534	89.1
	Northern catalpa	56,193	56,192	56,193	56,192	100.0
	Northern hackberry	919,464	705,702	919,464	705,702	100.0
	Northern pin oak	196,677	127,846	196,677	127,846	100.0
	Northern red oak	740,699	394,606	572,119	368,877	77.2
	Northern white cedar	1,238,712	1,049,846	1,238,712	1,049,846	100.0
	Norway maple	674,322	164,688	505,741	145,736	75.0
	Norway spruce	168,580	77,991	140,484	73,323	83.3

continued

Land use	Species	Total trees		Maintained trees		
		number	*SE*	*number*	*SE*	*%*
Residential cont.	Paper birch	309,064	118,958	309,064	118,958	100.0
	Pin cherry	28,097	28,096	28,097	28,096	100.0
	Plum spp	84,290	62,560	0	0	0.0
	Quaking aspen	140,484	61,488	112,387	55,298	80.0
	Red maple	1,782,734	857,372	947,561	506,390	53.2
	Red mulberry	28,097	28,096	28,097	28,096	100.0
	Red pine	449,548	213,858	196,677	170,611	43.8
	Russian olive	56,193	56,192	56,193	56,192	100.0
	Scotch pine	337,161	240,487	252,871	226,226	75.0
	Shagbark hickory	224,774	177,134	168,580	168,577	75.0
	Siberian elm	309,064	131,688	224,774	103,132	72.7
	Silver maple	1,284,722	720,841	1,144,238	716,916	89.1
	Slippery elm	252,871	252,866	252,871	252,866	100.0
	Sugar maple	600,216	361,033	56,193	39,524	9.4
	Weeping willow	56,193	39,524	28,097	28,096	50.0
	White ash	1,059,948	711,279	891,367	700,686	84.1
	White fir	56,193	56,192	56,193	56,192	100.0
	White mulberry	309,064	214,614	309,064	214,614	100.0
	White oak	224,774	130,452	56,193	56,192	25.0
	White spruce	309,064	118,958	196,677	107,510	63.6
	Willow spp	28,097	28,096	28,097	28,096	100.0
	Total	**29,612,158**	**5,990,106**	**19,038,322**	**4,474,507**	**64.3**
Wetland	Alder	64,511	64,510	64,511	64,510	100.0
	Green ash	161,277	105,014	161,277	105,014	100.0
	Total	**225,787**	**144,967**	**225,787**	**144,967**	**100.0**
State Urban Forest Total		**42,796,328**	**7,356,423**	**27,402,751**	**5,240,411**	**64.0**

Table 7—Species by percent of sampled trees in maintained areas, Wisconsin, 2012

Species	Trees	Sample size
	percent	*number*
Winged burning bush	100.0	6
American plum	100.0	2
Jack pine	100.0	2
Paper birch	100.0	11
White mulberry	100.0	11
Slippery elm	100.0	9
Northern pin oak	100.0	7
Eastern cottonwood	100.0	5
Black walnut	100.0	5
Black oak	100.0	5
Ash spp	100.0	4
Black locust	100.0	3
Black willow	100.0	3

continued

Species	Trees	Sample size
	percent	*number*
Alder	100.0	2
White fir	100.0	2
Northern catalpa	100.0	2
Russian olive	100.0	2
American beech	100.0	2
Littleleaf linden	100.0	2
Balsam fir	100.0	1
Mountain ash spp	100.0	1
Downy hawthorn	100.0	1
Red mulberry	100.0	1
Bigtooth aspen	100.0	1
Pin cherry	100.0	1
Common pear	100.0	1
Bur oak	100.0	1
Willow spp	100.0	1
Boxelder	96.3	30
Northern hackberry	93.7	12
Silver maple	93.3	37
Scotch pine	92.0	36
Eastern red cedar	91.3	17
Green ash	87.6	38
Siberian elm	87.1	13
Apple spp	86.5	25
Norway maple	84.4	37
White ash	83.6	23
Shagbark hickory	82.1	11
Quaking aspen	80.0	5
Northern red oak	79.7	18
Eastern white pine	78.0	18
American elm	74.6	13
Norway spruce	70.8	7
Callery pear	70.3	5
Eastern hophornbeam	66.7	3
Honeylocust	63.6	14
European buckthorn	56.3	10
Red maple	51.4	20
Blue spruce	50.3	17
Weeping willow	50.0	2
American basswood	50.0	2
White spruce	50.0	16

continued

Species	Trees	Sample size
	percent	*number*
Red pine	44.0	18
Black cherry	28.7	13
Northern white cedar	27.2	16
White oak	25.0	8
Sugar maple	8.5	12
Common lilac	0.0	14
Common chokecherry	0.0	1
Plum spp	0.0	3
Austrian pine	0.0	2
Bitternut hickory	0.0	2
Elm spp	0.0	1
Catalpa spp	0.0	1

Table 8—Species composition in maintained areas, Wisconsin, 2012

Species	Trees
	percent
Apple spp	10.3
Winged burning bush	8.1
Eastern red cedar	8.0
Silver maple	7.2
Boxelder	5.3
European buckthorn	5.2
White ash	5.1
Green ash	4.6
Northern white cedar	4.5
Scotch pine	3.5
Red maple	3.5
Northern hackberry	3.4
Norway maple	3.3
Siberian elm	2.8
American plum	2.5
Northern red oak	2.4
Eastern white pine	1.5
Jack pine	1.4
Paper birch	1.1
White mulberry	1.1
American elm	1.0
Honeylocust	1.0
Shagbark hickory	0.9
Blue spruce	0.9

continued

Species	Trees
	percent
Slippery elm	0.9
White spruce	0.8
Red pine	0.8
Black cherry	0.7
Northern pin oak	0.7
Eastern cottonwood	0.6
Black walnut	0.5
Black oak	0.5
Norway spruce	0.5
Callery pear	0.5
Quaking aspen	0.4
Ash spp	0.4
Black locust	0.3
Black willow	0.3
Alder	0.2
Sugar maple	0.2
White oak	0.2
Eastern hophornbeam	0.2
White fir	0.2
Northern catalpa	0.2
Russian olive	0.2
American beech	0.2
Littleleaf linden	0.2
Balsam fir	0.1
Mountain ash spp	0.1
Weeping willow	0.1
American basswood	0.1
Downy hawthorn	0.1
Red mulberry	0.1
Bigtooth aspen	0.1
Pin cherry	0.1
Common pear	0.1
Bur oak	0.1
Willow spp	0.1
Common lilac	0.0
Common chokecherry	0.0
Plum spp	0.0
Austrian pine	0.0
Bitternut hickory	0.0
Elm spp	0.0
Catalpa spp	0.0

Urban Forest Health

To evaluate tree condition, we used national FIA protocols for crown and damage ratings (Conkling and Byers 1992) for all trees ≥ 1 inch (see U.S. Department of Agriculture 2007 for details). Crown measurements evaluate the growth and vigor of the crown, as a whole, for each tree. Damage ratings describe symptoms on a tree where there are abnormalities in the visible roots, bark, branches and leaves. Taken together, crown and damage ratings give an overall description of tree health. In addition to damage ratings, crews were asked to note the presence or absence of 10 different damages that can occur on trees in urban areas. These urban damage indicators are of specific interest to arborists and plant health specialists, and included signs of trunk/bark inclusions, cankers/decay, wounds/cracks, root/stem girdling, chlorotic/necrotic foliage, dead/dying crowns, borers/bark beetles, vines in crown, dead tree top and defoliation.

Tree Mortality

Overall, 1.1 percent of the total urban tree population was standing dead. The species with the highest percent of its total urban population in standing dead trees were American elm, Russian olive, slippery elm, Eastern hophornbeam, and quaking aspen (Table 9).

Higher proportions of standing dead trees coupled with large tree populations may indicate potential insect, disease or environmental problems. Further evaluation and monitoring of these species is warranted. A high percent of dead trees does not necessarily indicate a health problem with the species, but could be due to the fact that some trees will naturally remain standing as dead trees for longer periods, or that they might be left standing dead depending upon the land use, risk associated with dead trees, and maintenance activities related to their removal. Thus, some species may have a higher proportion of dead trees as they are in locations where they are not immediately removed and therefore have a higher probability of being sampled as dead. Long-term monitoring of plots can help determine actual species mortality rates.

Land uses with the highest proportion of trees sampled as dead trees were agriculture/other and partially forested (Table 10).

Table 9—Species with the largest proportion of their total population classified as dead, Wisconsin, 2012

Species	Population	Dead
	number	*percent*
American elm	381,138	54.1
Russian olive	56,193	50.0
Slippery elm	252,871	44.4
Eastern hophornbeam	84,290	33.3
Quaking aspen	140,484	20.0
Black cherry	684,506	4.1
Siberian elm	893,236	3.1
Scotch pine	1,052,645	2.8

Table 10—Percent of tree population classified as dead by land use, Wisconsin, 2012

Land use	Dead
	percent
Agricullture/Other	6.3
Partially forested	4.8
Residential	1.3
Instit/Parks	0.5
Comm/Trans	0.0
Wetland	0.0

Crown Indicators of Forest Health

Measurement of tree crowns can be used as an indicator of tree health. Large dense crowns are often indicative of vigorously growing trees, while small, sparsely foliated crowns signal trees with little or no growth and possibly in a state of decline. One measurement of crown health used to estimate tree condition is dieback (Table 11).

Crown dieback is demonstrative of tree health and is defined as recent mortality of small branches and twigs in the upper and outer portion of the trees' crown. Trees with crown dieback > 25 percent may be in decline, for both hardwoods and conifers (Steinman 1998).

Table 11—Average percent crown dieback and percent of population for 20 most common species, Wisconsin, 2012

Species	Dieback	Population
	percent	
Common lilac	5.0	11.4
Northern white cedar	4.5	10.7
Apple spp	4.4	7.6
European buckthorn	5.0	5.9
Eastern red cedar	4.2	5.6
Winged burning bush	5.0	5.2
Silver maple	3.9	4.9
Red maple	4.2	4.3
White ash	5.0	3.9
Boxelder	4.0	3.5
Green ash	2.5	3.4
Norway maple	1.3	2.5
Scotch pine	1.6	2.5
Northern hackberry	4.2	2.3
Siberian elm	8.1	2.1
Northern red oak	3.0	1.9
American plum	5.0	1.6
Black cherry	8.1	1.6
Sugar maple	3.1	1.5
Red pine	0.6	1.2

Dieback

Based on the live tree population with a minimum sample size of 10, species with highest percent crown dieback were American elm and paper birch (Table 12). Higher levels of dieback may indicate a potential insect, disease, or environmental problem associated with this species and further evaluation is warranted.

Table 12—Species with highest average percent dieback (minimum sample size = 10), Wisconsin, 2012

Species	Sample	Dieback
	number	*percent*
American elm	13	58.8
Paper birch	11	15.0
Black cherry	13	8.1
Siberian elm	13	8.1
White ash	23	5.0
European buckthorn	10	5.0
Common lilac	14	5.0
Northern white cedar	16	4.5
Apple spp	25	4.4
Red maple	20	4.2

Damage Indicators of Forest Health

Signs of damage were recorded for all trees ≥ 1 inch d.b.h. and based upon the location of the damage. Damage at the root level or tree bole can potentially be more significant in terms of tree health as compared to damages in branches or upper bole. Up to three damages (see Glossary) were recorded per tree, with inspections starting at the roots and bole and progressing up the tree (U.S. Department of Agriculture 2005a).

The most common damage on trees was trunk/bark inclusion (32.8 percent of all trees) (Table 13). Trunk bark inclusions are places where branches are not strongly attached to the tree. A weak union occurs when two or more branches grow so closely together that bark grows between the branches and inside the union. This ingrown, or included, bark does not have the structural strength of wood and the union can become very weak. The inside bark may also act as a wedge and force the branch union to split apart. The land use with the greatest proportion of trees with trunk/bark inclusion was commercial/transportation (Table 13). Species with the highest percent of its population with trunk/bark inclusion were Northern white cedar and apple species (Table 14). Poor pruning practices can result in the formation of included trunk bark.

Cankers or signs of decay were the second most common damage (19.5 percent). Cankers or signs of decay are a serious concern in urban areas since the presence of wood decay increases the potential for tree failure. Apple species, common lilac, and silver maple had the highest proportions of their populations with cankers and signs of decay (Table 14).

Wounds or cracks were the third most common damage (5.3 percent), with green ash, Norway maple, and Northern red oak having the highest percent of its population exhibiting this damage (Table 14). A wound or crack is typically an area where bark is visibly damaged or absent on the stem of a tree, oftentimes resulting from an incident such as a lightning strike or lawn mower impacts.

The diameter distribution of trees with damage differed greatly between the damage classes (Figure 23). Damages that tended to occur more on larger trees (trees with a d.b.h. greater than 18 inches) were root/stem girdling and wounds or cracks. Damage that was most frequent on smaller trees (trees with a d.b.h. less than 3 inches) was trunk/bark inclusion and canker/decay.

In addition to the tree damages in Table 13, 2.1 percent of trees had overhead wire conflicts, 1.1 percent had issues with excess mulch, and 0.6 percent of the trees were noted as having topping and pruning damage (Table 15). Residential trees had the highest percent of its population with these maintenance and site issues.

Table 13—Percent of trees with various types of damage by land use, Wisconsin, 2012.

Damage Type	Ag/Other	Comm/Trans	Part. Forest	Instit/Parks	Residential	Wetland	Total
				percent			
Trunk/bark inclusion	62.5	65.0	47.6	11.6	31.0	0.0	32.8
Canker/decay	12.5	2.5	33.3	7.9	25.0	0.0	19.5
Wound/crack	18.7	0.8	14.3	8.3	4.7	42.9	5.3
Root/stem girdling	18.7	0.8	0.0	4.6	1.4	14.3	2.1
Chlorotic/necrotic foliage	0.0	0.0	0.0	0.0	1.1	0.0	0.8
Dead/dying crown	0.0	0.0	0.0	0.9	0.8	0.0	0.7
Borers/bark beetles	0.0	0.0	0.0	0.0	0.7	0.0	0.5
Vines in crown	6.2	0.0	0.0	0.9	0.3	0.0	0.4
Dead top	0.0	0.0	0.0	0.0	0.4	0.0	0.3
Defoliation	0.0	0.0	0.0	0.0	0.3	0.0	0.2

Table 14—Species with greatest proportion of their population having the specific damage class, Wisconsin, 2012. For example, 32.3 percent of apples had canker/decay

Damage Class and Species	Damage Class	Damage Class and Species	Damage Class
	percent		*percent*
Canker/decay		**Root/stem girdling**	
Apple spp	32.3	Norway maple	27.8
Common lilac	8.3	Silver maple	14.3
Silver maple	6.4	Green ash	13.3
Eastern red cedar	6.2	Eastern white pine	12.5
Red maple	5.5	Northern red oak	9.9
Chlorotic/necrotic foliage		**Trunk/bark inclusion**	
Silver maple	70.0	Northern white cedar	31.7
Norway maple	13.6	Apple spp	19.8
Paper birch	5.4	Common lilac	9.9
Boxelder	2.7	Silver maple	6.4
Red maple	2.7	Eastern red cedar	4.3

continued

Damage Class and Species	Damage Class	Damage Class and Species	Damage Class
	percent		*percent*
Dead/dying crown		**Vines in crown**	
Boxelder	30.8	Boxelder	48.1
Paper birch	19.8	White ash	19.5
Norway maple	9.9	Shagbark hickory	16.7
Red maple	9.9	Red maple	15.7
White ash	9.9		
Dead top		**Wound/crack**	
Boxelder	33.5	Green ash	25.6
Paper birch	32.5	Norway maple	11.6
Red maple	16.2	Northern red oak	7.7
		Red maple	6.2
Defoliation		Honeylocust	5.8
Paper birch	66.7		
Norway maple	33.3		

Note: Only species with minimum sample size of 10 trees are included in this analysis to minimize effect of small sample size on percentage estimates. All species values are given in appendices E and F.

There were not 5 species having the specific damage class borers/bark beetles, dead top, defoliation, or vines in crown with a minimum sample size of 10 trees

Table 15—Percent of trees with site or maintenance issue by land use, Wisconsin, 2012.

Site or Maintenance Issue	Ag/Other	Comm/Trans	Part. Forest	Instit/Parks	Residential	Wetland	Total
				percent			
Overhead wires	0.0	0.0	0.0	0.0	3.0	0.0	2.1
Excess mulch	0.0	0.0	0.0	0.0	1.6	0.0	1.1
Topping/pruning	0.0	0.0	0.0	2.3	0.4	0.0	0.6
Sidewalk-root conflict	0.0	0.0	0.0	0.0	0.4	0.0	0.3
Improper planting	0.0	0.0	0.0	0.0	0.0	0.0	0.0

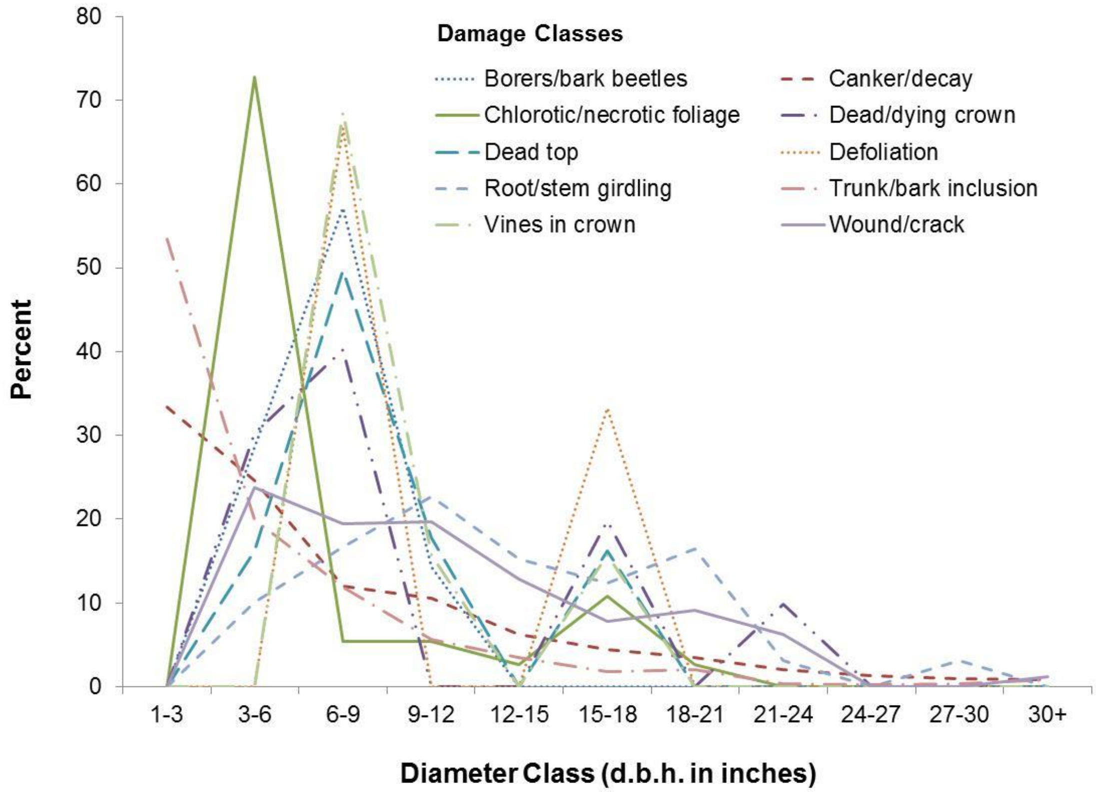

Figure 23—Diameter distribution of trees with various damage classes, Wisconsin, 2012.

Ecosystem Services and Values

Carbon Storage by Urban Trees

Trees can reduce the amount of carbon in the atmosphere by providing a net increase in new growth (carbon) every year (i.e., growth > decomposition). The amount of carbon annually sequestered is typically greatest in large healthy trees. Trees and forests are considered a significant sink of carbon within terrestrial ecosystems. The process by which a tree annually removes carbon from the atmosphere is called carbon sequestration. The amount or weight of carbon currently stored in a tree is considered carbon storage. To estimate monetary value associated with urban tree carbon storage and sequestration, carbon values were multiplied by $139.33 per metric ton of carbon (range = $44.00 -212.67 per tC) based on the estimated social costs of carbon for 2015 with a 3% discount rate (Interagency Working Group 2013).

The species that are estimated to sequester the most carbon annually are silver maple (9.5 percent of the total annual sequestration), Norway maple (7.6 percent), and Northern red oak (6.7 percent) (Figure 24). Sequestration estimates are based on estimates of growth, which are partially dependent upon tree condition. Annual carbon sequestration by urban trees is valued at $26.8 million per year (Table 16). Carbon storage by Wisconsin's urban forest is estimated at 4.0 million tons ($507 million). The species that are estimated to store the most carbon are silver maple (13.3 percent of the total storage), Norway maple (9.1 percent), and Northern red oak (8.8 percent) (Figure 25).

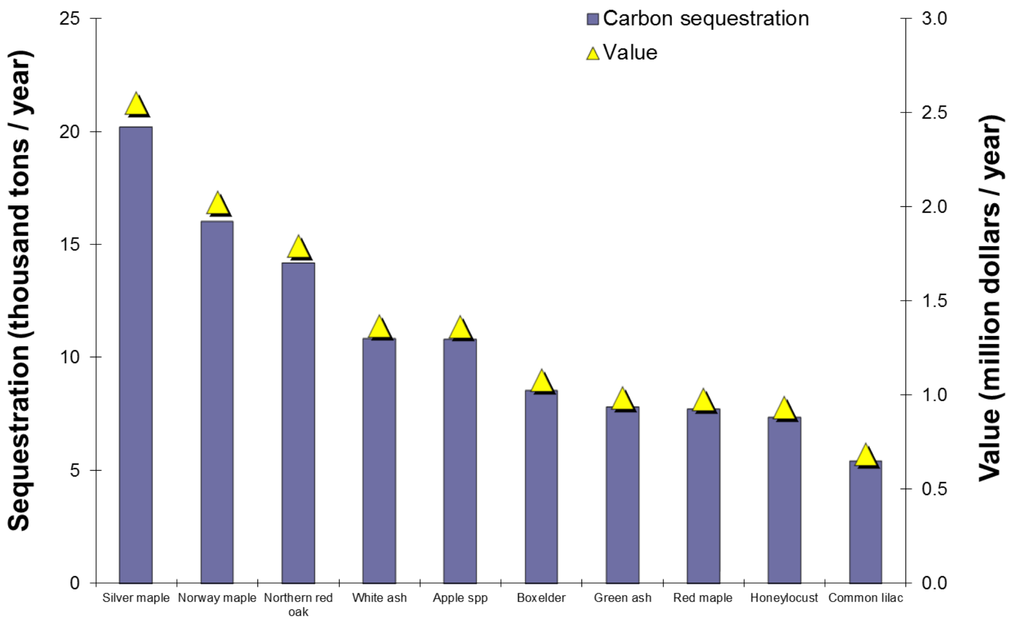

Figure 24—Annual carbon sequestration by top 10 species in terms of estimated annual gross carbon sequestration, Wisconsin, 2012.

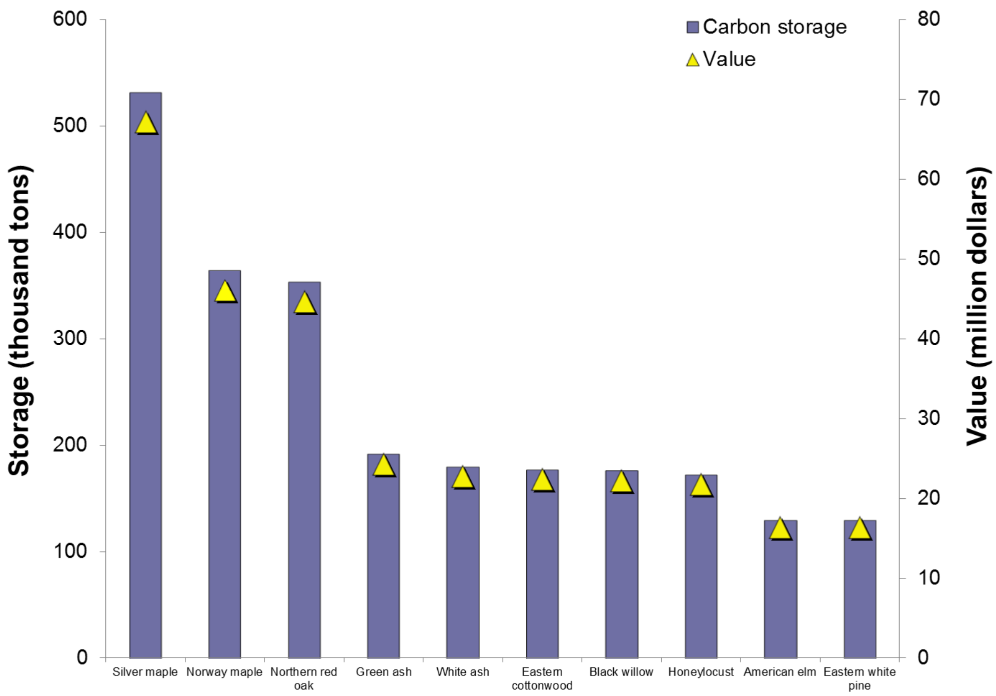

Figure 25—Cumulative carbon storage by top 10 species, Wisconsin, 2012.

Table 16—Carbon storage and annual sequestration by land use, Wisconsin, 2012.

Land use	Carbon storage		Carbon sequestration	
	tons	**dollars**	**tons per year**	**dollars per year**
	millions	*millions*	*thousands*	*millions*
Wetland	0.04	5.7	1.0	0.1
Residential	3.01	381.0	167.5	21.2
Institution/Parks	0.63	79.7	27.3	3.4
Partially forested	0.16	19.9	3.1	0.4
Commercial/Transportation	0.11	13.8	9.7	1.2
Agriculture/Other	0.05	6.5	3.4	0.4
Total urban	4.01	506.6	212.0	26.8

Heating and Cooling Effects of Urban Trees

Trees affect energy consumption of buildings by shading buildings, providing evaporative cooling, and by blocking winter winds. Trees tend to reduce energy use in the summer and either increase or decrease the 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.

In Wisconsin, interactions between trees and buildings are projected to decrease energy costs by $78.9 million annually, based on 2012 energy costs (Table 17). Because of reduced building energy use, power plants will burn less fossil fuel and, therefore, release less carbon dioxide. Changes in energy use will lead to reduced emission of carbon of about 102,000 tons per year (375,000 tons of carbon dioxide per year) in Wisconsin (Table 18).

Table 17—Annual monetary savings ($) in residential energy expenditures during heating and cooling seasons, Wisconsin, 2012.

	Heating[a]	Cooling[a]	Total
MBTU[b]	47,862,000	n/a	47,862,000
MWH[c]	3,666,000	27,356,000	31,022,000
Carbon avoided	7,929,000	4,983,000	12,912,000

[a] Based on 2012 statewide energy costs (Energy Information Administration 2012a, 2012b, 2014a, 2014b) and 2013 social cost of carbon (Interagency Working Group 2013)

[b] MBTU – Million British Thermal Units (not used for cooling)

[c] MWH – Megawatt-hour

Table 18—Annual energy savings (MBTU, MWH, or tons) due to trees near residential buildings, Wisconsin, 2012.

	Heating	Cooling	Total
MBTU[a]	3,440,000	n/a	3,440,000
MWH[b]	28,000	206,000	234,000
Carbon avoided (t)[c]	63,000	39,000	102,000

[a] MBTU – Million British Thermal Units (not used for cooling)

[b] MWH – Megawatt-hour

[c] To convert carbon estimates to carbon dioxide, multiply carbon value by 3.667

Air Pollution Removal by Urban Trees

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 the 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).

Air pollution removal by Wisconsin's urban forest is estimated for each county using the hourly pollution data from the monitors within the county, or nearest to the county, and weather data from the year 2010 (Nowak et al. 2014). Based on these inputs, the urban forests in Wisconsin are estimated to remove about 7,030 tons of pollution per year, with an associated annual value of about $47.7 million. Pollutant removal rate was greatest for ozone (O_3), followed by nitrogen dioxide (NO_2), sulfur dioxide (SO_2) , and particulate matter < 2.5 microns (PM10) (Figure 26, Table 20). Health effect values were greatest for reduction in mortality in relation to reduced ozone and particulate matter concentrations (Table 20). Over 5,300 of acute respiratory symptoms were reduced to trees reducing pollution concentrations (Table 20).

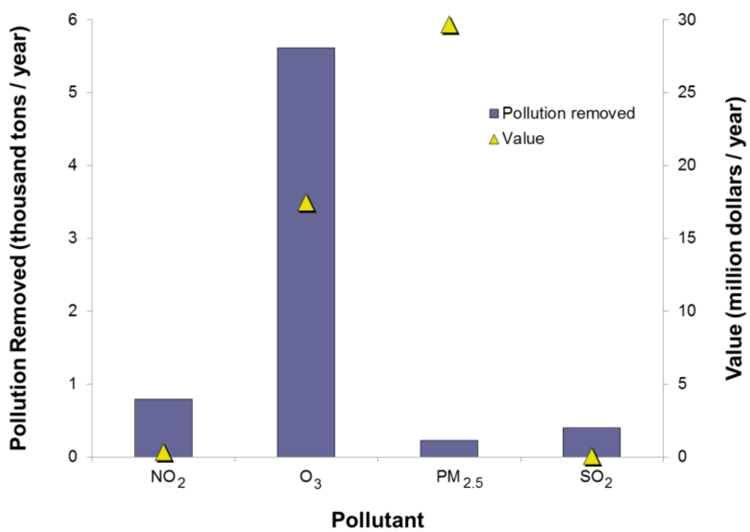

Figure 26—Annual pollution removal and value from the urban trees, Wisconsin, 2010.
NO_2 = nitrogen dioxide, O_3 = ozone, $PM_{2.5}$ = fine particulate matter, SO_2 = sulfur dioxide

Table 19—Annual pollution removal and value from the urban trees, Wisconsin, 2010.
NO_2 = nitrogen dioxide, O_3 = ozone, $PM_{2.5}$ = fine particulate matter, SO_2 = sulfur dioxide

Pollutant	Removal (t/yr)	Value ($/yr)
NO_2	790	348,000
O_3	5,613	17,469,000
$PM_{2.5}$	226	29,826,000
SO_2	402	52,000
Total	7,030	47,695,000

Table 20—Reduction in number of incidences and associated monetary value ($) for various health effects due to pollutant reduction from urban forests, Wisconsin, 2010.

Pollutant	Adverse Health Effect	No. Inc[a]	Value
NO_2	Asthma Exacerbation	2,534	212,400
	Hospital Admissions	4.3	128,800
	Acute Respiratory Symptoms	178	5,600
	Emergency Room Visits	1.8	800
	Total		347,600
O_3	Mortality	2.2	16,855,400
	Acute Respiratory Symptoms	3,780	323,200
	School Loss Days	1,613	158,300
	Hospital Admissions	4.3	131,800
	Emergency Room Visits	1.6	700
	Total		17,469,500
$PM_{2.5}$	Mortality	3.8	29,173,000
	Chronic Bronchitis	1.0	285,200
	Acute Respiratory Symptoms	1,318	129,200
	Asthma Exacerbation	1,170	95,100
	Acute Myocardial Infarction	0.9	79,400
	Work Loss Days	213	35,100
	Hospital Admissions, Cardiovascular	0.4	15,600
	Hospital Admissions, Respiratory	0.3	9,500
	Lower Respiratory Symptoms	37	1,900
	Upper Respiratory Symptoms	22	1,000
	Emergency Room Visits	1.6	700
	Acute Bronchitis	2.3	200
	Total		29,825,800
SO_2	Hospital Admissions	1.1	33,200
	Asthma Exacerbation	224	17,600
	Acute Respiratory Symptoms	26	800
	Emergency Room Visits	0.7	300
			52,000

[a] reduction in number of incidences

Value of Wisconsin's Urban Forest

Urban forests have a structural value based on the tree resource itself, which includes compensatory value and carbon storage value. The compensatory value is an estimate of the value of the forest as a structural asset (e.g., how much should one be compensated for the loss of the physical structure of the tree). The urban forest also annually produces functional values based on the functions the tree performs. These estimated 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 value of trees was developed by the Council of Tree and Landscape Appraisers (CTLA) (Council of Tree and Landscape Appraisers 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 4.5 feet above the ground), species, condition and location (Nowak et al., 2002, 2008).

The estimated compensatory value of Wisconsin's urban forest is about $19.3 billion (Figure 27). The other estimated structural value of the urban forest is carbon storage ($507 million). Estimated functional values include annual carbon sequestration ($26.8 million per year), annual air pollution removal ($47.7 million per year), and reduced annual building energy use ($78.9 million per year) (Table 21). These values tend to increase with increased size and numbers of healthy trees.

Table 21—Monetary value of urban forest structure and annual functions, Wisconsin, 2012

Benefit	Value
	dollars
Structural Values	
Compensatory value	19.3 billion
Carbon storage	507 million
Annual Functional Values	
Carbon sequestration	26.8 million
Pollution removal	47.7 million
Energy reduction	78.9 million

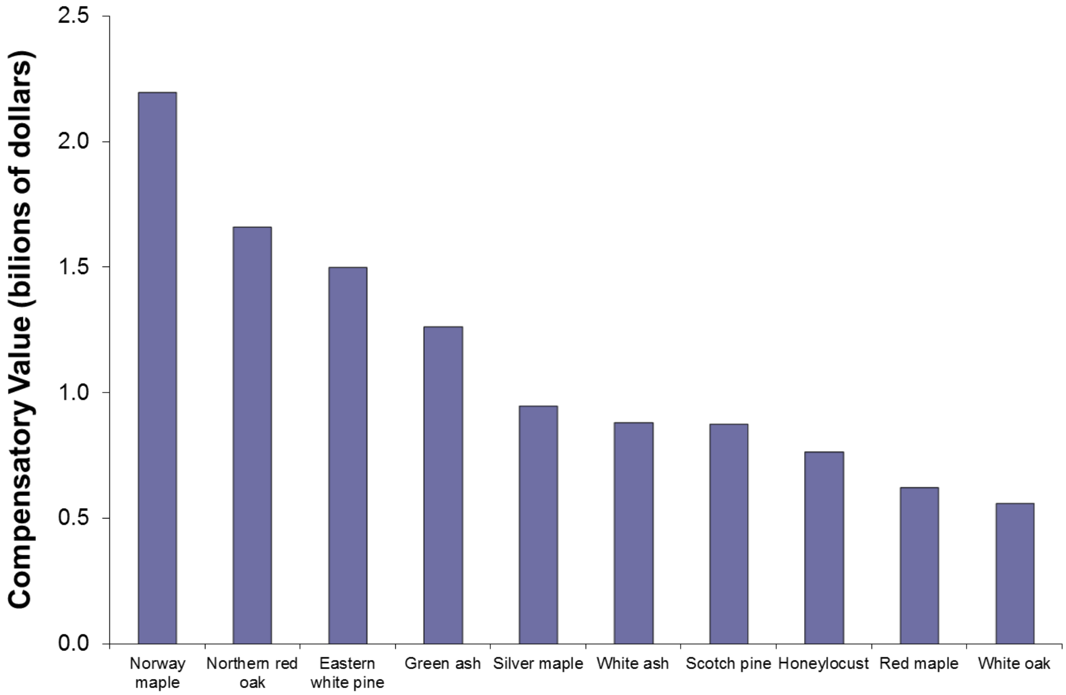

Figure 27—Tree species with the greatest compensatory value, Wisconsin, 2012.

Potential Risk from Pests

Based on the species distribution, the urban forest is at risk from various pests that could potentially impact the health and sustainability of the urban forest resource (Table 22). Thirty-one native or exotic pests and diseases were analyzed using the i-Tree Eco model (Appendix F). Of these pests, only 12 occur within Wisconsin (Figure 28). The greatest potential risks from insect and diseases in Wisconsin are from gypsy moth (5.8 million trees at risk; 13.6 percent of live tree population), emerald ash borer (3.2 million trees; 7.6 percent) and pine shoot beetle (2.7 million trees; 6.4 percent). The greatest risk from insects and diseases outside of Wisconsin come from Asian longhorned beetle (11.0 million trees; 26.0 percent), southern pine beetle (3.7 million trees; 8.7 percent), and sirex wood wasp (2.5 million trees; 5.9 percent). Trees species sampled that are susceptible to pests in Wisconsin are given in Appendix F.

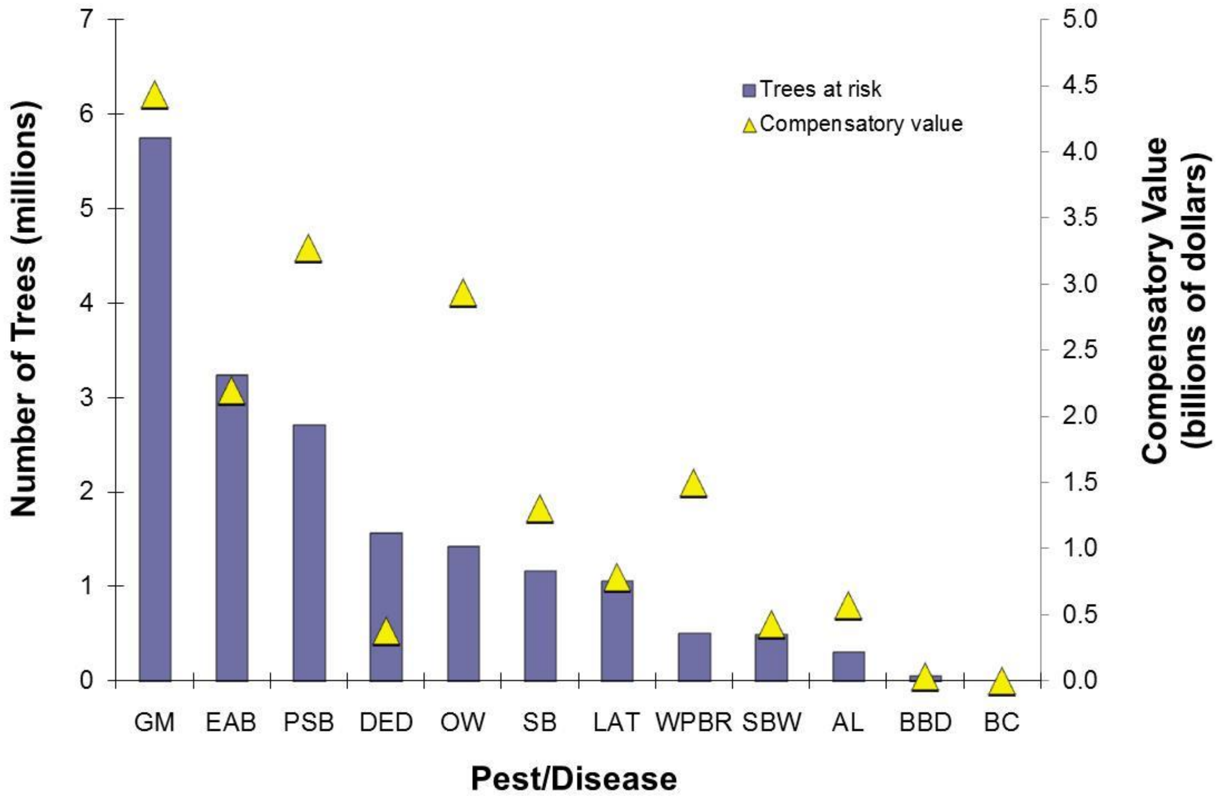

Figure 28—Potential risk (number of trees) and compensatory value of the 12 pests/diseases found in the state, Wisconsin, 2012.

As each pest/disease is likely to attack different host tree species, the implications for Wisconsin will vary. In Table 23, the number of trees at risk reflects only the known host species that are likely to experience mortality. The species host lists used for these pests/diseases can be found at https://www.itreetools.org/eco/resources/iTreeEco_pest_host_list_06292016.xlsx.

Table 22—Potential risk to urban trees by pests/diseases, Wisconsin, 2012

Abbreviation	Common Name	Trees at Risk	Compensatory Value
		number	*$ millions*
AL*	Aspen Leafminer	309,000	573
ALB	Asian Longhorned Beetle	11,008,000	6,940
BBD*	Beech Bark Disease	56,000	37
BC*	Butternut Canker	-	-
CB	Chestnut Blight	-	-
DA	Dogwood Anthracnose	-	-
DED*	Dutch Elm Disease	1,572,000	380
DFB	Douglas-Fir Beetle	-	-
EAB*	Emerald Ash Borer	3,235,000	2,203

continued

Abbreviation	Common Name	Trees at Risk	Compensatory Value
		number	*$ millions*
FE	Fir Engraver	56,000	19
FR	Fusiform Rust	-	-
GM*	Gypsy Moth	5,751,000	4,442
GSOB	Goldspotted Oak Borer	-	-
HWA	Hemlock Woolly Adelgid	-	-
JPB	Jeffrey Pine Beetle	-	-
LAT*	Large Aspen Tortrix	1,058,000	789
LWD	Laurel Wilt	-	-
MPB	Mountain Pine Beetle	1,251,000	1,213
NSE	Northern Spruce Engraver	463,000	410
OW*	Oak Wilt	1,425,000	2,941
POCRD	Port-Orford-Cedar Root Disease	-	-
PSB*	Pine Shoot Beetle	2,713,000	3,278
SB*	Spruce Beetle	1,168,000	1,306
SBW*	Spruce Budworm	498,000	434
SOD	Sudden Oak Death	830,000	1,659
SPB	Southern Pine Beetle	3,682,000	4,245
SW	Sirex Wood Wasp	2,515,000	2,939
TCD	Thousand Canker Disease	149,000	142
WPB	Western Pine Beetle	-	-
WPBR*	White Pine Blister Rust (Eastern U.S.)	511,000	1,501
WSB	Western Spruce Budworm	2,276,000	2,200

* found in Wisconsin

Wisconsin Change Analysis

To estimate change in urban trees between 2002 and 2012, tree data that were measured in both years were assessed. This change analysis was only conducted on urban plots for trees greater than 5 inches d.b.h. that were collected on entire plots in both years. Only trees greater than 5 inches in d.b.h. could be analyzed because while the 2002 data had data on all trees sizes within the entire plot (28 forest plots and 111 urban plots), the 2012 data had 185 urban plots that used microplots to sample trees <5” d.b.h. Thus, in the end, there were only 91 urban plots that had remeasurement data, but only for trees greater than 5 inches d.b.h.

Overall the total tree population grew from 26.9 million trees in 2002 to 42.8 million in 2012, but the amount of urban land increased and the number and location of plots were different, except for the 91 remeasured plots. In addition, two tree species classified as trees in 2002 were not classified as trees in 2012 and were subsequently removed from the change analysis. Thus, the 91 plots are used to assess if there were statistically significant differences in the number of trees greater than 5 inches between 2002 and 2012.

To estimate changes in the Wisconsin urban tree population greater than 5 inches d.b.h., plot data were compared among the sampled years (2002, 2012). As the data were usually not normally distributed (Shapiro-Wilk test; alpha = 0.05), the Wilcoxon signed rank test (alpha = 0.1) was used on the paired plots to test for statistically significant differences in total population and species population totals between years. A minimum of 5 plots was used to test for statistical change.

Of the 91 plots, only 67 plots had trees greater than 5 inches in 2002. While the average number of trees greater than 5 inches d.b.h. dropped by 2.6 trees per plot, there was no statistically significant change in number of trees. As illustrated in Figure 29, 15 plots had no net change in number of trees greater than 5 inches, 24 plots had net increases (maximum increase = 11 trees) and 28 plots had a net decrease (maximum decrease = 42 trees).

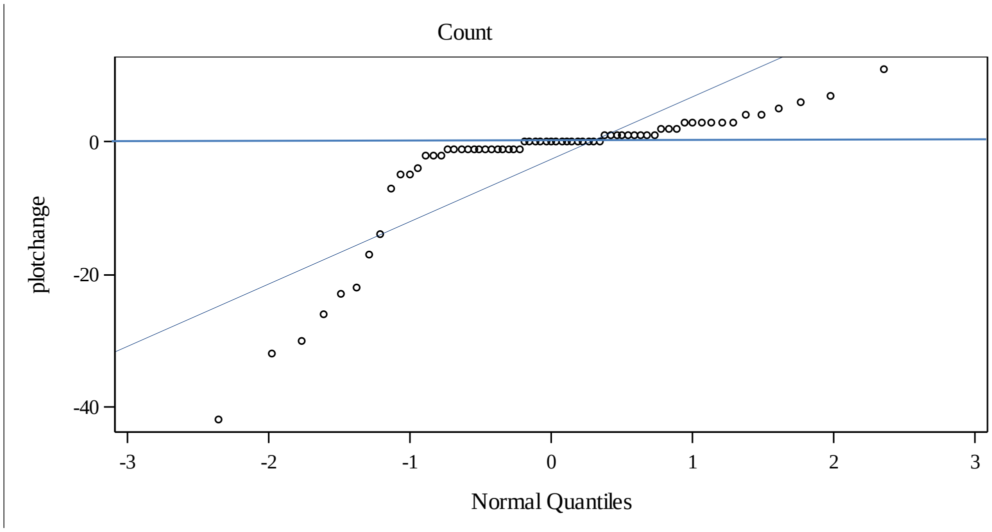

Figure 29—Distribution of change in trees greater than 5 inches d.b.h. Plot change = difference in number of trees greater than 5 inches between 2002 and 2012 on a plot.

Analyzing change by species was hampered by a limited sample size for individual species (e.g., many species were only measured on one plot). One species that had a statistically significant increase in trees greater than 5 inches was silver maple (*Acer saccharinum*). Species with statistically significant decreases were white ash (*Fraxinus americana*) and sugar maple (*Acer saccharum*) (Table 23).

Table 23—Average change in number of trees per plot by species.

Scientific name	Common name	n	Change[a]	p value[b]
Malus spp.	Crabapple	2	8.00	.
Euonymus alata	Winged burning bush	1	6.00	.
Syringa vulgaris	Common lilac	1	4.00	.
Acer saccharinum	Silver maple	9	2.22	0.008*
Crataegus mollis	Downy hawthorn	1	2.00	.
Pinus sylvestris	Scotch pine	2	2.00	.
Prunus americana	American plum	1	2.00	.
Rhamnus cathartica	European buckthorn	3	1.67	.
Abies concolor	White fir	1	1.00	.
Catalpa speciosa	Northern catalpa	1	1.00	.
Fraxinus spp.	Ash	1	1.00	.
Morus alba	White mulberry	1	1.00	.
Populus deltoides	Eastern cottonwood	1	1.00	.
Quercus macrocarpa	Bur oak	2	1.00	.
Sorbus spp.	Mountain ash	1	1.00	.
Ulmus spp.	Elm	1	1.00	.
Pinus banksiana	Jack pine	2	0.50	.
Pinus resinosa	Red pine	4	0.50	.
Quercus ellipsoidalis	Northern pin oak	2	0.50	.
Gleditsia triacanthos	Honeylocust	7	0.43	0.250
Juniperus virginiana	Eastern red cedar	5	0.20	1.000
Picea abies	Norway spruce	5	0.20	1.000
Picea pungens	Blue spruce	8	0.13	1.000
Acer platanoides	Norway maple	16	0.00	1.000
Aesculus glabra	Ohio buckeye	1	0.00	.
Cornus florida	Flowering dogwood	1	0.00	.
Elaeagnus angustifolia	Russian olive	1	0.00	.
Pinus nigra	Austrian pine	1	0.00	.
Pinus strobus	Eastern white pine	7	0.00	1.000
Populus grandidentata	Bigtooth aspen	1	0.00	.
Prunus spp.	Cherry	3	0.00	.
Prunus serotina	Black cherry	4	0.00	.
Quercus rubra	Northern red oak	9	0.00	1.000
Salix spp.	Willow	1	0.00	.
Salix babylonica	Weeping willow	1	0.00	.
Picea glauca	White spruce	16	-0.13	1.000
Populus tremuloides	Quaking aspen	3	-0.33	.
Prunus pensylvanica	Pin cherry	2	-0.50	.
Thuja occidentalis	Northern white cedar	7	-0.57	0.469
Betula papyrifera	Paper birch	7	-0.71	0.500

continued

Scientific name	Common name	n	Change[a]	p value[b]
Betula nigra	River birch	1	-1.00	.
Carpinus caroliniana	American hornbeam	1	-1.00	.
Fagus grandifolia	American beech	1	-1.00	.
Fraxinus nigra	Black ash	1	-1.00	.
Ostrya virginiana	Eastern hophornbeam	2	-1.00	.
Quercus marilandica	Blackjack oak	3	-1.00	.
Ulmus americana	American elm	5	-1.20	0.250
Ulmus pumila	Siberian elm	4	-1.25	.
Fraxinus pennsylvanica	Green ash	10	-1.40	0.547
Acer saccharum	Sugar maple	7	-1.43	0.031*
Celtis occidentalis	Northern hackberry	3	-1.67	.
Crataegus phaenopyrum	Washington hawthorn	1	-2.00	.
Juglans nigra	Black walnut	2	-2.00	.
Prunus virginiana	Common chokecherry	1	-2.00	.
Quercus alba	White oak	2	-2.50	.
Morus rubra	Red mulberry	5	-2.60	0.125
Abies balsamea	Balsam fir	1	-3.00	.
Crataegus monogyna	Oneseed hawthorn	1	-3.00	.
Malus pumila	Apple	2	-3.50	.
Acer rubrum	Red maple	6	-3.67	0.375
Prunus serrulata	Kwanzan cherry	3	-4.33	.
Carya ovalis	Red hickory	1	-5.00	.
Fraxinus americana	White ash	10	-5.40	0.062*
Acer negundo	Boxelder	10	-5.80	0.191
Ulmus rubra	Slippery elm	2	-7.50	.

n = number of plots with given species (sample size)
. = sample did not meet selected minimum sample size of 5 plots for statistical analysis
na – not applicable
[a] average change in number of trees per plot
[b] Wilcoxon signed rank test
* statistically significant difference at alpha = 0.10

DISCUSSION

2012 Results

Trees in Wisconsin's urban forest are mostly found within residential areas. Residential areas account of 46.3 percent of the area and 69 percent of the tree population. Thus residential lands are providing essential forest services to the people of Wisconsin. As this study focused predominantly on the non-forested urban areas, it is also important to note that forest lands within urban areas also contributed substantial services to urban populations. In the 2002 assessments, forests in urban areas contributed about 79% of the total number of urban trees in Wisconsin. As urban lands and urban populations increase, urban trees, particularly in forests and on residential lands will be essential to sustain as these trees provide the greatest amount of services and values to urban residents.

The urban forests of Wisconsin are fairly rich in terms of species, with 65 species being sampled. However, in terms of size distribution, the top 6 species in terms of number of trees are all small trees / large shrubs; none of these species reaching over 15 inches in diameter. The top six species in terms of numbers are: common lilac (all less than 3 inches d.b.h.), Northern white cedar, apples (all less than 12 inches d.b.h.); European buckthorn (invasive species, all less than 9 inches d.b.h.), Eastern red cedar and winged burning bush (all less than 3 inches d.b.h.). These six species comprise 46.4 percent of the total tree population, but only 14.2 percent of the leaf area. Thus these trees are important in terms of number of stems to manage, but relatively unimportant in terms of impact or benefits provided to the local residents.

The more important trees in terms of benefits are the large tree species. Only 25 of the 65 species encountered reached at least 15 inches in diameter, and these 25 species only accounted for 37.8 percent of the tree population, but 70 percent of the total leaf area. The most dominant of the species are silver maple, Norway maple (non-regulated invasive species), green ash, Northern red oak and Eastern white pine, which account for 13.9 percent of the population, but 37 percent of total basal area and 33 percent of total leaf area. One of these species, green ash, is likely to decline significantly in the coming years due to the emerald ash borer. Two other species, Norway maple and Eastern white pine, are likely to decline due to limited recent planting or natural regeneration. Norway maple only has 5.8 percent of its population less than 6 inches in diameter and over 34 percent greater than 18 inches in diameter. Eastern white pine has 0 percent of its population less than 6 inches in diameter and over 36 percent greater than 18 inches in diameter. There likely are not enough small trees currently to sustain these species' populations at current levels and these populations will likely decline as the older and larger trees pass away. With regards to Norway maple, which is classified as a non-regulated invasive species, it is either not invading many urban areas or there are controls to keep regeneration in check as there were not many small Norway maples encountered in the sample. Thus three of the five most important urban species in Wisconsin are likely to decline in importance and impact in the coming years. The question for the residents of Wisconsin is – what species, if any, will take their place in providing benefits to society. If not replaced, or replaced with smaller, more common species, then urban forest benefits to society will decline.

The urban forests of Wisconsin provide significant social and environmental benefits to the people of Wisconsin. The resource itself is worth about 20 billion dollars and provides annual benefits of more than $150 million per year. These annual benefits are only based on three benefits that were quantified: air pollution removal, carbon sequestration and building energy effects. Urban forests provide numerous other benefits (e.g., air temperature reduction, aesthetics, improved human health wildlife habitat, improved water quality, reduced flooding, etc.) yet to be valued. However, urban forest management comes with direct costs of maintenance and indirect costs associated with negative services (e.g., tree pollen). By understanding the urban forests and its impacts, urban forest management plans can be developed to optimize the benefits and minimize costs in developing sustainable and healthy urban forests for both current and future generations.

There are four dominant threats that are likely to affect Wisconsin's urban forests in the coming years. These threats are:

1) Development – as evidenced by the expansion of urban land in the state, this impact also includes perpetual development or redevelopment within existing urban areas. This development often either removes existing trees, or limits the expansion or regeneration of trees through the development of hardscapes that prohibit trees, or mowing that prevents regeneration of trees.

2) Insects and diseases – new insects and diseases, particularly potentially devastating ones like emerald ash borer, Asian longhorned beetle and sudden oak death have the potential to create large changes in urban forests in a relative short period of time. Management to limit the introduction and/or impact of the pests is critical to sustaining forest health. Emerald ash borer is already in Wisconsin as are other insects and diseases, but additional pests that are not within the state could have a substantial impact if introduced into Wisconsin's urban forest. Millions of trees are currently at risk to emerald ash borer and gypsy moth, the two most potentially devastating pests that already exist within Wisconsin's urban forest.

3) Invasive species – invasive species are an issue in Wisconsin's urban forest with about 20 percent of the trees classified as invasive. Nine species encountered are classified as invasive, with two invasive species (European buckthorn and winged burning bush) in the top 10 species in terms of total numbers and one species (Norway maple) providing the second most leaf area of any species (8.4 percent of total leaf area). While Norway maple appears to be heading for a decline in population due to the limited number of small diameter trees encountered, the other invasive plants could have an increasing influence on Wisconsin's urban forest (particularly buckthorn and winged burning bush).

4) Environmental change – though not directly addressed in this assessment, environmental change will likely influence the composition of Wisconsin's urban forest in the years to come. As temperature and rainfall patterns change, some species will perform better, and some worse, under the new environmental conditions. Thus species composition will change as some species will decline and others perform better, or possibly new species are introduced that will perform well in the altered environment. In addition to potential species shifts, severe environmental extremes could substantially impact forest structure and composition. Extreme wind, heat, rain or drought events could lead to significant losses in tree population in a relative short period of

time. Forest management to compensate for these extreme events (e.g., watering, pruning) may be needed to sustain urban forest health through these extreme events.

2002-2012 Change Analysis

Urban forest change is a certainty. Forests always change and always will change. Data on tree change in the last 10 years reveals that one species had a significant increase: silver maple and two species had significant declines: white ash (likely an artifact of emerald ash borer) and sugar maple. These changes could be due to many factors, including changes in planting or natural regeneration rates of these species. As emerald ash borer (EAB) continues to spread in Wisconsin, management decisions and activities of communities and the public are changing due to the actual or anticipated arrival of EAB. While the insect itself likely contributed to the observed decrease in the average number of white ash trees greater than 5 inches d.b.h., pre-emptive removals of ash by municipalities and private homeowners may have contributed as well.

While not statistically significant, the overall trend in the last 10 years has been a decline in the density of trees greater than 5 inches in diameter. More long-term monitoring of urban forests will help reveal patterns and possible reasons for change. Through better understanding of the amounts and types of changes that are occurring, forest management plans can be developed to better direct urban forests to a more sustainable and desirable future.

Methodology Evaluation

A major purpose of the 2012 study was to evaluate the Forest Service's Urban Forest Inventory and Analysis protocol as a means of characterizing and monitoring the state's urban forest resource over time. The comparison of the 2002 protocol and the 2012 protocol provide key insights into the opportunities and challenges of long-term urban forest monitoring at the statewide scale.

The first challenge was due to changes in data acquisition protocols between the years. While changes can occur due to procedural improvements, consistency in plot locations and remeasurement are essential. Some new plots are expected through time as urban areas expand; and some plots are expected to be lost through time due to loss of access permission. However, the lack of 2012 remeasurements of FIA forested plots limited the ability to assess change through time.

Plot measurements also changed between years. In 2002, all trees greater than one-inch d.b.h. were measured on the entire plot, regardless of species. In 2012, only trees greater than 5 inches d.b.h. were measured on the plot and trees less than 5 inches d.b.h. measured on microplots. This change negated the ability to assess change for trees less than 5 inches d.b.h. Also in 2012, tree species measured only included species on the USFS FIA tally-list, so some species were dropped from the original 2002 tally, which did not use a tally-list, but rather included all woody species greater than one-inch d.b.h.

One of the most significant observations from the two studies was that the traditional FIA plot density of 1 plot per 6,000 acres is insufficient to capture enough urban trees to produce statistically comparable results. There is a greater species diversity and lower tree density in the urban forest than in rural forests, so smaller sample sizes limits the ability to detect change and lowers the precision of the estimates related to the diverse tree population.

The plot-based Urban FIA program provides forest composition and characterization across all urban forest ownerships using a nationally standardized data gathering protocol and consistently trained and certified crews. It is now designed to be a continuous inventory, sampling a portion of all plots every year. Analysis is also nationally standardized and supported by the Forest Service. It combines both urban ecosystem services model outputs through i-Tree tools and traditional FIA timberland data outputs. Analysis and data tables from these analyses will be publically available online. No other inventory program exists that provides this level of urban forest resource information.

The urban FIA program has established urban forest monitoring programs in Austin, TX (Nowak et al. 2016); Baltimore, MD; Houston, TX; Providence, RI; Madison and Milwaukee, WI; St. Louis, MO; and Des Moines IA. Planned future program areas include San Antonio, TX; Springfield and Kansas City, MO; Denver and Fort Collins, CO; Burlington, VT; Rochester, NY; Pittsburgh and Philadelphia, PA; Detroit, MI; Minneapolis and St. Paul, MN; Cleveland, OH; Chicago, IL; Lincoln, NE; Wichita, KS; and San Diego, CA.

CONCLUSION

With the growth of urban areas and high concentration of human populations in urban areas, data on urban forests are becoming more essential, particularly as urban trees can have significant impacts on numerous local to global environmental issues and regulations (e.g., Clean Air Act, Clean Water Act). Having long-term data on this important resource will allow assessing changes in forest composition and associated ecosystem values. In addition, monitoring can provide essential data in relation to the potential use of urban forests within regulations set to protect human health and well-being. Not only does an urban forest monitoring program provide essential data for management and integration within local to international policies, the long-term data provide essential information for sustaining urban forest canopy cover and health.

Management of any natural resource requires knowledge of type, size and quantity of the resource. Inventories and assessments to monitor composition, size and health provide information about the current status of urban forests, and, if compiled periodically, information about how the forest changes over time. This current study is the first statewide assessment of urban forest change. Continued measurements could monitor how urban forests change over time due to urbanization pressures, management techniques, and the influence of stresses, such as invasive pests or extreme weather events. In addition, information could be compiled regarding which species perform the best under differing urban conditions and how long various species live on average in urban areas.

The results of the 2002 pilot demonstrated how a statewide urban forest inventory and analysis can be used to show the value of the resource, and to establish goals for its sustainable management. The 2012 remeasurement not only provided more current information, but identified gaps in desired analyses. Insights gained from this comparison will refine protocols to improve the precision of the estimates of the current urban forest status and its future trends. While plot-based inventories have certain inherent limitations, they are a critical component of a complete urban forest resource analysis because they characterize all urban forest land both public and private. With a plot sample intensification to improve precision, the USDA Forest Service's new continuous UFIA protocol will help meet Wisconsin's need for an all-lands component of its statewide urban forest assessment program.

Statewide estimates of urban forest and tree resources only exist for a few States in addition to Wisconsin (Indiana and Tennessee) (Nowak et al. 2007, Nowak et al. 2012), but only Wisconsin is implementing a statewide, long-term urban forest monitoring program. Additionally, long-term monitoring of metropolitan areas by the Forest Service FIA program began in 2014 with many cities currently being monitored, or to be monitored in the near future.

To sustain the health, environmental and social benefits received from urban forests, specific urban forest management plans and goals need to be developed. These plans also need to be dynamic due to the continuous forces of change that alter urban forest environments. Long-term urban forest monitoring data will provide the information necessary to make these specific, goal-oriented management plans. In addition, the monitoring data will allow for continual updating of plans to ensure that plan goals are met to facilitate forest sustainability. Long-term monitoring data will also reveal what factors (e.g., insects, diseases, decay, etc.) most threaten urban forest sustainability so that corrective management actions can be taken. Data from urban forest monitoring programs could be incorporated within State and local urban forest planning and management regimes to allow local constituents to develop canopy goals and/or tree planting goals to sustain or enhance urban forest canopy across the State.

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GLOSSARY

Biomass—The aboveground weight of wood and bark in measured live trees. Biomass is expressed as oven-dry weight and the units are tons.

Crown—The part of a tree or woody plant bearing live branches or foliage.

Crown dieback—Recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds toward the trunk. Dieback is only considered when it occurs in the upper and outer portions of the tree. Dead branches in the lower live crown are not considered as part of crown dieback, unless there is continuous dieback from the upper and outer crown down to those branches.

Damage/causal agents:

- Trunk (canker or decay)—Presence of decay fungi; hollow areas or weak, rotten wood.
- Trunk (wound or crack)—Physical damage to the main stem or stems of a tree. Bark is visibly damaged or absent. This includes: lightning strikes, lawn mower and line trimmer damage. Wound or crack must be at least 25 percent of circumference or over a 3 foot vertical section.
- Roots (stem girdling)—Roots that encircle the trunk of tree may cause bark and wood tissue compression. Roots stem girdling must be at least 25 percent of circumference of stem at base.
- Trunk/branches (bark inclusion)—"V" branching pattern. Signs of bark inclusion are evident. Bark inclusion is bark enclosed between branches with narrow angles of attachment, forming a wedge between the branches.
- Trunk (severe topping or poor pruning)—Tree has been reduced to a single "pole" due to severe overpruning and branch removal. Poor pruning techniques include leaving stubs outside the branch collar, cutting into the branch collar. Severe topping or poor pruning must be ≥ 30 percent of crown.
- Trunk (excessive mulch)—Mulch piled around the tree trunk. Root flare is not visible at base of trunk. Mulch piled high around stem and mulch depth > 8 inches.
- Branches (dead or dying crown)—Dead branches in crown. Dead or dying crown must be ≥ 30 percent of crown.
- Leaves (chlorotic/necrotic)—Leaves are chlorotic, necrotic, wilted, abnormal size/shape or have been defoliated from branches. Chlorotic/necrotic foliage must be ≥ 30 percent of crown.

- Branches (vines in crown)—Vines present in tree. Vines in crown must be ≥ 30 percent of crown volume.
- Main stem (dead top)—Main stem dead or missing. Main stem dead top must be at least 30 percent of tree height.
- Sidewalk (conflict with roots)—Damage to sidewalk directly caused by roots.
- Overhead wires (conflict with tree crown)—Tree crown (branches or leaves) are within 5 feet of utility wires.
- Improper planting (trees ≤ 10 inches d.b.h.)—Evidence that burlap, twine, or root ball wire was not removed prior to planting. Any of the following are visible at the soil surface: burlap, twine, or cage/wire.

Diameter at breast height (d.b.h.)—The diameter for tree stem, located at 4.5 feet above the ground (breast height) on the uphill side of a tree. The point of diameter measurement may vary on abnormally formed trees.

Foliage transparency—The amount of skylight visible through microholes in the live portion of the crown, i.e. where you see foliage, normal or damaged, or remnants of its recent presence. Recently defoliated branches are included in foliage transparency measurements. Macroholes are excluded unless they are the result of recent defoliation. Dieback and dead branches are always excluded from the estimate. Foliage transparency is different from crown density because it emphasizes foliage and ignores stems, branches, fruits, and holes in the crown.

Forest — The standard definition of forest land, used by the Forest Inventory and Analysis (FIA) Program, is an area 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.

i-Tree Eco—An i-Tree model formerly known as the Urban Forest Effects (UFORE) model that uses field data in conjunction with air pollution and meteorological inputs to quantify urban forest structure (such as species composition, tree density, tree health, leaf area, and biomass), environmental services (such as air pollution removal, carbon storage and sequestration, effects of trees on energy use), and potential pest impacts.

Land use—The purpose of human activity on the land; it is usually, but not always, related to land cover. Land use categories used were:

- Agriculture/other - land managed for crops, pasture, or other agricultural uses and land not classified within any of the other land use categories.
- Commercial/transportation - developed land used for commercial businesses or industrial purposes and transportation corridors, limited access roadways, airports, or railway. Trees along arterial streets were included as part of the adjacent land use (e.g., a street tree in front of a residence was classified as residential).

- Partially forested - plots with a portion of its area meeting the FIA definition of forest.
- Institutional/park - developed land used for schools, government or religious buildings, or hospital/medical complexes and land used primarily for parks, green/open space, or golf courses.
- Residential - developed land used primarily for human dwellings.
- Wetland - areas where water covers soil all or part of the time

Maintained—The maintained classification was applied to each tree in our sample. It designates the surrounding area in which the tree is located. Maintained areas are regularly impacted by mowing, mulching, or other types of landscape care. It does not imply that the tree is maintained.

Tree—A woody perennial plant, typically large, with a single well-defined stem carrying a more or less definite crown; sometimes defined as attaining a minimum diameter of 3 inches and a minimum height of 15 feet at maturity. For FIA, any plant on the tree list in the current field manual is measured as a tree.

Urban—Urban areas were classified based on the 2000 census and consisted of: all territory, population, and housing units located within either urbanized areas or urban clusters (U.S. Department of Commerce 2011). Urbanized area and urban cluster boundaries encompass densely settled territories, which generally consist of: (a) cluster of one or more block groups or census blocks with a population density of at least 1,000 people per square mile, (b) surrounding block groups and census blocks with a population density of 500 people per square mile, and (c) less densely settled blocks that form enclaves or indentations, or are used to connect discontinuous areas. Urbanized areas consist of densely settled territory that has ≥ 50,000 people; urban clusters consist of densely settled territory that has ≥ 2,500 people but < 50,000 people.

Urban forest—Term used for all trees within nonforested urban land.

Metric equivalents
1 acre = 4,046.87 m^2 or 0.404687 ha
1 cubic foot = 0.028317 m^3
1 inch = 2.54 cm or 0.0254 m
Breast height (4.5 feet) = 1.374 m above the ground
1 square foot = 929.03 cm^2 or 0.0929 m^2
1 square foot of basal area per acre = 0.229568 m^2/ha
1 cubic foot per acre = 0.0699722 m^3/ha
1 pound = 0.454 kg
1 ton = 0.908 metric ton

APPENDIX A—METHODS

Urban areas were classified based on the 2000 census and consisted of: (all territory, population, and housing units located within either urbanized areas or urban clusters (U.S. Department of Commerce 2011). Urbanized area and urban cluster boundaries encompass densely settled territories, which generally consist of (a) a cluster of one or more block groups or census blocks with a population density of at least 1,000 people per square mile, (b) surrounding block groups and census blocks with a population density of 500 people per square mile, and (c) less densely settled blocks that form enclaves or indentations, or are used to connect discontinuous areas. Urbanized areas consist of densely settled territory that contains ≥ 50,000 people; urban clusters consist of densely settled territory that has ≥ 2,500 people but < 50,000 people.

Within the urban areas, forest land exists. The U.S. Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) program define forests as areas at least 1 acre in size, at least 120 feet wide, and at least 10 percent stocked. Forested plots must also have an understory that is undisturbed by another land use (U.S. Department of Agriculture 2010). For the 2012 assessment, plots falling with forested land were excluded and only non-forested ("urban forest") plots were measured (Table A.1).

On each plot, trees and saplings were measured. Variables measured on the trees and the plot included species, diameter, height, height to live crown, crown dimensions, foliage transparency, tree damage, distance of tree to buildings, ground cover, impervious surface on plot, condition class, and ownership. Each plot consisted of four subplots with microplots contained within the subplot (Figure A.1). Data were collected on all trees ≥ 5 inches d.b.h. on four 1/24th acre subplots and on saplings between 1 and 4.9 inches d.b.h. on four 1/300th acre microplots (data collection methods are described in detail in U.S. Department of Agriculture 2005a, 2006).

Methods of the assessment of ecosystem services using the i-Tree model are detailed in Nowak et al. (2008). Additional forest health data were collected on urban trees, including estimates of tree crown condition (U.S. Department of Agriculture 2007) and tree damage (U.S. Department of Agriculture 2006).

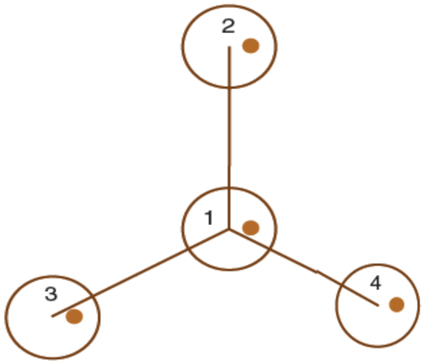

Figure A.1—FIA plot configuration.

Table A.1—Urban plots by land use / plot status in Wisconsin, 2012

Land use/ plot status	**Sampled**	
	Plots	**Live trees**
	number	
Agriculture/Other	16	15
Commercial/Transportation	23	28
Partially forested	16	20
Institutional/Parks	28	112
Residential	96	415
Wetland	6	7
Total	185	597

Sample intensity = 1 plot per 5,043 acres
n/a = not applicable

APPENDIX B—STATISTICS ON TREE SPECIES

Table B.1—Statistics of tree species by common and scientific name, Wisconsin, 2012

							D.b.h.	
Common name	Scientific name	Trees		Basal area			Avg	Median
		number	*%*	*ft²*	*ft²/ac*	*%*	*inches*	
Balsam fir	Abies balsamea	34,962	0.1	15,446	0	0.1	8.5	8.5
White fir	Abies concolor	56,193	0.1	15,324	0	0.1	6.5	6.0
Boxelder	Acer negundo	1,501,980	3.5	450,981	0.5	2.9	5.8	5.2
Norway maple	Acer platanoides	1,082,477	2.5	1,234,761	1.3	8.1	13.1	13.5
Red maple	Acer rubrum	1,844,512	4.3	405,872	0.4	2.6	4.1	2.3
Silver maple	Acer saccharinum	2,101,283	4.9	1,668,417	1.8	10.9	9.1	5.0
Sugar maple	Acer saccharum	661,994	1.5	207,828	0.2	1.4	6.3	4.0
Alder	Alnus x fallacina	64,511	0.2	12,667	0	0.1	5.5	5.5
Paper birch	Betula papyrifera	309,064	0.7	144,816	0.2	0.9	8.5	8.2
Bitternut hickory	Carya cordiformis	56,193	0.1	31,415	0	0.2	9.0	6.0
Shagbark hickory	Carya ovata	314,210	0.7	130,854	0.1	0.9	7.9	6.9
Catalpa species	Catalpa spp.	30,889	0.1	24,260	0	0.2	11.5	11.5
Northern catalpa	Catalpa speciosa	56,193	0.1	76,621	0.1	0.5	14.5	10.0
Northern hackberry	Celtis occidentalis	981,242	2.3	215,499	0.2	1.4	5.3	4.4
Downy hawthorn	Crataegus mollis	28,097	0.1	25,899	0	0.2	12.5	12.5
Russian olive	Elaeagnus angustifolia	56,193	0.1	48,578	0.1	0.3	12.0	11.0
Winged burning bush	Euonymus alata	2,223,535	5.2	36,395	0	0.2	1.3	1.3
American beech	Fagus grandifolia	56,193	0.1	26,051	0	0.2	8.5	7.0
White ash	Fraxinus americana	1,669,275	3.9	610,211	0.7	4.0	6.2	4.4
Green ash	Fraxinus pennsylvanica	1,453,204	3.4	968,281	1	6.3	9.3	7.8
Ash species	Fraxinus spp.	112,387	0.3	41,989	0	0.3	7.5	6.0
Honeylocust	Gleditsia triacanthos	431,140	1	556,890	0.6	3.6	13.9	13.2
Black walnut	Juglans nigra	149,059	0.3	101,787	0.1	0.7	10.3	9.8
Eastern red cedar	Juniperus virginiana	2,387,458	5.6	213,907	0.2	1.4	2.6	1.6
Apple species	Malus spp.	3,264,781	7.6	376,008	0.4	2.5	3.7	2.9
White mulberry	Morus alba	309,064	0.7	157,535	0.2	1.0	8.6	6.8
Red mulberry	Morus rubra	28,097	0.1	9,808	0	0.1	7.5	7.5
Eastern hophornbeam	Ostrya virginiana	84,290	0.2	31,568	0	0.2	7.5	6.5
Norway spruce	Picea abies	198,392	0.5	253,519	0.3	1.7	14.3	12.5
White spruce	Picea glauca	463,273	1.1	308,097	0.3	2.0	9.7	8.0
Blue spruce	Picea pungens	505,970	1.2	320,018	0.3	2.1	9.9	9.8
Jack pine	Pinus banksiana	377,157	0.9	15,545	0	0.1	1.9	1.5
Austrian pine	Pinus nigra	59,624	0.1	29,431	0	0.2	9.0	9.0
Red pine	Pinus resinosa	514,322	1.2	340,531	0.4	2.2	10.0	9.9
Eastern white pine	Pinus strobus	510,887	1.2	828,233	0.9	5.4	15.9	15.5
Scotch pine	Pinus sylvestris	1,052,645	2.5	552,792	0.6	3.6	9.2	9.2
Eastern cottonwood	Populus deltoides	173,123	0.4	560,947	0.6	3.7	21.6	13.9

continued

Common name	Scientific name	Trees		Basal area			D.b.h.	
							Avg	Median
		number	*%*	*ft²*	*ft²/ac*	*%*	*inches*	
Bigtooth aspen	Populus grandidentata	28,097	0.1	9,808	0	0.1	7.5	7.5
Quaking aspen	Populus tremuloides	140,484	0.3	93,326	0.1	0.6	10.1	9.5
American plum	Prunus americana	694,690	1.6	24,628	0	0.2	2.0	2.0
Pin cherry	Prunus pensylvanica	28,097	0.1	12,413	0	0.1	8.5	8.5
Black cherry	Prunus serotina	684,506	1.6	158,120	0.2	1.0	5.2	3.0
Plum species	Prunus spp.	84,290	0.2	21,761	0	0.1	6.2	5.5
Common chokecherry	Prunus virginiana	347,345	0.8	7,578	0	0.0	1.5	1.5
Callery pear	Pyrus calleryana	189,442	0.4	40,343	0	0.3	5.7	5.7
Common pear	Pyrus communis	28,097	0.1	5,517	0	0.0	5.5	5.5
White oak	Quercus alba	224,774	0.5	334,226	0.4	2.2	14.4	10.0
Northern pin oak	Quercus ellipsoidalis	196,677	0.5	176,844	0.2	1.2	9.8	7.2
Bur oak	Quercus macrocarpa	28,097	0.1	61,298	0.1	0.4	19.5	19.5
Northern red oak	Quercus rubra	830,135	1.9	964,256	1	6.3	11.2	8.7
Black oak	Quercus velutina	145,629	0.3	169,538	0.2	1.1	13.7	14.5
European buckthorn	Rhamnus cathartica	2,545,755	5.9	147,560	0.2	1.0	2.4	1.9
Black locust	Robinia pseudoacacia	92,667	0.2	65,027	0.1	0.4	10.8	10.7
Black willow	Salix nigra	84,290	0.2	432,761	0.5	2.8	28.8	23.5
Willow species	Salix spp.	28,097	0.1	34,480	0	0.2	14.5	14.5
Weeping willow	Salix x sepulcralis simonk	56,193	0.1	211,016	0.2	1.4	22.0	9.0
Mountain ash species	Sorbus spp.	29,812	0.1	16,260	0	0.1	9.5	9.5
Common lilac	Syringa vulgaris	4,862,830	11.4	144,018	0.2	0.9	1.8	1.7
Northern white cedar	Thuja occidentalis	4,558,408	10.7	264,445	0.3	1.7	2.1	1.6
American basswood	Tilia americana	56,193	0.1	147,726	0.2	1.0	18.5	8.0
Littleleaf linden	Tilia cordata	56,193	0.1	19,615	0	0.1	7.5	7.5
American elm	Ulmus Americana	381,138	0.9	413,604	0.4	2.7	10.9	7.4
Siberian elm	Ulmus pumila	893,236	2.1	210,341	0.2	1.4	4.9	2.8
Slippery elm	Ulmus rubra	252,871	0.6	75,243	0.1	0.5	6.7	6.2
Elm spp	Ulmus species	44,416	0.1	11,870	0	0.1	6.5	6.5

D.b.h. = diameter at breast height

APPENDIX C—TOTAL SPECIES SUMMARY

Table C.1— Total species summary, Wisconsin, 2012

Species	Trees			Carbon storage			Carbon sequestration			Net carbon sequestration		Leaf area			Leaf biomass			Compensatory value		
	%	*number*	*SE*	*%*	*tons*	*SE*	*%*	*tons*	*SE*	*tons*	*SE*	*%*	*acres (thousands)*	*SE*	*%*	*tons*	*SE*	*%*	*$ millions*	*SE*
Common lilac	11.4	4,862,830	3,161,046	0.3	12,198	7,971	2.6	5,437	3,533	5,344	3,473	1.0	6.5	3.9	1.1	2,783	1,666	1.2	226	147
Northern white cedar	10.7	4,558,408	3,481,744	0.6	22,690	12,161	1.6	3,395	2,075	3,279	2,023	1.3	8.9	4.8	3.0	7,667	4,132	2.8	531	301
Apple spp	7.6	3,264,781	2,465,244	1.6	63,277	31,768	5.1	10,791	7,058	10,523	6,907	4.4	29.3	19.3	4.4	11,277	7,424	2.0	381	202
European buckthorn	5.9	2,545,755	1,503,688	0.5	18,567	9,042	2.1	4,454	2,252	4,381	2,216	2.4	15.9	8.1	1.2	3,149	1,607	0.9	183	87
Eastern red cedar	5.6	2,387,458	1,050,624	1.0	40,622	20,042	1.4	2,937	1,280	2,754	1,201	4.9	32.8	20.7	15.7	40,626	25,645	2.0	376	183
Winged burning bush	5.2	2,223,535	2,223,532	0.1	2,313	2,313	0.5	1,071	1,071	1,053	1,053	0.2	1.5	1.5	0.2	508	507	0.7	129	129
Silver maple	4.9	2,101,283	857,142	13.3	531,591	165,158	9.5	20,184	5,952	17,796	5,312	10.6	71.3	19.7	6.5	16,730	4,626	4.9	948	291
Red maple	4.3	1,844,512	859,595	2.8	110,568	44,181	3.6	7,722	2,522	7,305	2,369	3.5	23.6	9.0	2.7	7,089	2,695	3.2	623	237
White ash	3.9	1,669,275	812,735	4.5	179,862	66,642	5.1	10,830	3,559	9,205	3,438	4.8	32.5	11.3	3.2	8,227	2,873	4.6	884	321
Boxelder	3.5	1,501,980	752,576	2.9	117,187	42,717	4.0	8,533	2,751	8,023	2,604	4.2	28.0	9.1	4.4	11,435	3,707	1.7	320	117
Green ash	3.4	1,453,203	444,147	4.8	192,242	49,414	3.7	7,807	1,890	7,295	1,775	5.4	36.4	10.2	4.1	10,577	2,956	6.6	1,262	337
Norway maple	2.5	1,082,477	255,363	9.1	364,684	101,885	7.6	16,015	3,973	14,610	3,605	8.4	56.6	16.1	5.3	13,623	3,884	11.4	2,196	599
Scotch pine	2.5	1,052,645	754,808	1.7	67,762	51,062	1.9	3,925	2,645	2,903	1,768	2.1	14.1	8.9	2.3	6,070	3,844	4.5	874	676
Northern hackberry	2.3	981,242	708,401	1.1	43,765	20,862	2.4	5,049	2,868	4,895	2,799	3.4	23.1	15.5	2.1	5,353	3,596	1.1	215	105
Siberian elm	2.1	893,236	569,576	1.0	39,336	15,779	1.4	3,073	1,231	350	2,895	1.6	10.5	4.0	1.2	3,191	1,229	0.5	89	40
Northern red oak	1.9	830,135	404,614	8.8	353,610	160,651	6.7	14,175	5,788	12,829	5,194	5.9	39.5	17.1	5.4	14,037	6,090	8.6	1,659	727
American plum	1.6	694,690	694,689	0.1	2,333	2,333	0.5	993	993	976	976	0.4	2.7	2.7	0.4	932	932	0.1	20	20
Black cherry	1.6	684,506	374,422	1.0	39,178	15,248	1.8	3,821	1,464	2,362	1,949	1.0	6.8	3.1	0.9	2,344	1,061	0.7	141	57
Sugar maple	1.5	661,994	366,281	1.5	60,314	26,202	2.4	5,181	2,027	4,974	1,949	2.1	14.4	5.8	1.5	3,864	1,556	1.4	267	115
Red pine	1.2	514,322	218,738	1.7	67,371	36,038	2.0	4,309	2,092	4,045	1,952	1.7	11.4	5.6	2.9	7,476	3,705	2.5	483	253
Eastern white pine	1.2	510,887	237,454	3.2	129,480	67,056	2.5	5,244	2,520	4,742	2,269	2.8	18.7	8.8	2.1	5,374	2,537	7.8	1,501	738

Species	Trees			Carbon storage			Carbon sequestration			Net carbon sequestration		Leaf area			Leaf biomass			Compensatory value		
	%	*number*	*SE*	*%*	*tons*	*SE*	*%*	*tons*	*SE*	*tons*	*SE*	*%*	*acres (thousands)*	*SE*	*%*	*tons*	*SE*	*%*	*$ millions*	*SE*
Blue spruce	1.2	505,970	189,190	1.6	64,074	25,162	1.8	3,825	1,447	3,589	1,353	1.4	9.5	3.7	2.8	7,162	2,827	2.9	557	226
White spruce	1.1	463,274	149,063	1.6	63,273	23,831	1.6	3,457	1,123	3,219	1,039	1.8	12.0	4.3	3.3	8,629	3,050	2.1	410	148
Honeylocust	1.0	431,139	139,179	4.3	172,110	71,374	3.5	7,378	2,671	6,775	2,436	1.9	12.5	5.1	2.3	5,839	2,388	4.0	765	294
American elm	0.9	381,138	162,846	3.2	129,525	82,378	0.8	1,711	1,071	(5,611)	5,134	1.4	9.1	5.0	1.1	2,942	1,635	1.2	226	166
Jack pine	0.9	377,157	348,621	<0.1	1,848	1,333	0.1	293	236	286	230	0.2	1.1	0.9	0.2	413	332	0.1	24	17
Common chokecherry	0.8	347,345	347,344	<0.1	457	457	0.1	308	308	304	304	0.1	0.5	0.5	0.1	181	181	0.1	10	10
Shagbark hickory	0.7	314,210	198,431	0.7	29,928	18,087	1.3	2,761	1,694	2,639	1,624	1.0	6.9	4.4	0.9	2,247	1,439	0.9	166	96
Paper birch	0.7	309,064	118,958	1.0	41,429	17,529	1.6	3,361	1,361	2,601	1,364	1.0	6.6	3.1	0.8	2,057	958	1.0	191	81
White mulberry	0.7	309,064	214,614	0.9	37,474	33,365	1.4	3,053	2,425	2,902	2,293	1.6	10.6	9.1	1.3	3,449	2,959	1.0	200	174
Slippery elm	0.6	252,871	252,866	0.3	11,921	11,921	0.4	837	837	(691)	691	0.3	1.8	1.8	0.1	357	357	0.3	50	50
White oak	0.5	224,774	130,452	3.0	119,514	63,574	2.4	5,082	2,583	4,618	2,347	1.5	10.3	5.1	1.3	3,347	1,662	2.9	562	288
Norway spruce	0.5	198,392	83,494	1.5	59,674	32,114	1.2	2,506	1,199	2,283	1,078	2.0	13.7	7.7	3.9	10,210	5,710	1.8	339	177
Northern pin oak	0.5	196,677	127,846	1.7	66,802	57,332	1.4	3,001	1,924	2,740	1,723	1.3	8.5	5.5	1.5	3,904	2,522	1.5	284	220
Callery pear	0.4	189,442	144,611	0.2	7,000	5,512	0.5	1,157	892	1,126	868	0.2	1.4	1.2	0.2	481	405	0.2	46	38
Eastern cottonwood	0.4	173,123	108,650	4.4	177,088	142,417	2.6	5,414	3,834	4,734	3,299	3.2	21.6	16.5	2.7	6,965	5,320	0.9	179	115
Black walnut	0.3	149,059	105,633	0.6	25,561	18,998	0.6	1,290	928	1,203	860	1.0	6.8	4.9	0.9	2,416	1,755	0.7	142	108
Black oak	0.3	145,629	105,622	1.7	66,673	49,179	1.5	3,121	2,239	2,861	2,049	0.8	5.1	3.6	0.6	1,604	1,141	1.7	331	252
Quaking aspen	0.3	140,484	61,488	0.4	17,793	9,281	0.5	1,094	569	520	746	0.4	2.7	1.8	0.4	955	619	0.2	43	24
Ash spp	0.3	112,387	88,567	0.2	7,618	5,364	0.4	785	574	754	553	0.3	1.8	1.5	0.3	723	621	0.3	57	41
Black locust	0.2	92,667	92,665	0.5	21,509	21,509	0.3	691	691	676	676	0.4	2.5	2.5	0.2	610	610	0.1	18	18
Eastern hophornbeam	0.2	84,290	62,560	0.2	6,230	4,638	0.2	500	371	187	344	0.2	1.5	1.0	0.2	424	302	0.2	33	27
Plum spp	0.2	84,290	62,560	0.1	4,596	3,348	0.3	648	457	629	443	0.2	1.3	1.0	0.2	440	341	0.1	19	15
Black willow	0.2	84,290	84,289	4.4	176,131	176,128	2.0	4,298	4,298	3,626	3,626	1.3	8.5	8.5	0.9	2,404	2,404	1.7	326	326
Alder	0.2	64,511	64,510	0.1	2,712	2,712	0.1	177	177	175	175	0.1	0.4	0.4	0.1	142	142	<0.1	4	4

Species	Trees			Carbon storage			Carbon sequestration			Net carbon sequestration		Leaf area			Leaf biomass			Compensatory value		
	%	*number*	*SE*	*%*	*tons*	*SE*	*%*	*tons*	*SE*	*tons*	*SE*	*%*	*acres (thousands)*	*SE*	*%*	*tons*	*SE*	*%*	*$ millions*	*SE*
Austrian pine	0.1	59,624	59,623	0.1	2,878	2,878	0.1	160	160	149	149	0.2	1.4	1.4	0.2	603	603	0.3	56	56
White fir	0.1	56,193	56,192	0.1	2,205	2,205	0.1	244	244	235	235	0.1	0.9	0.9	0.2	567	567	0.1	19	19
Bitternut hickory	0.1	56,193	39,524	0.2	8,252	7,460	0.3	638	498	605	469	0.4	2.5	2.1	0.3	692	590	0.2	38	33
Northern catalpa	0.1	56,193	56,192	0.6	22,119	22,119	0.5	1,054	1,054	968	968	0.1	0.7	0.7	0.1	203	203	0.5	94	94
Russian olive	0.1	56,193	56,192	0.3	12,707	12,707	0.2	466	466	(694)	694	0.2	1.3	1.3	0.2	428	428	0.2	41	41
American beech	0.1	56,193	56,192	0.2	7,410	7,410	0.3	669	669	639	639	0.6	4.0	4.0	0.3	757	757	0.2	37	37
Weeping willow	0.1	56,193	39,524	2.2	88,729	85,946	1.1	2,438	2,178	2,098	1,851	0.8	5.2	4.4	0.6	1,483	1,249	0.9	178	163
American basswood	0.1	56,193	39,524	0.9	35,213	34,044	0.5	1,029	899	894	770	0.7	4.4	3.7	0.2	571	485	1.0	201	188
Littleleaf linden	0.1	56,193	56,192	0.1	2,723	2,723	0.1	302	302	291	291	0.2	1.5	1.5	0.2	511	511	0.2	31	31
Elm spp	0.1	44,416	44,416	<0.1	1,683	1,683	0.1	233	233	226	226	0.1	0.4	0.4	<0.1	125	125	0.1	14	14
Balsam fir	0.1	34,962	34,962	0.1	2,183	2,183	0.1	188	188	179	179	0.1	0.6	0.6	0.1	260	260	0.1	24	24
Catalpa spp	0.1	30,889	30,888	0.2	6,645	6,645	0.1	218	218	213	213	<0.1	0.2	0.2	<0.1	66	66	<0.1	9	9
Mountain ash spp	0.1	29,812	29,811	0.1	3,607	3,607	0.1	222	222	213	213	0.1	0.6	0.6	0.1	219	219	0.1	22	22
Downy hawthorn	0.1	28,097	28,096	0.2	6,229	6,229	0.2	387	386	362	362	0.2	1.4	1.4	0.2	471	471	0.2	33	33
Red mulberry	0.1	28,097	28,096	<0.1	1,796	1,796	0.1	212	212	205	205	0.1	0.7	0.7	0.1	325	325	0.1	13	13
Bigtooth aspen	0.1	28,097	28,096	<0.1	1,601	1,601	0.1	186	186	179	179	0.1	0.5	0.5	<0.1	120	120	0.1	12	12
Pin cherry	0.1	28,097	28,096	0.1	2,778	2,778	0.1	289	289	278	278	0.1	0.4	0.4	<0.1	90	90	0.1	15	15
Common pear	0.1	28,097	28,096	<0.1	904	904	0.1	165	165	161	161	<0.1	0.3	0.3	<0.1	87	87	<0.1	5	5
Bur oak	0.1	28,097	28,096	0.5	18,983	18,983	0.4	773	773	700	700	0.3	2.1	2.1	0.4	919	919	0.5	104	104
Willow spp	0.1	28,097	28,096	0.2	9,108	9,108	0.2	482	482	395	395	<0.1	0.2	0.2	<0.1	63	63	0.1	26	26
Total		42,796,327	7,356,424		4,007,641	503,730		212,050	23,083	180,084	21,837		670.5	74.9		258,792	34,808		19,265	2,389

APPENDIX D—TREE SPECIES STATISTICS BY LAND USE

Table D.1—Tree statistics by land use and species, Wisconsin, 2012

Land use and species	Trees	Basal area	D.b.h. Avg	D.b.h. Median
	number	*ft²/ac*	*inches*	
Ag/Other				
Norway maple	139,848	82,187	9.3	7.0
Green ash	104,886	38,138	7.5	7.5
White ash	104,886	46,719	8.5	8.5
European buckthorn	69,924	27,650	8.0	8.0
American elm	34,962	6,865	5.5	5.5
Balsam fir	34,962	15,446	8.5	8.5
White spruce	34,962	6,865	5.5	5.5
Red pine	34,962	6,865	5.5	5.5
Comm/Trans				
Northern white cedar	3,319,696	72,425	1.5	1.5
Eastern red cedar	775,365	59,221	2.4	0.0
Siberian elm	553,283	27,159	2.5	2.5
Silver maple	177,665	160,614	12.3	12.5
Callery pear	133,249	29,310	5.8	5.7
Eastern cottonwood	88,833	82,367	12.5	12.0
Honeylocust	88,833	49,662	9.0	6.0
White ash	44,416	8,721	5.5	5.5
European buckthorn	44,416	11,870	6.5	6.5
Blue spruce	44,416	70,011	16.5	16.5
Elm spp	44,416	11,870	6.5	6.5
Wetland				
Green ash	161,277	157,630	12.3	12.5
Alder	64,511	12,667	5.5	5.5
Residential				
Common lilac	4,862,830	144,018	1.8	1.7
Apple spp	3,172,114	343,324	3.6	2.9
European buckthorn	2,431,415	108,040	2.2	1.9
Red maple	1,782,734	372,177	3.9	2.3
Silver maple	1,284,722	1,202,299	9.9	4.8
Northern white cedar	1,238,712	192,021	3.6	2.4
Eastern red cedar	1,210,615	135,819	2.9	1.9
Boxelder	1,144,238	217,500	4.6	2.8
White ash	1,059,948	370,095	5.9	3.5
Northern hackberry	919,464	184,332	5.1	4.3
Green ash	824,990	543,874	8.9	7.3
Northern red oak	740,699	909,444	11.3	8.4
American plum	694,690	24,628	2.0	2.0
Black cherry	684,506	158,120	5.2	3.0
Norway maple	674,322	793,393	13.2	12.0
Sugar maple	600,216	176,660	6.0	3.9
Red pine	449,548	325,699	10.6	10.5
Eastern white pine	421,451	703,357	16.0	15.5
Jack pine	347,345	7,578	1.5	1.5
Common chokecherry	347,345	7,578	1.5	1.5
Scotch pine	337,161	154,766	8.5	8.5
White mulberry	309,064	157,535	8.6	6.8
White spruce	309,064	254,079	10.8	9.5
Siberian elm	309,064	172,400	9.0	8.5
Paper birch	309,064	144,816	8.5	8.2
Slippery elm	252,871	75,243	6.7	6.2

continued

Land use and species	Trees	Basal Area	D.b.h. Avg	D.b.h. Median
	number	*ft²/ac*	*inches*	
Partially forested				
Green ash	123,556	33,358	6.5	6.5
Apple spp	92,667	32,684	7.5	7.5
Black locust	92,667	65,027	10.8	10.7
American elm	61,778	191,723	19.5	7.0
Northern hackberry	61,778	31,168	9.0	8.0
Red maple	61,778	33,695	9.5	9.5
Sugar maple	61,778	31,168	9.0	8.0
Eastern red cedar	30,889	10,782	7.5	7.5
Siberian elm	30,889	10,782	7.5	7.5
Catalpa spp	30,889	24,260	11.5	11.5
Instit/Parks				
Winged burning bush	2,223,535	36,395	1.3	1.3
Scotch pine	715,484	398,026	9.5	9.4
Silver maple	638,896	305,504	6.5	2.9
White ash	460,025	184,676	6.3	4.6
Eastern red cedar	370,589	8,085	1.5	1.5
Boxelder	357,742	233,481	9.6	8.0
Norway maple	268,307	359,181	14.9	14.3
Green ash	238,495	195,281	11.1	9.5
Blue spruce	208,683	113,006	9.4	9.5
Black walnut	149,059	101,787	10.3	9.8
White spruce	119,247	47,154	8.0	8.0
Honeylocust	89,436	162,274	17.5	18.5
Shagbark hickory	89,436	29,100	7.2	6.7
Eastern white pine	89,436	124,877	15.5	15.5
Northern red oak	89,436	54,812	9.8	11.3
Black oak	89,436	110,080	14.5	14.5
American elm	59,624	24,227	8.0	7.0
Austrian pine	59,624	29,431	9.0	9.0

Land use and species	Trees	Basal Area	D.b.h. Avg	D.b.h. Median
	number	*ft²/ac*	*inches*	
Residential continued				
Honeylocust	252,871	344,953	14.3	13.5
Blue spruce	252,871	137,001	9.3	8.8
American elm	224,774	190,789	10.1	8.0
Shagbark hickory	224,774	101,754	8.3	7.0
White oak	224,774	334,226	14.4	10.0
Northern pin oak	196,677	176,844	9.8	7.2
Norway spruce	168,580	230,105	14.8	13.0
Quaking aspen	140,484	93,326	10.1	9.5
Ash spp	112,387	41,989	7.5	6.0
Plum spp	84,290	21,761	6.2	5.5
Eastern cottonwood	84,290	478,581	31.2	34.5
Eastern hophornbeam	84,290	31,568	7.5	6.5
Black willow	84,290	432,761	28.8	23.5
Callery pear	56,193	11,034	5.5	5.5
Black oak	56,193	59,458	12.5	8.0
White fir	56,193	15,324	6.5	6.0
Bitternut hickory	56,193	31,415	9.0	6.0
Northern catalpa	56,193	76,622	14.5	10.0
Russian olive	56,193	48,578	12.0	11.0
American beech	56,193	26,051	8.5	7.0
Weeping willow	56,193	211,016	22.0	9.0
American basswood	56,193	147,726	18.5	8.0
Littleleaf linden	56,193	19,615	7.5	7.5
Red mulberry	28,097	9,808	7.5	7.5
Bur oak	28,097	61,298	19.5	19.5
Downy hawthorn	28,097	25,899	12.5	12.5
Bigtooth aspen	28,097	9,808	7.5	7.5
Pin cherry	28,097	12,413	8.5	8.5
Common pear	28,097	5,517	5.5	5.5
Willow spp	28,097	34,480	14.5	14.5

continued

Land use and species	Trees	Basal Area	D.b.h. Avg	D.b.h. Median	Land use and species	Trees	Basal Area	D.b.h. Avg	D.b.h. Median
	number	*ft²/ac*	*inches*			*number*	*ft²/ac*	*inches*	
Instit/Parks continued									
Red pine	29,812	7,967	6.5	6.5					
Norway spruce	29,812	23,414	11.5	11.5					
Jack pine	29,812	7,967	6.5	6.5					
Mountain ash spp	29,812	16,260	9.5	9.5					

APPENDIX E—DAMAGE TYPE OR MAINTENANCE OR SITE ISSUE STATISTICS

Table E.1—Percent of Trees Identified with Damage or Maintenance or Site Issues, Wisconsin, 2012

		Damage type										Maintenance or site issue				
Species	Sample	Borers/ bark beetles	Canker/ decay	Chlorotic/ necrotic foliage	Dead top	Defoliation	Dead/ dying crown	Root/ stem girdling	Trunk/ bark inclusion	Vines in crown	Wound/ crack	Improper planting	Excess mulch	Overhead wires	Sidewalk root conflict	Topping/ pruning
	n								*percent*							
Alder	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
American basswood	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
American beech	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
American elm	13	0.0	7.4	0.0	0.0	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	7.4	0.0	0.0
American plum	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apple spp	25	0.0	82.5	0.0	0.0	0.0	0.0	0.0	85.0	0.0	2.7	0.0	10.6	0.0	0.0	0.0
Ash spp	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Austrian pine	2	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balsam fir	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bigtooth aspen	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bitternut hickory	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black cherry	13	0.0	8.2	4.1	0.0	0.0	4.1	4.1	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black locust	3	0.0	66.7	0.0	0.0	0.0	0.0	0.0	33.3	0.0	33.3	0.0	0.0	0.0	0.0	0.0
Black oak	5	0.0	39.8	0.0	0.0	0.0	0.0	0.0	20.5	0.0	20.5	0.0	0.0	0.0	0.0	0.0
Black walnut	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black willow	3	0.0	100.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	33.3	0.0	0.0	0.0	0.0	0.0
Blue spruce	17	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	0.0	5.6	0.0	0.0	11.8
Boxelder	30	0.0	17.0	1.9	3.9	0.0	5.8	0.0	9.6	5.7	7.6	0.0	0.0	1.9	0.0	0.0
Bur oak	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Callery pear	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catalpa spp	1	0.0	100.0	0.0	100.0	0.0	0.0	0.0	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0

continued

Species	Sample	Damage type										Maintenance or site issue				
		Borers/ bark beetles	Canker/ decay	Chlorotic/ necrotic foliage	Dead top	Defoliation	Dead/ dying crown	Root/ stem girdling	Trunk/ bark inclusion	Vines in crown	Wound/ crack	Improper planting	Excess mulch	Overhead wires	Sidewalk root conflict	Topping/ pruning
	n	*percent*														
Common chokecherry	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common lilac	14	0.0	14.3	0.0	0.0	0.0	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common pear	1	0.0	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Downy hawthorn	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eastern cottonwood	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eastern hophornbeam	3	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eastern red cedar	17	0.0	21.6	0.0	0.0	0.0	0.0	0.0	25.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eastern white pine	18	0.0	5.5	5.5	0.0	0.0	0.0	22.0	16.5	0.0	0.0	0.0	0.0	5.5	0.0	0.0
Elm spp	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
European buckthorn	10	0.0	13.6	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Green ash	38	0.0	6.3	0.0	0.0	0.0	0.0	8.3	28.8	0.0	39.8	0.0	0.0	7.7	0.0	5.8
Honeylocust	14	0.0	19.9	0.0	0.0	0.0	0.0	0.0	19.6	0.0	30.3	0.0	0.0	6.5	0.0	0.0
Jack pine	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0	0.0
Littleleaf linden	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mountain ash spp	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern catalpa	2	0.0	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0
Northern hackberry	12	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0
Northern pin oak	7	14.3	28.6	0.0	0.0	0.0	0.0	0.0	28.6	0.0	14.3	0.0	0.0	14.3	0.0	0.0
Northern red oak	18	0.0	14.2	0.0	0.0	0.0	0.0	10.8	59.4	0.0	20.9	0.0	0.0	3.4	0.0	0.0
Northern white cedar	16	0.0	0.6	0.0	0.0	0.0	0.0	0.0	97.5	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Norway maple	37	0.0	35.3	13.0	0.0	2.6	2.6	23.1	50.2	0.0	24.3	0.0	0.0	2.6	2.6	0.0
Norway spruce	7	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.2	0.0	15.0

continued

		Damage type										Maintenance or site issue				
Species	**Sample**	**Borers/ bark beetles**	**Canker/ decay**	**Chlorotic/ necrotic foliage**	**Dead top**	**Defoliation**	**Dead/ dying crown**	**Root/ stem girdling**	**Trunk/ bark inclusion**	**Vines in crown**	**Wound/ crack**	**Improper planting**	**Excess mulch**	**Overhead wires**	**Sidewalk root conflict**	**Topping/ pruning**
	n	*percent*														
Paper birch	11	0.0	45.5	18.2	18.2	18.2	18.2	0.0	27.3	0.0	9.1	0.0	0.0	9.1	0.0	0.0
Pin cherry	1	100.0	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Plum spp	3	0.0	33.3	0.0	0.0	0.0	0.0	66.7	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quaking aspen	5	0.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0
Red maple	20	0.0	25.1	1.5	1.5	0.0	1.5	3.0	12.2	1.5	7.6	1.5	0.0	3.0	1.5	0.0
Red mulberry	1	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0
Red pine	18	0.0	5.8	0.0	0.0	0.0	0.0	0.0	18.1	0.0	10.9	0.0	16.4	0.0	0.0	0.0
Russian olive	2	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0
Scotch pine	36	0.0	8.2	0.0	0.0	0.0	0.0	5.7	11.3	0.0	0.0	0.0	2.7	0.0	0.0	0.0
Shagbark hickory	11	0.0	8.9	0.0	0.0	0.0	0.0	0.0	17.9	9.5	0.0	0.0	0.0	0.0	0.0	0.0
Siberian elm	13	0.0	12.6	0.0	0.0	0.0	0.0	0.0	16.0	0.0	3.1	0.0	0.0	6.3	0.0	0.0
Silver maple	37	0.0	25.2	34.4	0.0	0.0	0.0	6.1	42.6	0.0	2.8	0.0	0.0	6.7	1.3	0.0
Slippery elm	9	55.6	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugar maple	12	0.0	4.2	0.0	0.0	0.0	0.0	0.0	13.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weeping willow	2	0.0	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0
White ash	23	0.0	27.5	0.0	0.0	0.0	1.7	0.0	3.8	2.1	5.2	0.0	0.0	5.2	1.7	0.0
White fir	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
White mulberry	11	0.0	90.9	0.0	0.0	0.0	0.0	0.0	81.8	0.0	9.1	0.0	0.0	9.1	0.0	9.1
White oak	8	0.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
White spruce	16	0.0	6.1	0.0	0.0	0.0	6.1	0.0	13.6	0.0	6.1	0.0	0.0	6.1	0.0	12.9
Willow spp	1	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Winged burning bush	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Trees		0.5	19.5	2.4	0.4	0.2	0.7	2.1	32.8	0.4	5.3	0.0	1.1	2.2	0.3	0.6

APPENDIX F—POTENTIAL INSECT AND DISEASE IMPACT

The following insects and diseases were analyzed to quantify their potential impact on the urban forests of Wisconsin.

- **AL**: Aspen Leafminer (*Phyllocnistis populiella*) - AL is an insect that causes damage primarily to trembling or small tooth aspen by larval feeding of leaf tissue. While outbreaks of the aspen leafminer have been recorded throughout parts of Alaska, Canada, and the western United States, the pest is relatively uncommon in eastern North America (Kruse et al. 2007).

- **ALB**: Asian Longhorned Beetle (*Anoplophora glabripennis*) - The Asian longhorned beetle (USDA Animal and Plant Health Inspection Service 2010, U.S. Department of Agriculture 2002) is an insect that bores into and kills a wide range of hardwood species. This beetle was discovered in 1996 in Brooklyn, NY and has subsequently spread to Long Island, Queens and Manhattan. In 1998, the beetle was discovered in the suburbs of Chicago, IL and successfully declared eradicated in 2006. Beetles have also been found in Jersey City, NY (2002), Toronto/Vaughan, Ontario (2003) and Middlesex/Union counties, NJ (2004). In 2007, the beetle was found on Staten and Prall's Island, NY. Most recently, beetles were detected in Worcester, MA (2008) and Bethel, OH (2011). In addition to the eradication in Chicago, successful eradication has since occurred in Hudson County, NJ (2008) and Islip, NY (2011).

- **BBD**: Beech Bark Disease (*Cryptococcus fagisuga*) - Beech bark disease is an insect-disease complex that primarily impacts American beech. It is caused by the infestation of several different species. First, the insect, *Cryptococcus fagisuga*, feeds on the sap of the beech trees. These affected trees can become hosts to the nectria fungi. The two primary species of nectria fungi in North America are *N. coccinea* var. *faginata* and *N. gallifena* (Houston and O'Brien 1983).

- **BC**: Butternut Canker (*Sirococcus clavigignenti-juglandacearum*) - Butternut canker is caused by a fungus that infects butternut trees. The disease was first discovered in 1967 in Wisconsin and has since caused significant declines in butternut populations in the United States (Ostry et al. 1996).

- **CB**: Chestnut Blight (*Cryphonectria parasitica*) - The most common hosts of the fungus that cause chestnut blight are American and European chestnut. This disease causes canker formation in host trees resulting in dead limbs, brown or yellowing leaves, or mortality (Diller 1965).

- **DA**: Dogwood Anthracnose (*Discula destructive*) - Dogwood anthracnose is a disease that affects dogwood species, specifically flowering and Pacific dogwood. It is caused by a fungus that produces leaf spots and necrotic blotches and canker formation on twigs, branches, and the main stem of infected trees (Mielke and Daughtrey no date)

- **DED**: Dutch Elm Disease (*Ophiostoma novo-ulmi*) - American elm, one of the most important street trees in the 20th century, has been devastated by the Dutch elm disease. Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States (Stack et al. 1996).

- **DFB**: Douglas-Fir Beetle (*Dendroctonus pseudotsugae*) - The Douglas-fir beetle is a bark beetle that infests Douglas-fir trees. Infestations of DFB have been seen throughout the western United States, British Columbia, and Mexico often resulting in tree mortality (Schmitz and Gibson 1996).

- **EAB**: Emerald Ash Borer (*Agrilus planipennis*) - Since being discovered in Detroit in 2002, emerald ash borer (U.S. Department of Agriculture et al. 2010) has killed millions of ash trees in Illinois, Indiana, Kentucky, Maryland, Michigan, Minnesota, Missouri, New York, Ohio, Ontario, Pennsylvania, Quebec, Virginia, West Virginia, and Wisconsin.

- **FE**: Fir Engraver (*Scotylus ventralis*) - One common pest of white fir, grand fir, and red fir trees is the fir engraver. This bark beetle is distributed primarily in the western United States (Ferrell 1986).

- **FR**: Fusiform Rust (*Cronartium fusiforme*) – Fusiform rust is a fungal disease that is distributed in the southern United States. It is particularly damaging to slash pine and loblolly pine because it infects the living tissue of the host's stems and branches. Pine trees affected by the fungus can develop fatal galls and cankers (Phelps and Czabator 1978).

- **GM**: Gypsy Moth (*Lymantria dispar*) - The gypsy moth (U.S. Department of Agriculture 2005c) is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years.

- **GSOB**: Goldspotted Oak Borer (*Agrilus auroguttatus*) - Infestations of the goldspotted oak borer have been a growing problem in southern California. This forest pest is native to southeastern Arizona and Mexico and believed to have been transported to California by the movement of firewood. The three known host species for GOB are coast live oaks, California black oaks, and canyon live oaks (Society of American Foresters 2011).

- **HWA**: Hemlock Woolly Adelgid (*Adelges tsugae*) – As one of the most damaging pests to Eastern hemlock and Carolina hemlock, HWA has played a large role in hemlock mortality in the United States. Since the pest was first discovered in 1951, infestations have expanded to cover about half of the range of hemlock in the Eastern United States (U.S. Department of Agriculture 2005b).

- **JPB**: Jeffrey Pine Beetle (*Dendroctonus jeffreyi*) - The Jeffrey pine beetle is native to North America and is distributed across California, Nevada, and Oregon where its only host, Jeffrey pine, also occurs (Smith et al. 2009).

- **LAT**: Large Aspen Tortrix (*Choristoneura conflictana*) – Quaking aspen is a principal host for the defoliator, large aspen tortrix. The insect has been found across much of the northeastern, north central, and western United States, as well as Alaska and Canada. LAT can reach outbreak levels where quaking aspen are abundant and will potentially strip hosts of all of their foliage (Ciesla and Kruse 2009).

- **LWD:** Laurel Wilt (*Raffaelea lauricola*) - Laurel wilt is a fungus-caused disease that is introduced to host trees by the redbay ambrosia beetle. Redbay, as well as other tree species in the Laurel family, are common hosts for laurel wilt which has been observed in North Carolina, South Carolina, Georgia, Alabama, Mississippi, and Florida (U.S. Department of Agriculture no date).

- **MPB:** Mountain Pine Beetle (*Dendroctonus ponderosae*) - Mountain pine beetle is a bark beetle that primarily attacks pine species in the western United States. The major host species of MPB, lodgepole pine, ponderosa pine, western white pine, sugar pine, limber pine, and whitebark pine, have a similar distribution as this pest (Gibson et al. 2009).

- **NSE**: Northern Spruce Engraver (*Ips pertubatus*) - This insect has had a significant impact on the boreal and sub-boreal forests of North America where the pest's distribution overlaps with the range of its major hosts, white spruce, Englemann spruce, and Lutz's spruce. This forest pest has been found in Alaska, Maine, Michigan, Minnesota, and Montana within the United States and in most of the provinces of Canada (Burnside et al. 2011).

- **OW:** Oak Wilt (*Ceratocystis fagacearum*) - Oak wilt, which is caused by a fungus, is a prominent disease among oak trees producing leaf wilting and discoloration, heavy defoliation, or fungal mats beneath the bark. The disease has been found in 21 states throughout most of the Midwestern United States and it is still unknown whether any species of oak are immune to it (Rexrode and Brown 1983).

- **POCRD:** Port-Orford-Cedar Root Disease (*Phytophthora lateralis*) - Port-Orford-cedar root disease is a root disease that is caused by a fungus. This fungus is most damaging to Port-Orford cedar and Pacific yew species (Liebhold 2010).

- **PSB:** Pine Shoot Beetle (*Tomicus piniperda*) - The pine shoot beetle is a wood borer that attacks various pine species, though Scotch pine is the preferred host in North America. The beetle has an international geographic distribution. In the United States it has been discovered in Illinois, Indiana, Maine, Maryland, Michigan, New Hampshire, New York, Ohio, Pennsylvania, Vermont, West Virginia, and Wisconsin, as well as in Ontario and Quebec in Canada (Ciesla 2001).

- **SB:** Spruce Beetle (*Dendroctonus rufipennis*) - All species of spruce that fall within the spruce beetle's range are suitable hosts for attack. This bark beetle causes significant mortality and covers large areas of Alaska, Canada, and the northern United States, as well as some patches through the Rocky Mountain range (Holsten et al. 1999).

- **SBW**: Spruce Budworm (*Choristoneura fumiferana*) - Spruce budworm is an insect that causes severe damage to balsam fir. During the larval stage of the budworm's life, it feeds primarily on the needles or expanding buds of its hosts. Years of heavy defoliation can ultimately lead to tree mortality. Other hosts for the spruce budworm include white, red, and black spruce (Kucera and Orr 1981).

- **SOD**: Sudden Oak Death (*Phytophthora ramorum*) - Sudden oak death is a disease that is caused by a fungus. It is most common in British Columbia, Washington, Oregon, and California and impacts many different species including southern red oak, California black oak, Northern red oak, pacific madrone, tanoak, and coastal live oak (Kliejunas 2005).

- **SPB:** Southern Pine Beetle (*Dendroctonus frontalis*) - Although the southern pine beetle will attack most pine species, its preferred hosts are loblolly, Virginia, pond, spruce, shortleaf, and sand pines. The range of this particular bark beetle covers much of the southeastern United States (Clarke and Nowak 2009).

- **SW**: Sirex Woodwasp (*Sirex noctilio*) - The sirex woodwasp is a wood borer that primarily attacks pine species. It is not native to the United States, but is known to cause a high percentage of tree mortality among North American species that have been planted in countries of the southern hemisphere (Haugen and Hoebeke 2005).

- **TCD**: Thousand Cankers Disease (*Pityophthorus juglandis* & *Geosmithia* spp.) - Thousand cankers disease is an insect-disease complex that kills several species of walnuts, including black walnut. It is known to occur primarily in the western states of Washington, Oregon, California, Idaho, Utah, Arizona, New Mexico, and Colorado. Tennessee is the first state in the east where thousand cankers disease has been found. Tree mortality is the result of attacks by the walnut twig beetle and subsequent canker development caused by associated fungi (Cranshaw and Tisserat 2009; Seybold et al. 2010, U.S. Department of Agriculture 2011).

- **WPB**: Western Pine Beetle (*Dendroctonus brevicomis*) - The western pine beetle is an aggressive attacker of ponderosa and Coulter pines. This bark beetle has caused significant swaths of damage in California, Oregon, Washington, Idaho, British Columbia, Montana, Nevada, Utah, Colorado, Arizona, New Mexico, Texas, and parts of northern Mexico (DeMars and Roettgering 1982).

- **WPBR:** White Pine Blister Rust (*Cronartium ribicola*) - Since its introduction to the United States in 1900, white pine blister rust has had a detrimental effect on white pines, particularly in the Lake States (Nicholls and Anderson 1977).

- **WSB:** Western Spruce Budworm (*Choristoneura occidentalis*) - Western spruce budworm is an insect that causes defoliation in western conifers. It has been found in Arizona, New Mexico, Colorado, Utah, Wyoming, Montana, Idaho, Oregon, and Washington in the United States and British Columbia and Alberta in Canada. The western spruce budworm feeds on new foliage of its hosts. Common host species include Douglas-fir, grand fir, white fir, subalpine fir, corkbark fir, blue spruce, Engelmann spruce, white spruce, and western larch (Fellin and Dewey 1986).

The following table displays which sampled tree species are susceptible to various insects and diseases found in Wisconsin.

		Pests[a]											
Common Name	**Number of Trees**	**GM**	**EAB**	**PSB**	**DED**	**OW**	**SB**	**LAT**	**WPBR**	**SBW**	**AL**	**BBD**	**BC[b]**
Apple spp.	3,265,000	x											
White ash	1,669,000		x										
Green ash	1,453,000		x										
Scotch pine	1,053,000			x									
Siberian elm	893,000				x								
Northern red oak	830,000	x				x							
Red pine	514,000			x									
Eastern white pine	511,000			x					x				
Blue spruce	506,000						x						
White spruce	463,000						x			x			
American elm	381,000				x								
Jack pine	377,000			x									
Common chokecherry	347,000							x					
Paper birch	309,000	x						x					
Slippery elm	253,000				x								
White oak	225,000	x				x							
Norway spruce	198,000			x			x						
Northern pin oak	197,000	x				x							
Callery pear	189,000	x											
Black oak	146,000	x				x							
Quaking aspen	140,000	x						x			x		
Ash spp.	112,000		x										
Eastern hophornbeam	84,000	x											
Black willow	84,000	x						x			x		
Alder	65,000							x					
Austrian pine	60,000			x									
American beech	56,000											x	

continued

		Pests[a]											
Common Name	**Number of Trees**	**GM**	**EAB**	**PSB**	**DED**	**OW**	**SB**	**LAT**	**WPBR**	**SBW**	**AL**	**BBD**	**BC[b]**
Weeping willow	56,000	x						x			x		
American basswood	56,000	x											
Littleleaf linden	56,000	x											
Elm spp.	44,000				x								
Balsam fir	35,000									x			
Downy hawthorn	28,000	x											
Bigtooth aspen	28,000	x						x					
Bur oak	28,000	x				x							
Willow spp.	28,000	x						x			x		

‘x’ indicates tree species is a host to the pest

[a] Includes only pests found in Wisconsin

[b] Butternut canker (BC) is found in Wisconsin, but no host species were sampled