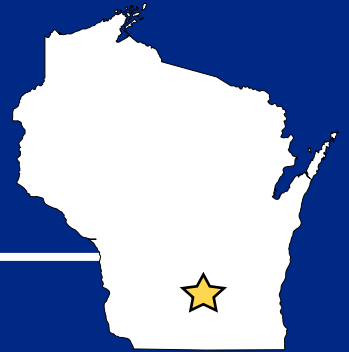




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Madison's Urban Forest, 2021



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Abstract

Data collected from almost 200 plots in Madison, Wisconsin from 2015 through 2021, reveal that the city has an estimated 2.9 million live trees at least 1.0-inch in diameter across all ownerships. The most common tree species by number are common buckthorn, boxelder, and white ash, while those at least 5.0 inches or greater are boxelder, honeylocust, and northern white cedar. The largest number of trees (49.7 percent; 1.4 million trees) are found on forest land. Trees on public lands total 1.7 million and account for almost 58 percent of all live trees. Trees at least 15.0 inches in diameter are only 10 percent of the population, but represent 53 percent of all trees' leaf area, which in turn produce many of the benefits of the urban forest. It is estimated that the urban forest in Madison produces over \$11.5 million in annual benefits (Table 1), while the overall compensatory value of the urban forest is estimated at \$1.3 billion. Buckthorn is the most common invasive species, covering 2.8 percent of the city's area. The information presented in this report may be used to support urban forest management programs and to inform policy and planning to improve environmental quality and human health in Madison. The analysis also provides a basis for monitoring changes in the urban forest over time.

Keywords: Urban FIA, UFIA, i-Tree, Wisconsin, WI, My City's Trees, carbon, city, cities, tree volume and biomass, carbon sequestration, Urban Forest Inventory and Analysis, urban forest structure and health, urban forest values, ecosystem services

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Cover photo: Trees significantly contribute to the character and enjoyment of the city of Madison, WI. Courtesy photo by Eric Tadsen, Tadsen Photography.

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Madison's Urban Forest, 2021

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Acknowledgments

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Plot selection and pre-field preparation work was done by James Blehm, Brian Gasper, Daniel Kaisershot, Kevin Nimerfro, Cassandra Olson, Kelly Peterson, Mitch Slater and Paul Sowers. Data collection employees included James Blehm, Thomas Davis, Michael Duwe, Erick Fruehling, Peter Koehler, Paul Mueller, Pat Nelson, Benjamin Nurre, Terry Schriber, and Willard Smith. These employees not only collect data, but also research land ownership, speak with owners to help them understand the program, and keep denied access rates as low as possible. Mark Hatfield, Lucie Lepine, Katie Jennings and Alexander R. Young are invaluable for their expertise with the Universal National Information Management System (UNIMS) database. Special thanks goes to Mark Majewsky, who took on the challenge of leading the Urban Forest Inventory and Analysis from a concept to a Nationwide program which currently monitors urban forests in 44 cities and across all urban areas of 26 states.

EXECUTIVE SUMMARY



Many different types of trees make up the urban forest of Madison, WI. Courtesy photo by Eric Tadsen, Tadsen Photography.

The city of Madison was sampled from 2015 through 2021 to establish a baseline assessment of the magnitude, composition, and value of its urban forest resource. The sampled area of the city (representing a total of 60,182 acres), is estimated to contain 2.9 million live trees, 62.7 percent of which are less than 5.0 inches in **diameter**¹. The most common large-diameter tree species (11.0+ inches in diameter) are Norway maple, honeylocust, black locust, black walnut, and white oak. The most common tree species² at least 1.0-inch in diameter are common buckthorn, boxelder, white ash, chokecherry, and black locust. The most dominant species based on the number of trees and leaf area are common buckthorn, boxelder, white ash, Norway maple, and black walnut.

¹ See glossary for definition of bolded terms.

² Common and scientific names for tree species observed in the 2021 Urban FIA inventory of Madison are reported in Appendix 2.



The majority of trees are found on **forest land** (49.7 percent; 1.4 million trees). Overall, 19.7 percent of trees are classified as growing in maintained areas. Trees on public lands total 1.7 million and account for 57.8 percent of the total live tree population. Trees on private lands total 1.2 million and account for 42.3 percent of the population.

Urban forest ecosystem services are evaluated in terms of air pollution removal, carbon sequestration, reduction in stormwater runoff, and effects on residential building energy use and carbon emissions. The compensatory value of the urban forest (roughly equivalent to the replacement value of all trees in the urban forest) is estimated at \$1.33 billion with the urban forest producing over \$11.5 million in annual benefits (Table 1).

Invasive plant species threaten to alter forest composition and are found on 43.2 percent of the sampled plots. Common buckthorn is estimated to cover the largest area (1,676 acres) of any invasive plant species in the city.

Through better understanding of the benefits conferred by and potential threats to the urban forest, resource managers, arborists, and city planners can improve forest management, leading to healthier urban forests and more livable communities.

Table 1.—Summary of urban forest estimates, city of Madison, 2021

Feature	Estimate
Number of trees^a	
Total live trees	2.9 million (603,388) ^b
Live saplings (1.0 to 4.9 inches in diameter)	1.8 million (526,000) ^b
Live trees (at least 5.0 inches in diameter)	1.1 million (134,390) ^b
Standing dead saplings (1.0 to 4.9 inches in diameter)	181,000 (64,000) ^b
Standing dead trees (at least 5.0 inches in diameter)	68,000 (17,000) ^b
Most abundant species	
By number of live trees	common buckthorn
By leaf area	silver maple
Ecosystem impacts and services	
VOC emissions	267 tons/year
Pollution removal	368 tons/year (\$2.7 million/year)
Reduction in acute respiratory symptoms	370 cases/year (\$33,000/year)
Avoided runoff	36.5 million cubic feet (\$2.4 million/year)
Carbon storage ^c	420,000 tons (\$71.6 million)
Carbon sequestration	11,000 tons/year (\$1.9 million/year)
Net aboveground volume	22.5 million cubic feet
Reduced building energy use ^{c,d}	225,000 GJ/year (\$3.2 million/year)
Reduced carbon emissions ^{c,d}	6,400 tons/year (\$1.2 million/year)
Compensatory value	\$1.3 billion

Due to rounding, not all values will add up exactly.

VOC = volatile organic compound (a negative ecosystem impact)

Ton = short ton (U.S.) (2,000 lbs.).

To convert carbon estimates to carbon dioxide, multiply carbon value by 3.667.

GJ = gigajoule (one billion [10⁹] joules).

^a Diameter measurements were taken at breast height (d.b.h.).

^b Numbers in parentheses are standard error.

^c Estimates are for the live and dead tree population. All other estimates are based on the live tree population only, except where noted.

^d Estimates are calculated using trees greater than or equal to 5.0 inches in diameter.

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BACKGROUND



Honeylocust trees provide dappled shade on the University of Wisconsin-Madison campus. Courtesy photo from the City of Madison.

Urban forests offer a wide range of environmental, social, and public health benefits, such as wildlife habitat, aesthetic appeal, social cohesion, enhanced recreational opportunities, reduced air temperatures, improved water quality, mitigated air and noise pollution, and benefits to mental health and well-being. Since 1930, the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program has provided information on the amount, status, and character of **forest land**³ across the country.

The 2014 U.S. Farm Bill (Agricultural Act of 2014) directed FIA to explore possibilities to expand the scope of the FIA inventory to include monitoring in U.S. urban areas, an effort that led to the development of an Urban FIA program (USDA Forest Service 2016). The goal of this program is to provide an accurate estimate of the composition, distribution, health, and values of urban forests to aid in sustainable urban forest management and planning. This report presents information about the current state of Madison's urban forest and the benefits it provides to residents of the city.

³ See glossary for definition of bolded terms

In this report, the term “urban forest” describes all trees located in the city across both public and private ownerships, including planted trees along streets and boulevards, trees in parks and residential yards, remnant forest along railroads and riparian areas, small woodlots, and larger forested areas. FIA has partnered with the Forest Service i-Tree team, which has a long tradition of conducting urban forest inventories and delivering data about urban forests and their associated ecosystem services. This combined national urban forest inventory effort leverages the strengths of both groups, drawing on the urban data processing and reporting strengths of the i-Tree program and FIA’s strengths in quality, consistency, and comprehensiveness of data collection.

Like all cities, the area now known as Madison has experienced immense change due to its natural environment. Centered on the isthmus between Lakes Mendota and Monona the city of Madison encompasses land that had previously been dominated by oak forest, with pockets of marsh lands, oak openings, and maple forests present (WDNR 2017a). The area was designated as the capital site of the Wisconsin Territory in 1836, even before the city existed, and remained the capital after Wisconsin gained statehood in 1848 (WHS 2009). Fueled by its status as the home of State government, the site of a major university, and the presence of many industries, Madison has seen sustained growth throughout most of its existence. It is currently the second biggest city in the state of Wisconsin and is also located within the fastest growing county by population (WDOA 2024).

Due to both the development of its road infrastructure and the presence of many parks and institutional grounds, about half of Madison’s land is managed by public entities. The municipal government plays a significant role in managing Madison’s canopy, particularly along road **rights-of-way** where the city’s Streets Division maintains about 100,000 trees. Additionally, the Parks Division manages trees in parks, and the Engineering Division has responsibility over trees in stormwater greenways. University of Wisconsin-Madison and Dane County (county government of Madison) also manage large numbers of trees within the city. Some of these entities maintain tree inventories, though most parts of Madison have not received any tree surveys.

Urban FIA is thus particularly useful in that it provides estimates of the urban forest across all ownerships and land uses. This approach can provide critical information beyond the detailed public tree inventories that many cities, including Madison, have available. A close inspection of these data can help planners understand where improvements can be made and develop tree planting and conservation goals for the future. For example, an Urban Forestry Task Force composed of residents, elected officials, and city staff was formed and released a report in 2020 sharing goals and recommendations to help build the urban canopy and improve its resilience (UFTF 2020). As different groups work to build the urban canopy, these data can serve as a baseline against which the future results from continued monitoring can be compared. These comparisons will allow managers to assess rates of tree growth and mortality, as well as

changes in species composition, health condition, and corresponding changes in benefits associated with the urban forest. Effective monitoring allows for the development of data-driven management strategies to maximize the benefits of Madison's urban forest while minimizing the cost associated with its maintenance.

When reviewing the estimates in this report, it is important to understand that they are based upon a sample made up of 199 randomly selected research plots. Some of these research plots have no trees present, while others are fully forested. Some tree species were found on many of these research plots while others were only found at a single site. Due to the large area of the city covered by lakes, more than 20 percent of the sampled area landed in water. After this initial set of data collection, the number of sampled plots has been increased to provide approximately 200 research plots on dry land. Once collected, these additional data will be incorporated into future reporting.

As with all sample-based estimates, standard error must be considered when assessing the data and its potential use. In general, broader estimates, such as the number of trees in the city, will have a smaller standard error than subsets of the data (e.g., the estimated count of a single species within a particular land use). Additionally, **seedling** and **sapling** counts occur on a smaller sample area than trees 5.0 inches in **diameter** and greater, and therefore typically have a larger standard error. Due to the broad range of possible uses for the data, ranging from strategic planning to the identification of needed additional research, this report does not limit results to a minimum standard error threshold. To further explore the standard error of individual estimates, the [Urban Forest Stats tool](#) can be used or raw data can be downloaded from the [Urban DataMart](#) for independent calculations.

Methods

To evaluate the extent, composition, and benefits of Madison's urban forest and establish a baseline for future monitoring, a sample-based inventory was conducted following Urban FIA monitoring methods described in the Urban FIA Northern Research Station (NRS) Field Guide Version 7.1 (USDA Forest Service 2017) and [version 2 of the online supplement](#) to Urban FIA city forest reports (Baer et al. 2025), along with i-Tree Eco modeling software (Nowak 2024). This process established survey plots across Madison and aims to revisit those plots every 7 years. Future reports can build on these data and consistently provide information on urban forest extent, diversity, health condition, and benefits. Data for Madison's first 7-year measurement cycle was collected from 2015 through 2021. The sampling area was defined by the U.S. Census Bureau Designated Places boundary for Madison (highlighted in red in Fig. 1a). In total, the Urban FIA sample surveyed 199 plots⁴ across the city's 60,182 acres within the designated sampling area in Madison (Fig. 1).

⁴ Information about the exact location of FIA plots is federally protected. Maps in this report use altered or "fuzzed" coordinates, available through the public Urban DataMart. This may cause plots to appear outside the study area. These maps are meant to provide a general overview, and the visual representation of the plot location does not reflect actual plot conditions.

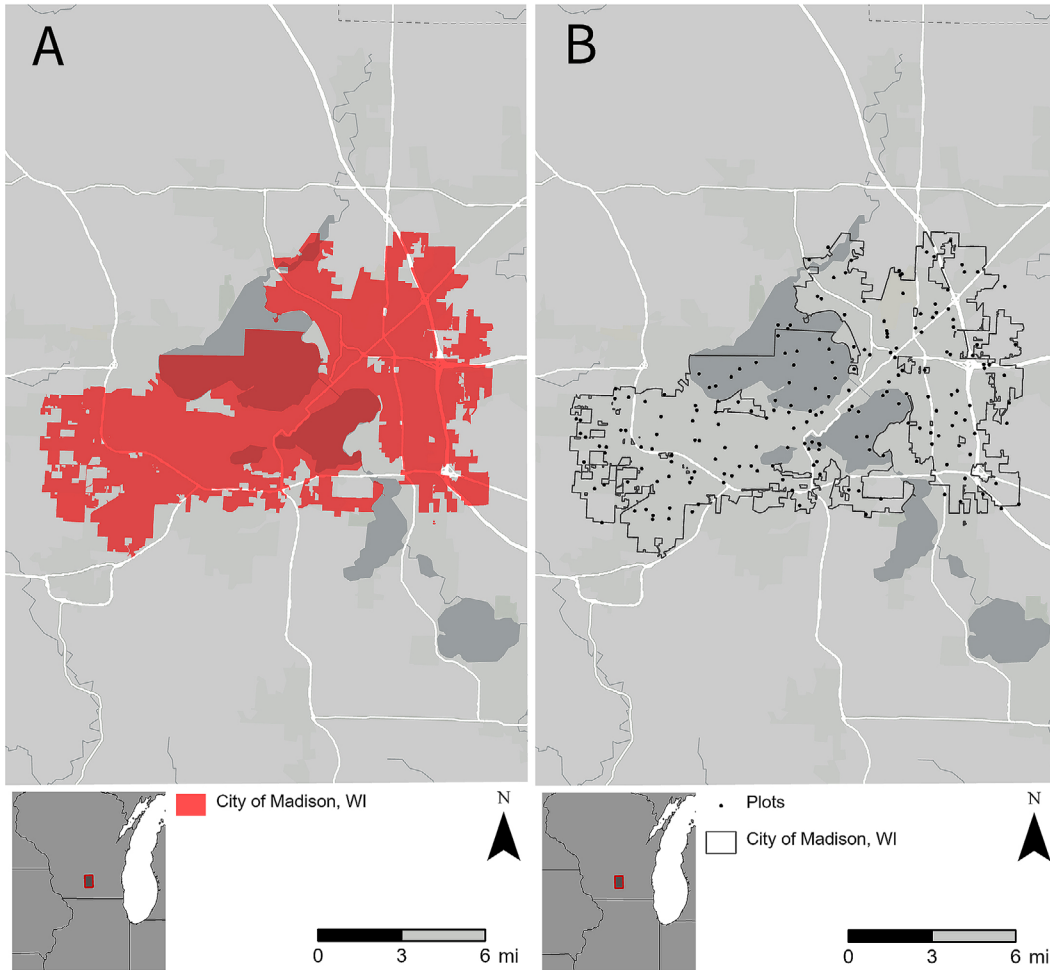


Figure 1.—Study area (A) and approximate plot locations (B) for the Urban Forest Inventory and Analysis (FIA) inventory, city of Madison, 2021. The Light Gray Canvas basemap layer was provided by Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

New methods were implemented in the 2021 inventory of Madison’s urban forest to allow for flexibility in the estimation of tree characteristics for forked trees. In this inventory, all stems of forked trees are quantified and characterized as part of the same tree. All extrapolated estimates for forked trees are based on this approach except for estimates of tree merchantability and volume estimation. Refer to Baer et al. (2025) for more detailed information. Throughout this report, except where explicitly noted, trees refer to woody plant species listed in Appendix 3 and 3B of the NRS Field Guide Version 7.1 (USDA Forest Service 2017) with diameters of at least 1.0-inch, and results are given for live trees.

The collected data were analyzed using FIA methodology and i-Tree Eco modeling software outlined in Baer et al. (2025). Additional analyses were conducted using R Statistical software version 4.2.1 (R Core Development Team 2022) and Microsoft Excel.

Figures presented in this report were generated using the base, dplyr (Wickham et al. 2022), and ggplot2 (Wickham 2016) packages within the R Statistical Software platform, and Microsoft Excel. Maps throughout this document were created using ArcGIS® software by Esri (ArcGIS Pro version 2.9, Esri 2021). ArcGIS® is the intellectual property of Esri and is used herein under license.

This report summarizes the findings of these analyses and includes information on forest structure, ecosystem services, and associated monetary values. Structure describes various physical attributes of the urban forest, including tree species composition, number of trees, tree density, tree health, leaf area, biomass, and species diversity. Ecosystem services discussed in this report were evaluated based on forest structure in conjunction with local environmental variables and include such attributes as air pollution removal and carbon storage and sequestration. Monetary values are an economic estimate of various ecosystem services or structural attributes.

In addition to this report, information from this analysis is accessible via [My City's Trees](#) and [Urban Forest Stats](#), online interactive tools that allow users to explore results and print data queries. Data tables are also available for download from FIA's [Urban DataMart](#).

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AREA AND COVER CHARACTERISTICS



A sharp contrast in canopy cover aligns with differences in land use on Madison's west side. Courtesy photo by Eric Tadsen, Tadsen Photography.

In 2010, Wisconsin had 1,204,000 acres of urban land that covered 3.5 percent of the state area, and this urban area is projected to increase to 9.2 percent by the year 2060 (Nowak and Greenfield 2018). Madison is the second largest city in Wisconsin by population (233,000 residents with a population density of 3,037 per square mile in 2010) (U.S. Census 2025).

Land Cover

The 2011 National Land Cover Database (NLCD 2011) land cover classes (Appendix 1) were used to analyze variability of the urban forest across the city (Homer et al. 2015; MRLC 2018). Plots were then categorized into land cover class groups as defined in Table 2.

The most prevalent land cover classification is developed-low, followed by developed-medium/high, water, and developed-open (Table 3). Figure 2 shows the distribution of landcover class groups across the city. Areas of forest/shrub land cover are estimated to contain the greatest proportion of trees in the sampling area of any land cover (50.4 percent), followed by developed-open, crop and developed-low land covers (16.3 percent, 13.2 percent, and 11.1 percent of the trees in the sampling area, respectively).

Table 2.—National Land Cover Database (NLCD) land cover class groups, city of Madison, 2021

NLCD land cover class group	NLCD land cover classes
Water	Open water
Developed-open	Developed- open space
Developed-low	Developed-low intensity
Developed-medium/high	Developed-medium intensity and developed-high intensity and barren land
Forest/shrub	Deciduous forest, mixed forest, emergent herbaceous wetlands, evergreen forest, shrub/scrub and woody wetlands
Herbaceous/crop	Pasture/hay and grassland/herbaceous/cultivated crops

Source: Homer et al. 2015.

See Appendix 1 for descriptions of the NLCD land cover classes.

Table 3.—Sample area and plot counts within National Land Cover Database (NLCD) land cover class groups, city of Madison, 2021

NLCD land cover class group	Area (acres)	Land (percent)	Plots (number)
Developed-low	15,368	26	45
Developed-medium/high	12,628	21	43
Water	10,973	18	44
Developed-open	7,662	13	27
Forest/shrub	5,519	9	13
Crop	4,348	7	12
Herbaceous	3,684	6	15
Total	60,182	100	199

Due to rounding, not all values will add up exactly.

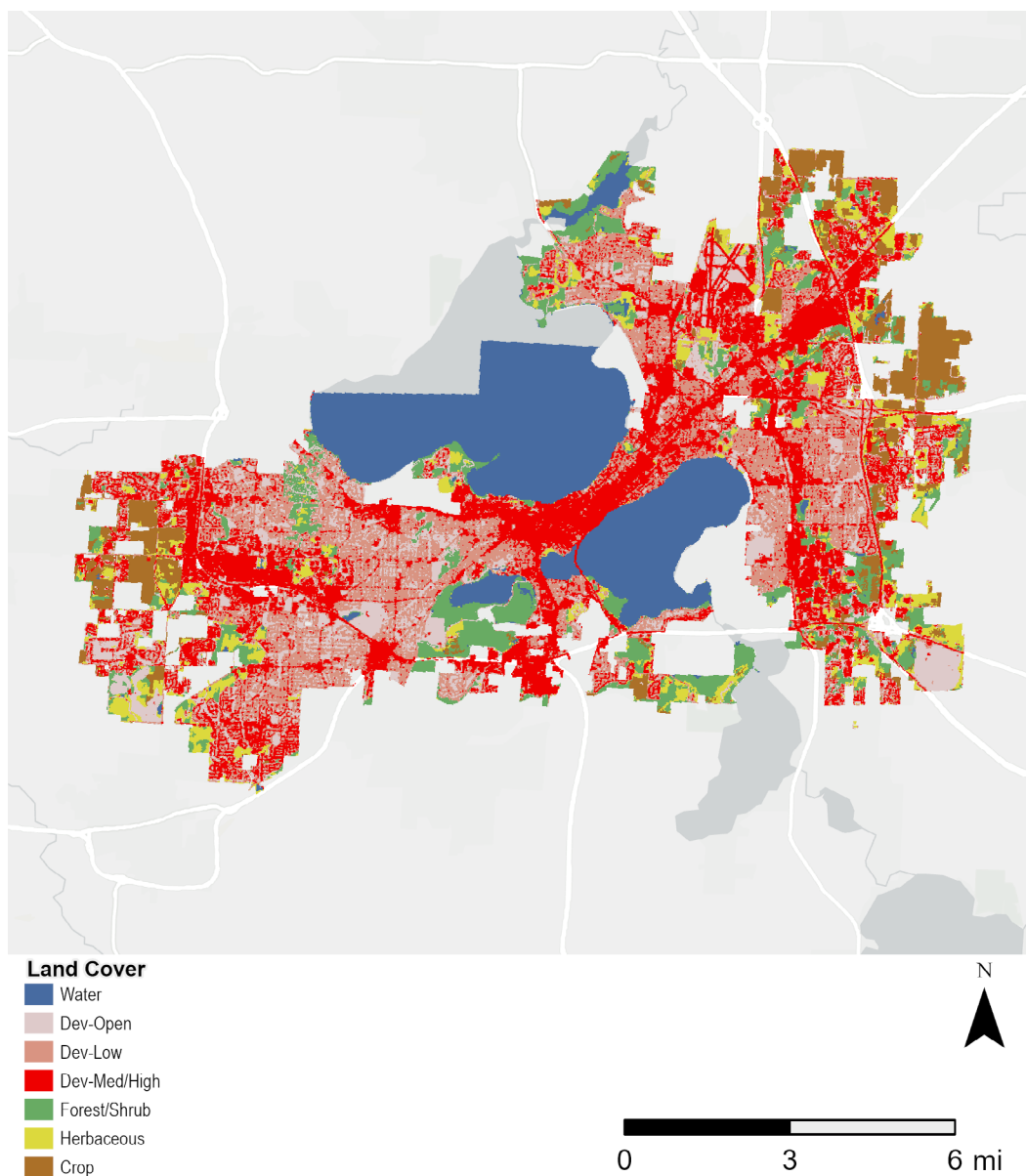


Figure 2.—Distribution of National Land Cover Database (NLCD; Homer et al. 2015) landcover class groups, city of Madison, 2021. The Light Gray Canvas basemap layer was provided by Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

FIA Land Use

In addition to categorization according to NLCD land cover class groups, plots were also classified in the field based on FIA land use classes (Table 4). There are often multiple land uses on a single plot. When this occurs, the area of each land use is mapped, and a percent of the total plot area is assigned. These categories provide a specific look at how the land is being used by the local population in Madison.

Rights-of-way is the most prevalent land use class in Madison, covering 21.9 percent of the city area (containing 10.2 percent of the city's trees), followed by residential (19.5 percent of the city area), water (18.1 percent), commercial/industrial (12.2 percent), and recreation/cemetery (7.2 percent) (Table 5).

Table 4.—Forest Inventory and Analysis (FIA) land use classes and subclasses, city of Madison, 2021

FIA land use class	FIA land use subclasses
Agriculture	Agriculture, Christmas tree plantation, cropland, idle farmland, maintained wildlife openings, nursery, orchard, pasture, shelterbelt, windbreak
Commercial/industrial	Commercial, cultural, developed, industrial, institutional, mining, wasteland
Forest	None
Multi-family residential	None
Natural lands	Beach, nonvegetated land, other, wetland
Rangeland/chapparral	None
Recreation/cemetery	Cemetery, golf course, park, recreation
Residential	None
Rights-of-way	Rights-of-way, transportation, utility
Water	None

Source: USDA Forest Service 2017.

Table 5.—Sample area and plot counts within Forest Inventory and Analysis (FIA) land use classes, city of Madison, 2021

FIA land use class	Area (acres)	Standard error (acres)	Land (percent)	Plots (number)
Forest land	3,765	824	6.3	10.3
Agriculture	3,909	820	6.5	11.2
Rangeland/chaparral	983	501	1.6	4.0
Commercial/industrial	7,327	1,286	12.2	24.5
Multi-family residential	2,313	706	3.8	7.2
Residential	11,720	1,342	19.5	36.6
Recreation/cemetery	4,362	1,042	7.2	14.7
Rights-of-way	13,169	1,336	21.9	41.8
Natural lands	1,730	726	2.9	5.0
Water	10,903	166	18.1	43.6
Total	60,182	254	100.0	199.0

Due to rounding, not all values will add up exactly.

Tree, Shrub, and Ground Cover

On every Urban FIA plot visited, an overall tree canopy cover and shrub cover is visually estimated. These field plot estimates can have a relatively high degree of uncertainty due to the nature of tree cover data collection in the field and the effects of sample size. Many cities also have tree canopy estimates available which are derived from photo interpretation or light detection and ranging (LiDAR) technology which can provide high-resolution maps of vegetative cover and an overall, citywide estimate of canopy cover.

Based on the Urban FIA evaluations, tree cover in Madison overall is estimated at 19.3 percent and shrub cover at 5.3 percent. Tree cover ranges from 0.01 percent to 93.4 percent on plots where trees are present (Fig. 3a). Shrub cover on plots ranges from 0.06 percent to 75 percent on plots where shrubs are present (Fig. 3b). Average tree cover is highest on forest land (71.3 percent tree cover), residential (37.6 percent), and rights-of-way land uses (21.1 percent) (Table 6). Shrub cover is highest on forest land (50.0 percent shrub cover), residential (4.7 percent), and multi-family residential land uses (4.4 percent). (Table 6).



Figure 3.—Tree (A) and shrub (B) cover estimates for each Forest Inventory and Analysis (FIA) plot using approximate plot locations city of Madison, 2021. The Light Gray Canvas basemap layer was provided by Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

Table 6.—Average percent tree and shrub cover by Forest Inventory and Analysis (FIA) land use classes, city of Madison, 2021

FIA land use class	Tree (percent)	Shrub (percent)
Forest land	71.3	50.0
Agriculture	3.2	0.2
Rangeland/chaparral	0.5	0.2
Commercial/industrial	9.4	3.7
Multi-family residential	16.4	4.4
Residential	37.6	4.7
Recreation/cemetery	10.6	0.9
Rights-of-way	21.1	1.9
Natural lands	4.6	4.0
Water	0.0	0.4
Total	19.3	5.3
Total standard error	8.4	0.8

Due to rounding, not all values will add up exactly.

Field crews categorized ground surface cover on each field plot according to five classes: building, low vegetation (woody plants under 1 foot tall and all herbaceous plants), permeable (soil, leaf litter, mulch, gravel, etc.), impervious (non-building), or water. Across all land uses combined, permeable and low vegetation ground covers account for 55.5 percent of all ground covers, while building and other impervious cover account for 26.3 percent (Figs. 4 and 5). An additional 18.2 percent of the city is classified as water. Impervious cover is highest on rights-of-way (56.2 percent impervious cover), commercial/industrial (22.8 percent), and multi-family residential land uses (19.2 percent) (Figure 4).

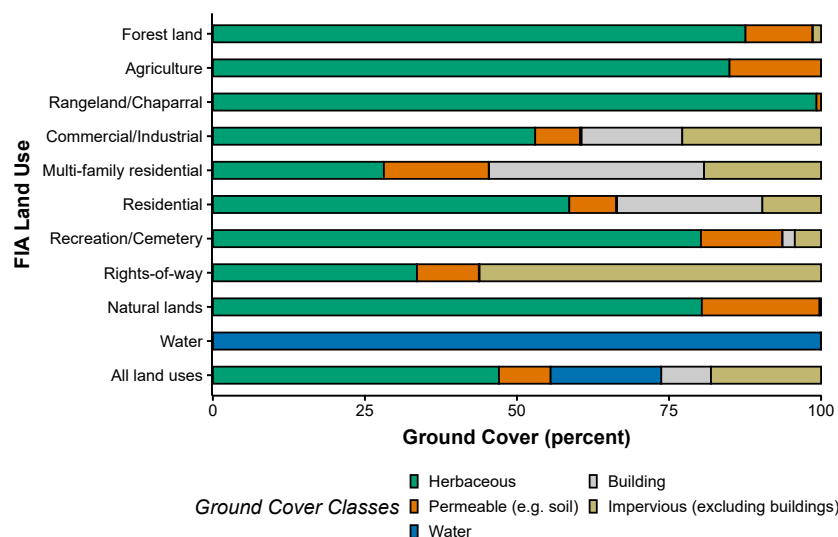
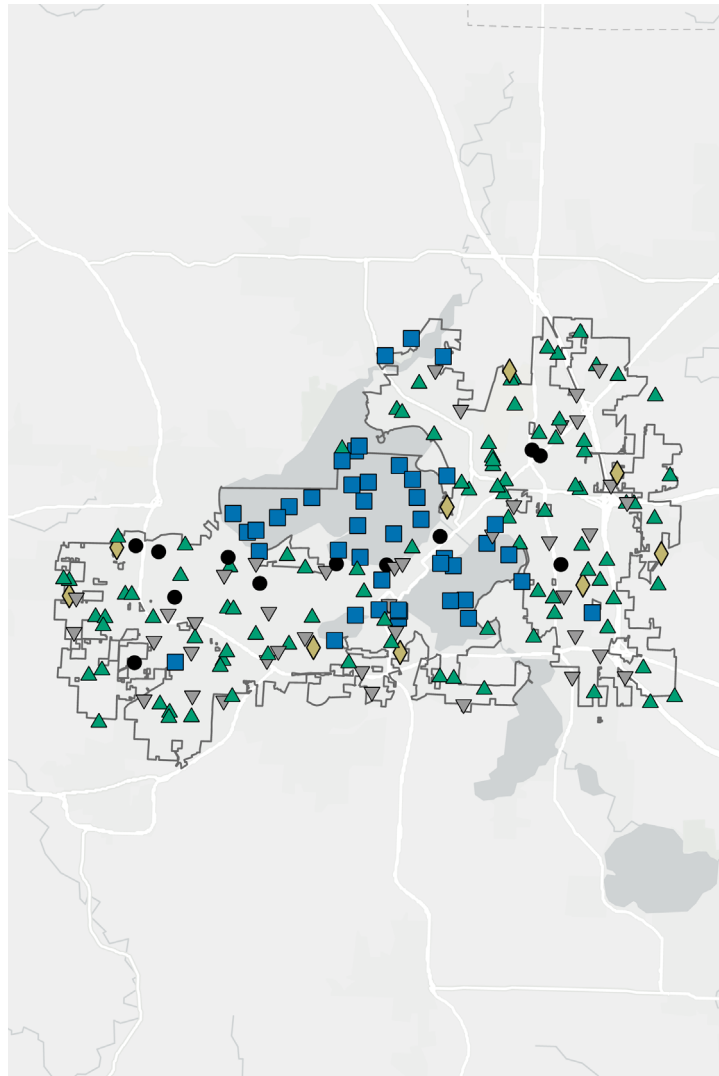


Figure 4.—Average ground cover by Forest Inventory and Analysis (FIA) land use class, city of Madison, 2021.



Dominant Ground Cover

- Building
- ▲ Herbaceous
- ▼ Impervious (non-building)
- ◆ Permeable (non-herbaceous)
- Water



0 3 6 mi

Figure 5.—Dominant ground cover for each Forest Inventory and Analysis (FIA) plot using approximate plot locations, city of Madison, 2021. The Light Gray Canvas basemap layer was provided by Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

Ownership

Plot ownership was divided into private, state and local government, federal government, and unknown (water) classes. The most dominant ownership in Madison is state and local (41.0 percent), followed by private (40.4 percent), unknown (water) (18.1 percent) and federal (0.5 percent) (Table 7). Percent tree canopy cover is greatest in private (24.1 percent), followed by state and local (23.3 percent). In Madison, there are a total of 1.7 million trees (57.8 percent of the live tree population) on state and local lands, and 1.2 million trees (42.2 percent) on private land (Table 7).

Table 7.—Number of trees by ownership and diameter class, city of Madison, 2021

Ownership class	1.0–4.9 in. diameter trees (number)	5.0 –10.9 in. diameter trees (number)	11.0+ in. diameter trees (number)	Total (number)	Area (acres)
Private	728,000	280,000	197,000	1,210,000	24,000
State and local	1,060,000	307,000	282,000	1,650,000	25,000
Federal	0	0	0	0	300
Unknown (water)	0	0	0	0	11,000
Total	1,790,000	586,000	479,000	2,860,000	60,000

Due to rounding, not all values will add up exactly.

FOREST STRUCTURE



Norway maple is one of the most common trees in Madison, WI, particularly in maintained areas. Courtesy photo by Chris Tall, Wisconsin Department of Natural Resources.

Number of Trees

Madison's urban forest has an estimated 2.9 million live trees and 250,000 standing dead trees. The number of trees varies by land use and diameter class. The greatest proportion of the trees in Madison are located on forest land (49.7 percent, 1.4 million trees) (Table 8). Overall, 62.7 percent of Madison's trees are saplings, while the remaining 20.5 percent and 16.8 percent are medium trees (5.0 to 10.9 inches in diameter) and large trees (at least 11.0 inches in diameter), respectively.

The greatest proportion of trees (50.4 percent) and the highest tree density (260.9 trees per acre) are found within the National Land Cover Database (NLCD) forest/shrub land cover class group. (Table 9).



Table 8.—Number of trees by Forest Inventory and Analysis (FIA) land use class and diameter class, city of Madison, 2021

FIA land use class	1.0–4.9 in. diameter trees (number)	5.0–10.9 in. diameter trees (number)	11.0+ in. diameter trees (number)	Total (number)	Standard error (number)	Density (no./ac)
Forest land	997,000	243,000	182,000	1,420,000	502,000	378
Agriculture	27,000	8,700	0	36,000	34,000	9
Commercial/ industrial	272,000	38,000	16,000	325,000	279,000	44
Multi-family residential	191,000	63,000	12,000	266,000	207,000	115
Residential	184,000	142,000	135,000	461,000	121,000	39
Recreation/ cemetery	0	21,000	32,000	53,000	24,000	12
Rights-of-way	121,000	71,000	99,000	291,000	93,000	22
Natural lands	0	0	2,600	2,600	2,200	1
Rangeland/ chaparral	0	0	0	0	0	0
Water	0	0	0	0	0	0
Total	1,790,000	586,000	479,000	2,860,000	–	47
Total standard error	526,000	97,000	61,000	603,000	–	–

Due to rounding, not all values will add up exactly.

– = no value for cell

Table 9.—Distribution of trees by National Land Cover Database (NLCD) land cover class group and diameter class, city of Madison, 2021

NLCD land cover class group	1.0–4.9 in. diameter trees (number)	5.0–10.9 in. diameter trees (number)	11.0+ in. diameter trees (number)	Total (number)	Total standard error (number)	Density (no./ac)
Water	0	0	0	0	0	0
Developed- open	262,000	106,000	98,000	466,000	244,000	61
Developed-low	52,000	110,000	154,000	316,000	56,000	21
Developed- medium/high	134,000	85,000	34,000	253,000	85,000	20
Forest/shrub	1,020,000	235,000	184,000	1,440,000	466,000	260
Herbaceous	0	4,400	3,000	7,400	5,900	2
Crop	326,000	46,000	6,500	378,000	276,000	87
Total	1,790,000	586,000	479,000	2,860,000	–	47
Total standard error	526,000	97,000	61,000	603,000	–	–

Due to rounding, not all values will add up exactly.

– = no value for cell

Species Composition

The 10 most common tree species⁵ by number account for 74.2 percent of all recorded live trees and are common buckthorn, boxelder, white ash, chokecherry, black locust, northern white-cedar, black cherry, Siberian elm, black walnut, and apple spp. (Table 10, Fig. 6). A breakdown of the estimated number of each recorded tree species by diameter classes is presented in Appendix 2. The relative abundance of the most common trees by species and diameter class is presented in Table 11 and Figures 7 and 8. Small diameter trees (saplings) are generally the most abundant of the three tree size classes for the 10 most common tree species, representing 76.2 percent of the total, while large diameter trees make up only 7.1 percent of the total (Table 11, Fig. 7).

Table 10.—Urban forest species composition, city of Madison, 2021

Common name	Trees (number)	Percent	Common name	Trees (number)	Percent	Common name	Trees (number)	Percent
common buckthorn	871,000	30.5	mulberry spp.	32,000	1.1	littleleaf linden	5,000	0.2
boxelder	273,000	9.5	northern red oak	30,000	1.1	ginkgo, maidenhair tree	4,200	0.1
white ash	231,000	8.1	white oak	30,000	1.1	Douglas-fir	3,900	0.1
chokecherry	193,000	6.8	paper birch	30,000	1.1	Norway spruce	3,500	0.1
black locust	106,000	3.7	silver maple	26,000	0.9	black willow	2,600	0.1
northern white-cedar	100,000	3.5	white mulberry	25,000	0.9	balsam poplar	2,100	0.1
black cherry	99,000	3.5	black oak	24,000	0.8	Japanese tree lilac	2,100	0.1
Siberian elm	92,000	3.2	eastern white pine	19,000	0.7	London planetree	2,100	0.1
black walnut	81,000	2.8	Amur maple	14,000	0.5	pear spp.	2,100	0.1
apple spp.	75,000	2.6	hackberry	13,000	0.5	Rocky Mountain juniper	1,800	0.1
American elm	68,000	2.4	American basswood	9,700	0.3	black maple	1,800	0.1
hawthorn spp.	59,000	2.0	red maple	8,600	0.3	Freeman maple	1,800	0.1
Norway maple	56,000	2.0	red pine	8,400	0.3	Callery pear	1,800	0.1
green ash	45,000	1.6	eastern redcedar	8,300	0.3	silver poplar	1,700	0.1
honeylocust	44,000	1.5	river birch	8,300	0.3	katsura tree	1,700	0.1
white spruce	43,000	1.5	sugar maple	7,000	0.2	Total	2,860,000	100.0
shagbark hickory	41,000	1.4	blue spruce	6,200	0.2	Due to rounding, not all numbers will add up exactly.		
bur oak	34,000	1.2	eastern redbud	6,200	0.2	For a breakdown of tree species composition by diameter class, refer to Appendix 2.		
			quaking aspen	5,400	0.2			

⁵ Common and scientific names for tree species observed in the 2021 Urban FIA inventory of Madison are reported in Appendix 2.

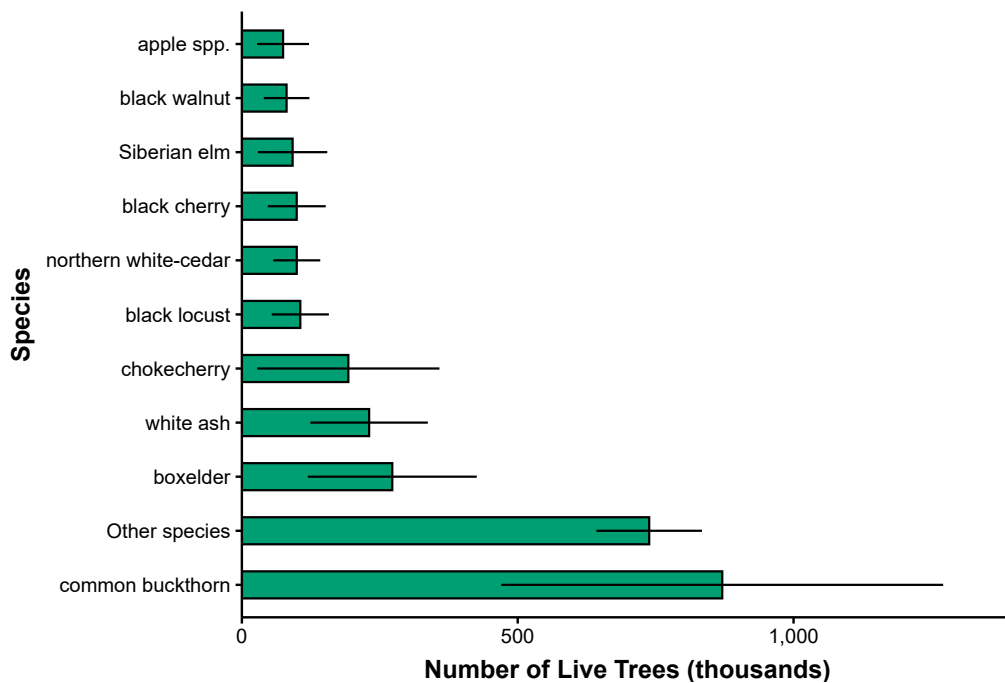


Figure 6.—The 10 most common tree species by number of trees, city of Madison, 2021. Other species is the total number of all other tree species in the inventory. Error bars represent 68 percent confidence intervals around the estimated means.

Table 11.—Number of trees by diameter class for the 10 most common tree species, city of Madison, 2021

Common name	1.0–4.9 in. diameter trees (number)	5.0–10.9 in. diameter trees (number)	11.0+ in. diameter trees (number)	Total (number)
common buckthorn	859,000	12,000	0	871,000
boxelder	168,000	83,000	21,000	273,000
white ash	159,000	57,000	14,000	231,000
chokecherry	191,000	2,100	0	193,000
black locust	32,000	33,000	41,000	106,000
northern white-cedar	26,000	65,000	8,000	100,000
black cherry	54,000	32,000	13,000	99,000
Siberian elm	54,000	31,000	7,200	92,000
black walnut	27,000	16,000	38,000	81,000
apple spp.	45,000	22,000	7,600	75,000
Total	1,610,000	355,000	150,000	2,120,000

Due to rounding, not all values will add up exactly.

Standard errors for each estimate are reported in Appendix 2.

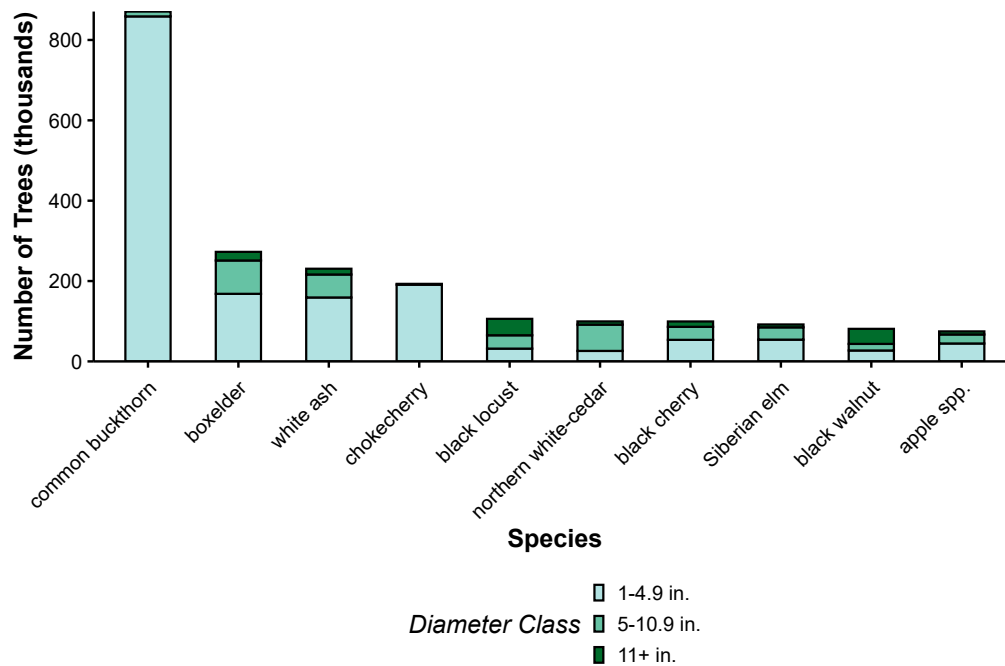


Figure 7.—Number of trees in each diameter class for the 10 most common tree species, city of Madison, 2021.

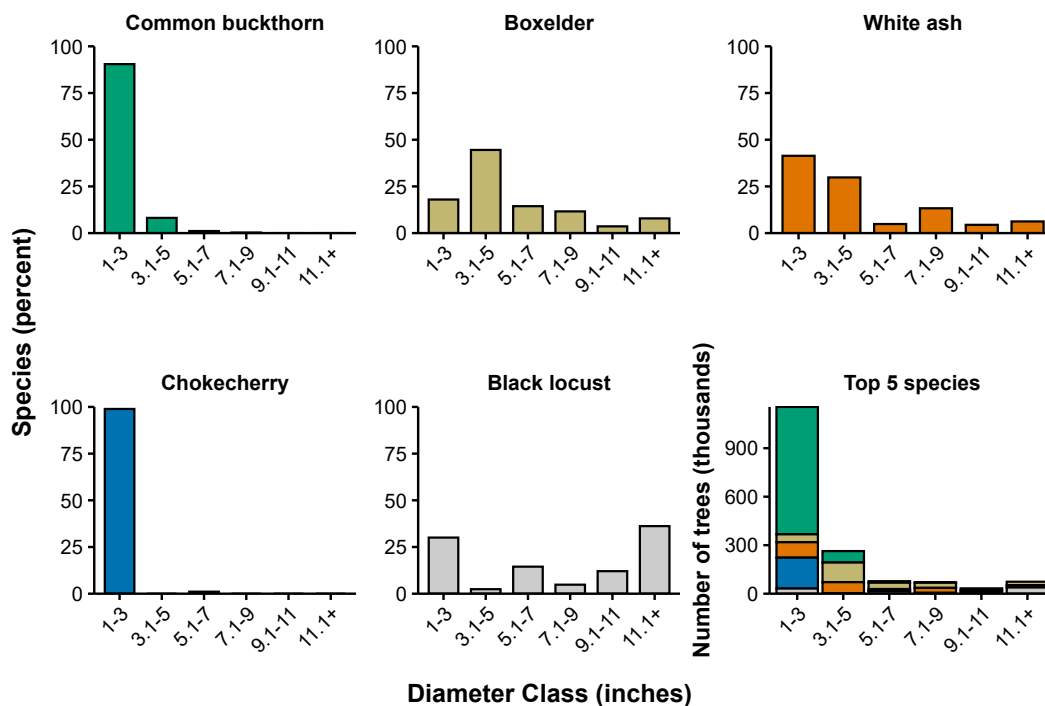


Figure 8.—Percentage of species population by diameter class for the five most common tree species, city of Madison, 2021.

The preceding tables and figures highlight the most prominent species by number for all trees 1.0-inch in diameter and larger. Because smaller diameter trees are generally more abundant per unit area, the overall species composition may be more reflective of the smaller diameter species when analyzing estimates based on number of trees. For this reason, it is also helpful to rank species according to other metrics such as the number of trees within various size classes, leaf area, importance value, volume, or biomass. The three most common species in terms of stem numbers in the smallest-diameter size classes (less than 5.0 inches in diameter) are common buckthorn, chokecherry, and boxelder, together representing more than half (67.9 percent) of all live trees less than 5.0 inches in diameter (Table 12, Appendix 2). Boxelder, northern white-cedar, and white ash are the most common species in intermediate diameter size classes, representing 35.1 percent of all live trees between 5.0 and 10.9 inches in diameter. Dominant species in the largest diameter classes, often the most recognizable component of the urban forest canopy, are Norway maple, honeylocust, and black locust, which represent 27.7 percent of live trees at least 11.0 inches in diameter (Table 12, Appendix 2).

Table 12.—The five most common tree species by number of trees within each diameter class, city of Madison, 2021

Diameter class (inches)	Common name	Trees (number)
1.0–4.9	common buckthorn	859,000
	chokecherry	191,000
	boxelder	168,000
	white ash	159,000
	Siberian elm	54,000
5.0–10.9	boxelder	83,000
	northern white-cedar	65,000
	white ash	57,000
	black locust	33,000
	black cherry	32,000
11.0+	Norway maple	51,000
	honeylocust	42,000
	black locust	41,000
	black walnut	38,000
	white oak	30,000

Estimates are rounded.

Standard errors for each estimate are reported in Appendix 2.

In Madison, tree species composition on private land is led by common buckthorn (40.9 percent), northern white-cedar (8.2 percent), and Siberian elm (4.7 percent) (Table 13). The most common tree species on public lands are common buckthorn (22.8 percent), white ash (14.0 percent), and boxelder (13.2 percent) (Table 14). A total of 41 tree species are recorded on private lands, resulting in a **Shannon-Wiener diversity index** value of 2.6. The 36 species of trees recorded on public lands results in a Shannon-Wiener diversity index value of 2.6. As calculated, this diversity index takes into account tree species richness (total number of species) and species evenness (relative abundances among species) and ranges from approximately 2.0-3.5 within cities measured using Urban FIA protocol. On private land, the top three genera with the greatest number of trees are buckthorn (*Rhamnus*), maple (*Acer*), and arborvitae (*Thuja*). On public land they are buckthorn, maple, and cherry/plum (*Prunus*) (Fig. 9). Species composition within NLCD land cover class groups is detailed in Appendix 3.

Table 13.—Tree species composition on private lands, city of Madison, 2021

Common name	Trees (percent)	Common name	Trees (percent)
common buckthorn	41.0	eastern redcedar	0.7
northern white-cedar	8.3	eastern white pine	0.7
Siberian elm	4.7	river birch	0.7
boxelder	4.6	honeylocust	0.7
black locust	3.7	hackberry	0.6
white spruce	3.3	black cherry	0.5
hawthorn spp.	2.6	eastern redbud	0.5
paper birch	2.5	quaking aspen	0.4
northern red oak	2.3	American basswood	0.4
shagbark hickory	2.3	Douglas-fir	0.3
American elm	2.2	Norway spruce	0.3
silver maple	2.2	blue spruce	0.2
bur oak	2.1	balsam poplar	0.2
apple spp.	1.9	chokecherry	0.2
white mulberry	1.9	pear spp.	0.2
green ash	1.6	Rocky Mountain juniper	0.1
black oak	1.5	black maple	0.1
Norway maple	1.4	Callery pear	0.1
black walnut	1.2	katsura tree	0.1
white oak	0.9	littleleaf linden	0.1
red pine	0.7		

Estimates are rounded.

Table 14.—Tree species composition on public lands, city of Madison, 2021

Common name	Trees (percent)	Common name	Trees (percent)
common buckthorn	22.8	eastern white pine	0.6
white ash	14.0	bur oak	0.6
boxelder	13.2	red maple	0.5
chokecherry	11.6	sugar maple	0.4
black cherry	5.6	hackberry	0.4
black walnut	4.0	black oak	0.4
black locust	3.7	American basswood	0.3
apple spp.	3.1	blue spruce	0.3
American elm	2.6	ginkgo, maidenhair tree	0.3
Norway maple	2.4	white spruce	0.2
honeylocust	2.2	littleleaf linden	0.2
Siberian elm	2.1	northern red oak	0.2
mulberry spp.	1.9	black willow	0.2
hawthorn spp.	1.6	Japanese tree lilac	0.1
green ash	1.6	London planetree	0.1
white oak	1.2	Freeman maple	0.1
Amur maple	0.8	white mulberry	0.1
shagbark hickory	0.8	silver poplar	0.1

Estimates are rounded

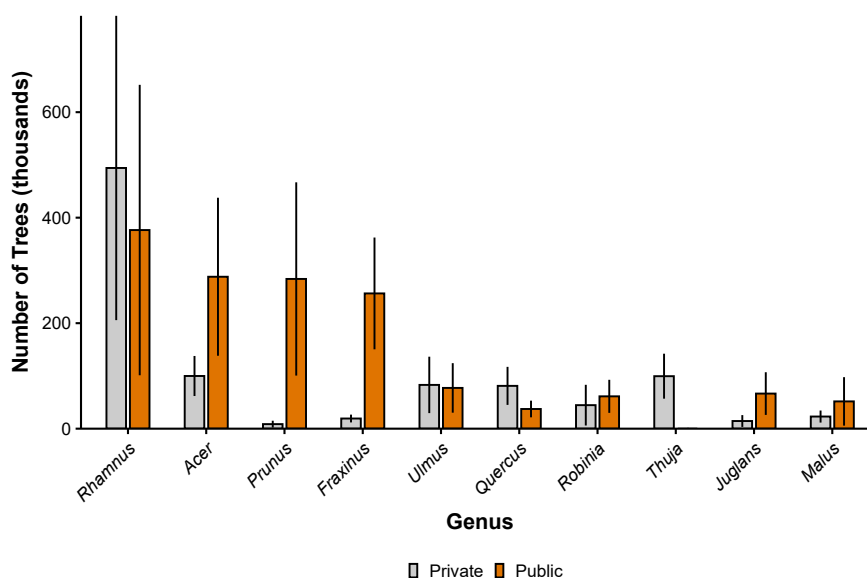


Figure 9.—The 10 most common tree genera within ownership classes, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

Trees in Maintained Areas

Overall, 19.7 percent of trees in Madison are found in maintained areas. Maintained areas are those which are regularly impacted by mowing, weeding, cutting, brush clearing, herbicide applications, etc. Examples of maintained areas include, but are not limited to, lawns, shrub and flower beds, rights-of-way, and manicured parks. However, a tree found in a maintained area has not necessarily received care. In Madison, the most common tree species in maintained areas are northern white-cedar (14.7 percent of all trees in maintained areas), Norway maple (9.7 percent), and honeylocust (7.8 percent) (Table 15; Appendix 4).

Table 15.—The 10 most common tree species in maintained areas by number of trees, city of Madison, 2021

Common name	Trees (number)	Percent of all trees in maintained areas
northern white-cedar	83,000	14.8
Norway maple	54,000	9.7
honeylocust	44,000	7.8
white spruce	43,000	7.7
apple spp.	30,000	5.4
paper birch	30,000	5.4
American elm	28,000	5.0
northern red oak	28,000	5.0
hawthorn spp.	27,000	4.8
Siberian elm	24,000	4.4

Estimates are rounded.

Leaf Area

Leaf area is correlated with many ecosystem services provided by the urban forest. It is estimated as the surface area (on one side) of the leaves on a given tree or in an area. The proportion of total leaf area in the urban forest is greatest for trees in the unlimited 29.1+ inches in diameter class (11.2 percent), followed by 17.1–19.0 inches in diameter (10.7 percent), and 13.1–15.0 inches in diameter (10.6 percent) (Fig. 10). In Madison, leaf area is greatest in forest land uses (40.3 percent of total leaf area), followed by residential (29.4 percent), and rights-of-way land uses (16 percent) (Fig. 11).

Leaf area index (LAI) refers to a standardized measure of leaf surface area per unit of tree cover and is calculated as the total leaf area divided by the total ground area covered by tree canopies. Higher LAI values indicate a greater depth or layering of leaves in the tree canopy. As each land use class has a different amount of area covered by trees, LAI allows for standardized comparison of leaves per unit canopy area among land use classes (acres of leaves per acre of tree cover). The leaf area index in land uses with trees ranges from 16.3 in forest land use to 0.1 in natural lands (Fig. 11).

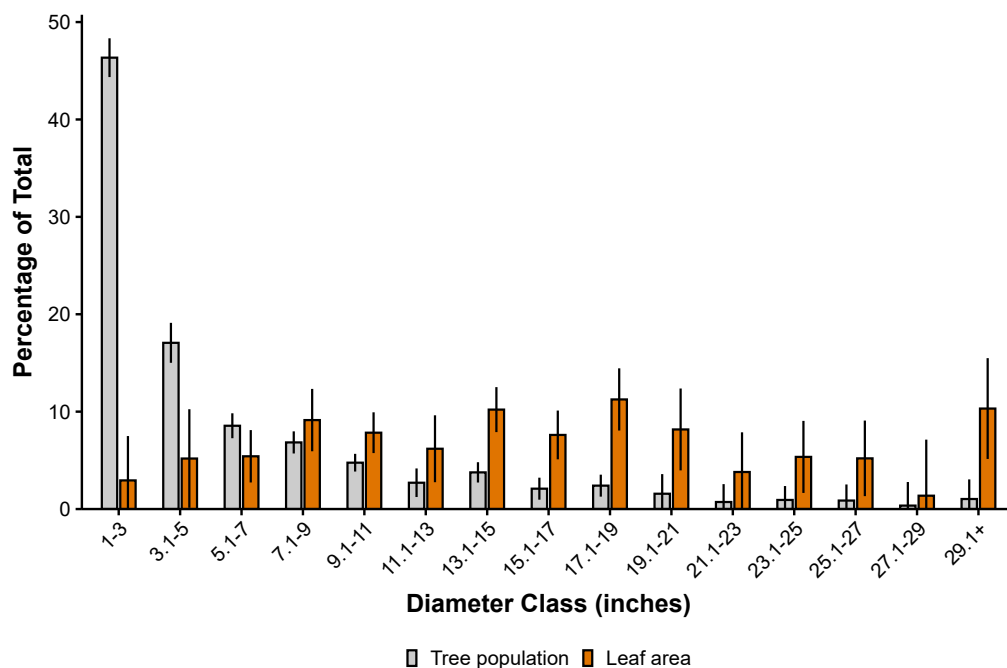


Figure 10.—Percentage of tree population and leaf area by 2-inch diameter class, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

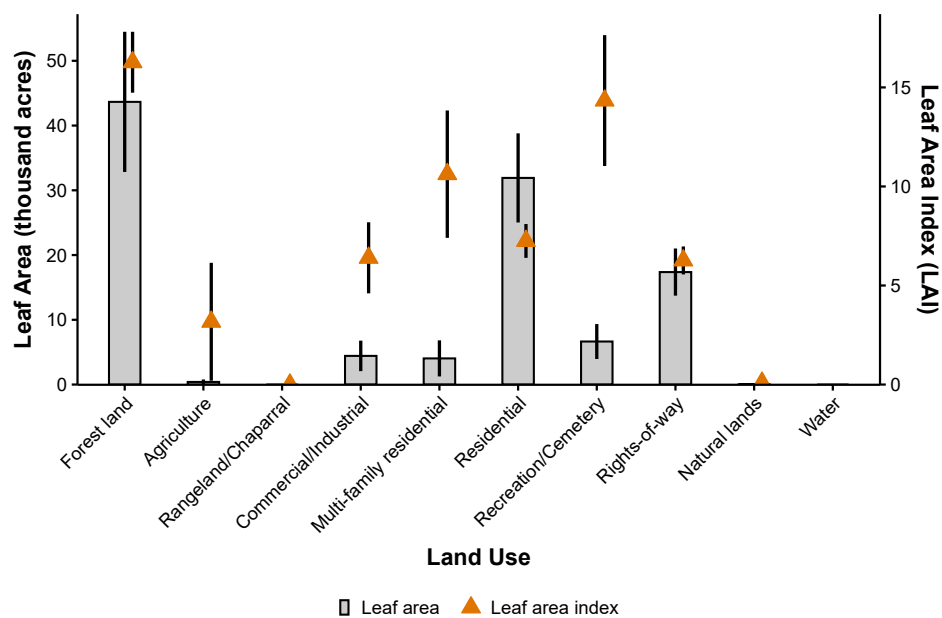


Figure 11.—Leaf area and leaf area index (LAI) by Forest Inventory and Analysis (FIA) land use class, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

Species Importance

Importance values (IVs) establish the relative contribution of the observed species to the overall species composition of the urban forest and are calculated by summing the values of its relative leaf area and relative abundance. High importance values do not mean that these trees should be encouraged in the future, but rather that they currently dominate the urban forest structure in terms of their population size and leaf area. The species in Madison's urban forest with the greatest IVs are common buckthorn (33.0), boxelder (15.8), and white ash (15.2) (Table 16).

Table 16.—Percentage of total tree population represented by tree species with the highest importance value (IV), city of Madison, 2021

Common name	Population (percent)	Leaf area (percent)	Importance value
common buckthorn	30.5	2.5	33.0
boxelder	9.5	6.3	15.8
white ash	8.1	7.2	15.2
Norway maple	2.0	7.4	9.3
black walnut	2.8	6.1	8.9
silver maple	0.9	7.7	8.6
honeylocust	1.5	6.6	8.1
black locust	3.7	4.1	7.8
white oak	1.1	6.2	7.2
chokecherry	6.8	0.3	7.0

Estimates are rounded.

Importance value = population (%) + leaf area (%).

VOLUME AND BIOMASS



Magnificent, large-diameter trees are scattered throughout Madison including on the grounds of the Wisconsin State Capitol where this northern red oak was measured. Courtesy photo by Wisconsin Department of Natural Resources.

Wood Volume and Value

Wood volume is a measure of the solid content of the tree stem and is used to estimate wood quantity. A detailed description of methods used to compute wood volume in terms of net cubic-foot volume and **sawtimber volume** for this report is presented in Baer et al. (2025). Understanding the net volume of wood provided by a community's trees can serve a variety of purposes. From a management perspective, a thorough knowledge of wood volume can help predict potential storm damage and support planning for post-disaster recovery, including debris removal and cost. Volume data can also inform urban wood markets, which add value to traditional wood waste derived from tree removal, storm damage, and general tree maintenance. Such data can incentivize repurposing wood waste into traditional wood products such as lumber, handcrafted furniture, nature-based landscape supplies, and biofuel (e.g., Nowak et al. 2019).

In Madison, live trees at least 5.0 inches in diameter are estimated to contain 22.6 million cubic feet of net volume, of which 52.2 million board feet is sawtimber volume. To put this value in perspective, the median size of American homes constructed in 2019 was 2,301 square feet (U.S. Census Bureau 2020), which would require approximately 14,500 board feet to construct. Thus, the net sawtimber volume of Madison's urban forest



is roughly equivalent to the amount of wood that would be needed to construct 3,599 median-sized homes. Silver maple contributes the greatest net cubic-foot volume at 11.2 percent of the city's total (Table 17). Black walnut contributes 16.0 percent of the total net board-foot sawtimber volume (Table 18). The greatest net cubic-foot-volume is provided by the largest trees which are represented in the 29.1 inches or greater class, which in the Madison dataset includes trees up to 44.5 inches in diameter (Fig. 12).

Table 17.—Net cubic-foot volume for tree species with the greatest net volume, city of Madison, 2021

Common name	Net volume (cubic-feet)	Standard error (cubic-feet)	Net volume (percent)
silver maple	2,500,000	1,190,000	11.1
white oak	2,180,000	988,000	9.7
honeylocust	2,020,000	535,000	8.9
black walnut	1,820,000	1,140,000	8.1
Norway maple	1,510,000	411,000	6.7
black locust	1,330,000	782,000	5.9
bur oak	1,260,000	1,280,000	5.6
black oak	1,260,000	795,000	5.6
white ash	1,050,000	522,000	4.6
American basswood	868,000	641,000	3.9
Other species	6,750,000	933,000	29.9
Total	22,530,000	3,050,000	100.0

Due to rounding, not all values will add up exactly.

Other species is the total for all other tree species in the inventory.

Table 18.—Net board-foot sawtimber volume for tree species with the greatest net volume, city of Madison, 2021

Common name	Net volume (board feet)	Standard error (board feet)	Net volume (percent)
black walnut	8,350,000	5,440,000	16.0
white oak	7,510,000	3,490,000	14.4
black locust	5,300,000	3,110,000	10.2
bur oak	4,300,000	4,400,000	8.2
silver maple	3,980,000	2,740,000	7.6
black oak	3,750,000	2,330,000	7.2
American basswood	3,520,000	2,730,000	6.7
eastern white pine	3,450,000	1,880,000	6.6
white ash	3,130,000	2,070,000	6.0
shagbark hickory	2,170,000	1,190,000	4.2
Other species	6,730,000	1,640,000	12.9
Total	52,180,000	10,960,000	100.0

Due to rounding, not all values will add up exactly.

Other species is the total for all other tree species in the inventory.

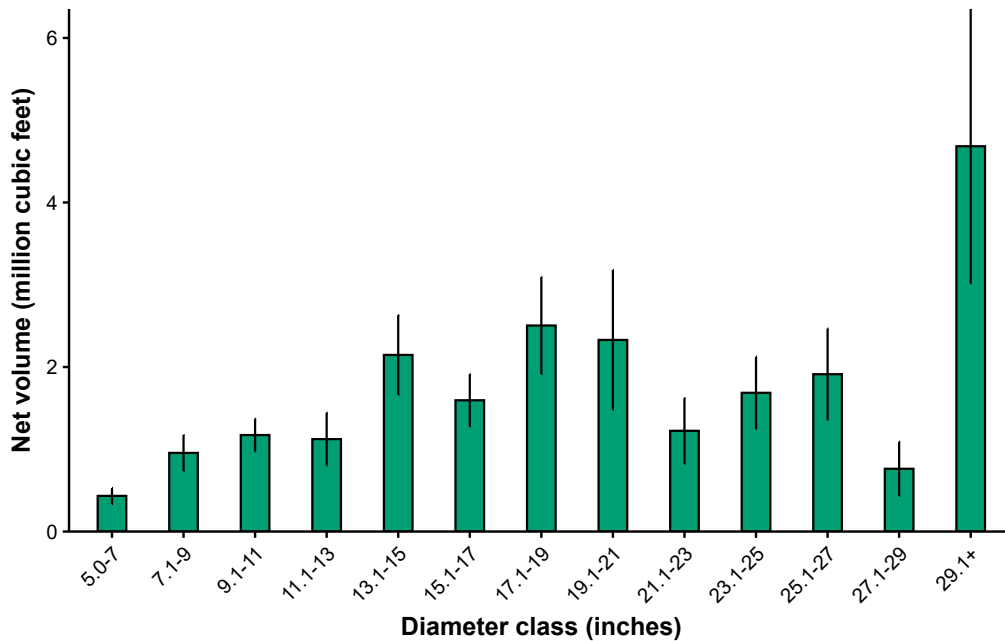


Figure 12.—Net cubic-foot volume by tree diameter class, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated values.

While sawtimber could potentially be derived from urban forests to provide economic value, the broader social-ecological value of this forest is derived from healthy trees. Healthy urban forests provide benefits that support environmental and human health and well-being and are valued at over \$18 billion per year nationally (Nowak and Greenfield 2018). Harvesting healthy urban trees will reduce local annual benefits. Utilizing urban wood waste, however, does not affect the healthy tree canopy and augments the value of the urban forest. Urban wood waste could produce between \$89-786 million per year nationally depending upon the product derived (e.g., wood chips to lumber) (Nowak et al. 2019).

Increasing public interest in environmentally responsible and sustainable products presents opportunities for urban wood utilization programs. In urban settings, trees generally only become a source for wood products after removal for development purposes or because of safety factors including age, pest and disease damage, or storm events. Many of these urban trees are unsuitable for traditional sawtimber products but may still have economic and cultural value. Methods to evaluate the quality of urban wood for potential products are not well defined since wood markets and products are quite varied across different geographic areas. Further research would allow for the development of metrics to evaluate the amount of urban wood waste available for specialty products. For example, many consumers of urban wood are interested in wood with grain character. Character wood that contains knots, insect damage and distorted grain is often highly desirable for specialty products but are the same wood qualities that

make for less desirable traditional lumber. Urban wood waste utilization programs and markets may be better informed by drawing upon available FIA information about net growth, removals, and mortality.

Biomass

Like wood volume, tree biomass information is important in estimating both wood production and carbon storage. The overall aboveground biomass of all live trees in Madison is estimated at 1.3 million green tons, which includes the weight of its moisture content (Table 19). The amount of biomass stored by live trees in Madison varies by species. The tree species with the greatest total aboveground biomass are silver maple (13.0 percent), honeylocust (10.3 percent), and white oak (10.2 percent) (Table 19).

Table 19.—Aboveground biomass for tree species with the greatest biomass, city of Madison, 2021

Common name	Biomass (green tons)	Standard error (green tons)	Biomass (percent)
silver maple	163,000	76,000	12.8
honeylocust	131,000	35,000	10.3
white oak	131,000	60,000	10.2
black walnut	96,000	58,000	7.6
black oak	94,000	66,000	7.4
Norway maple	74,000	20,000	5.8
black locust	69,000	40,000	5.4
bur oak	60,000	60,000	4.7
white ash	46,000	22,000	3.6
shagbark hickory	39,000	22,000	3.1
Other species	372,000	53,000	29.1
Total	1,280,000	171,000	100.0

Due to rounding, not all values will add up exactly.

Other species is the total for all other tree species in the inventory.

URBAN FOREST VALUES



People enjoy the shade of a Kentucky coffeetree on the grounds of the Wisconsin State Capitol. Courtesy photo by Wisconsin Department of Natural Resources.

Urban forest values can be quantified as functional or structural. Social and biophysical functional values, either positive (e.g., decreased energy use) or negative (e.g., increased energy use) are based on the annual functions the trees perform, including sequestering carbon, removing air pollutants, and influencing surrounding microclimates which affect the amount of energy used to heat or cool buildings. The forest may provide many other functional values that are not quantified in this report (e.g., reduction in ultraviolet radiation, wildlife habitat, enhanced recreational opportunities, fostering social cohesion, and community health and well-being). Thus, the functional estimates provided in this report represent only a portion of the total forest functional values. Structural values include the amount of carbon stored by a tree and the tree's compensatory value, which can be thought of as the replacement value of the tree. Structural and functional values tend to increase with increased number and size of healthy trees and are usually on the order of several million dollars per year at a city scale.

Forest management activities can increase the values and services provided by the urban forest. However, these values and benefits can also decrease if the amount of healthy tree cover declines. Various costs associated with urban forest management, such as tree pruning, inspection, removal and disposal are not accounted for in this assessment and may offset some of the estimated monetary benefits described here (McPherson et al. 2005).



Urban forest ecosystem services associated with air pollution removal, avoided runoff, carbon sequestration, and compensatory value exclude dead trees, as these benefits are mainly based on existing leaf area, leaf biomass, or live tree conditions. However, standing dead trees do contribute to carbon storage and energy effects and are included in estimates for these values.

Air Pollution Removal

Poor air quality is a widespread problem in urban areas. Air pollution can adversely affect human health through increased rates of pulmonary, cardiac, vascular, and neurological diseases and mortality (Pope et al. 2002), along with negatively impacting ecosystem processes and reducing visibility. Urban forests can improve air quality by directly removing pollutants from the air and reducing energy consumption by buildings, which consequently reduces air pollution emissions from power plants and other energy sources. While trees emit volatile organic compounds (VOCs) that can contribute to ozone (O₃) formation (Fehsenfeld et al. 1992, Karlik and Pittenger 2012), integrative studies have revealed that an increase in tree cover tends to reduce O₃ formation, although the extent to which this is the case depends upon species composition (Calfapietra et al. 2013; Manes et al. 2012; Nowak et al. 2000, 2006).

Pollution removal by the urban forest in Madison is greatest for O₃ (283.2 tons per year), followed by nitrogen dioxide (NO₂; 63.9 tons per year), particulate matter less than 2.5 microns (PM_{2.5}; 17.4 tons per year), carbon monoxide (CO; 3.3 tons per year), and sulfur dioxide (SO₂; 0.1 tons per year) (Fig. 13). The economic value of this removed pollution is estimated using i-Tree methodology in one of two ways, depending on the pollutant. For NO₂, SO₂, O₃, and PM_{2.5}, estimates are based on avoided health effects due to lower pollution concentrations. For CO, the estimated value is based on the avoided externality costs of air pollution to society (Nowak 2024). The estimated value associated with pollution removal is greatest for PM_{2.5} (\$2.0 million), followed by O₃ (\$677,000), NO₂ (\$20,000), CO (\$4,300), and SO₂ (\$0) (Table 20). It is estimated that trees in Madison remove a total of 368 tons of air pollution per year with an associated value of \$2.7 million. More information about value calculations can be found in Baer et al. (2025).

Decreases in the concentration of various air pollutants due to removal by trees is expected to have a positive effect on human health in Madison (Nowak et al. 2014, U.S. EPA 2012). Using measured field data and pollution data from 2015, air quality improvements from trees produce numerous health benefits including an estimated 370 fewer cases of acute respiratory symptoms per year with an associated value of over \$33,000 (Table 20).

Trees in Madison emit an estimated 267 tons of VOCs (77 tons of isoprene and 189 tons of monoterpenes) per year. Emissions vary among species based on species characteristics (e.g., some genera such as oaks are high isoprene emitters) and leaf biomass. Oak (*Quercus*) and maple (*Acer*) contribute 65.0 percent of VOC emissions (Fig. 14). These VOCs are precursor chemicals to ozone formation.

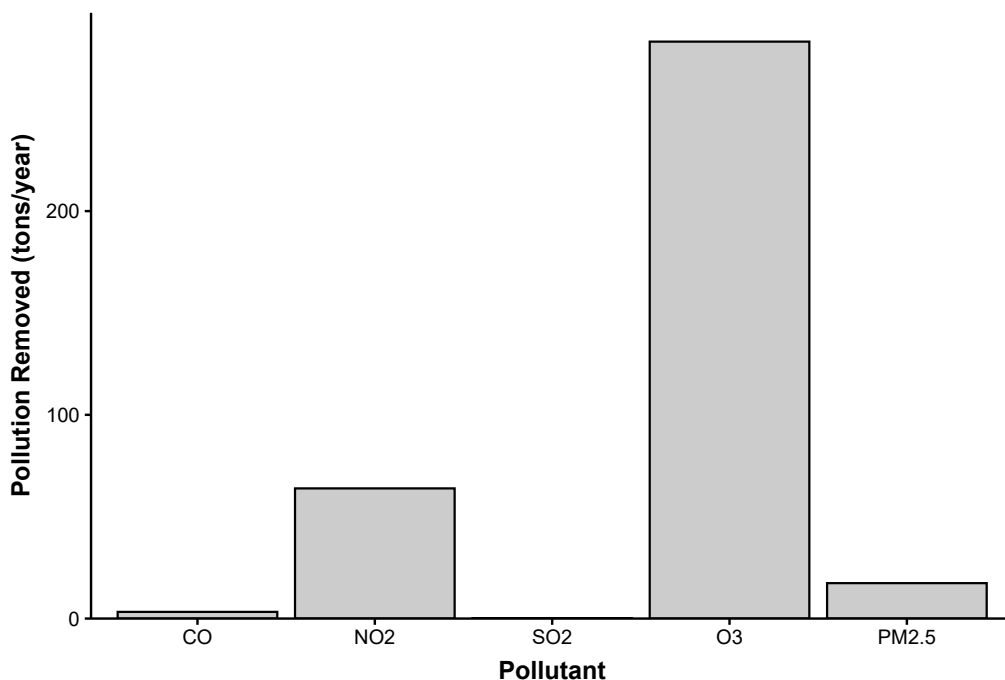


Figure 13.—Air pollution removal by trees, city of Madison, 2021.

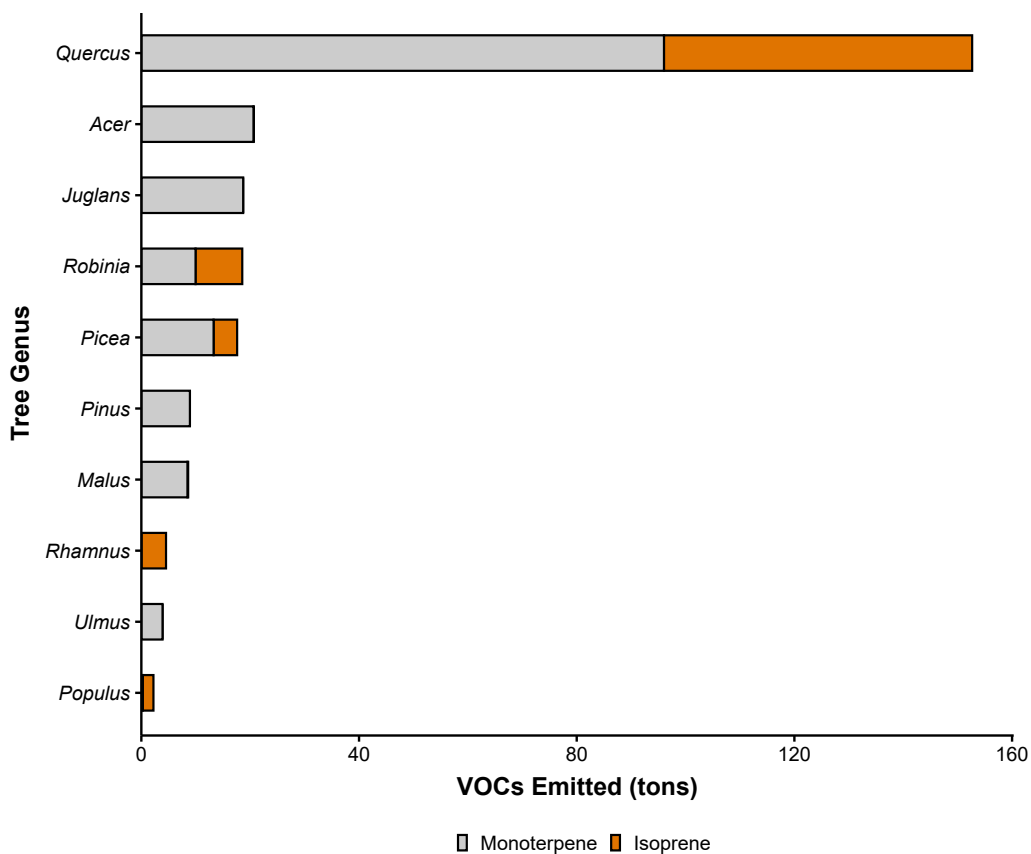


Figure 14.—Volatile organic compound (VOC) emissions by tree genus, city of Madison, 2021.

Table 20.—Incidence and associated value of avoided health effects from changes in pollution concentrations due to pollution removal by trees, city of Madison, 2021

	Nitrogen dioxide (NO ₂)		Ozone (O ₃)		Particulate matter (PM _{2.5})		Sulfur dioxide (SO ₂)	
Health effect	Incidence (cases/year)	Associated value (\$/year)	Incidence (cases/year)	Associated value (\$/year)	Incidence (cases/year)	Associated value (\$/year)	Incidence (cases/year)	Associated value (\$/year)
Acute bronchitis	-	-	-	-	0.1	13.1	-	-
Acute myocardial infarction	-	-	-	-	<0.1	3,400	-	-
Acute respiratory symptoms	10	320	230	20,000	130	12,000	<0.1	0.3
Asthma exacerbation	150	13,000	-	-	60.6	4,900	0.1	7
Chronic bronchitis	-	-	-	-	0.1	26,000	-	-
Emergency room visits	0.1	29.9	<0.1	19	<0.1	17.7	<0.1	0.1
Hospital admissions	0.2	6,900	0.2	4,900	-	-	<0.1	22.6
Hospital admissions, cardiovascular	-	-	-	-	<0.1	1,000	-	-
Hospital admissions, respiratory	-	-	-	-	<0.1	600	-	-
Lower respiratory symptoms	-	-	-	-	1.5	77.6	-	-
Mortality	-	-	0.1	646,000	0.3	1,950,000	-	-
School loss days	-	-	57.7	5,700	-	-	-	-
Upper respiratory symptoms	-	-	-	-	1.4	64.9	-	-
Work loss days	-	-	-	-	22	3,900	-	-
Total	160	20,000	290	677,000	210	2,002,051	0.1	30.0

Due to rounding, not all values will add up exactly.

Dashes indicate that the value is not estimated for that pollutant and health effect. The same health effects were not analyzed for each pollutant.

PM_{2.5} = particulate matter less than 2.5 microns.

Avoided runoff

Surface water runoff (commonly referred to as surface runoff or stormwater runoff) can contribute pollution to streams, wetlands, rivers, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation, while the remainder reaches the ground. The portion of the precipitation that reaches the ground does not infiltrate into the soil or end up in surface depression storage and becomes surface runoff (Hirabayashi 2013). In urban areas, the substantial extent of impervious surfaces increases the amount of surface runoff.

Urban trees can reduce surface runoff. Tree canopies intercept precipitation, while root systems promote infiltration and water storage in the soil. The amount of avoided runoff is less than the total amount intercepted because soils also absorb precipitation and thus reduce runoff in the absence of trees. The trees in Madison are estimated to reduce runoff by 36 million cubic feet per year (273 million gallons annually), with an estimated value of \$2 million per year based on a national average cost of stormwater control and treatment of \$0.008936 per gallon (Nowak 2024). Tree species with the greatest overall impact on runoff are silver maple, Norway maple, and white ash due to their large leaf surface area (Fig. 15).

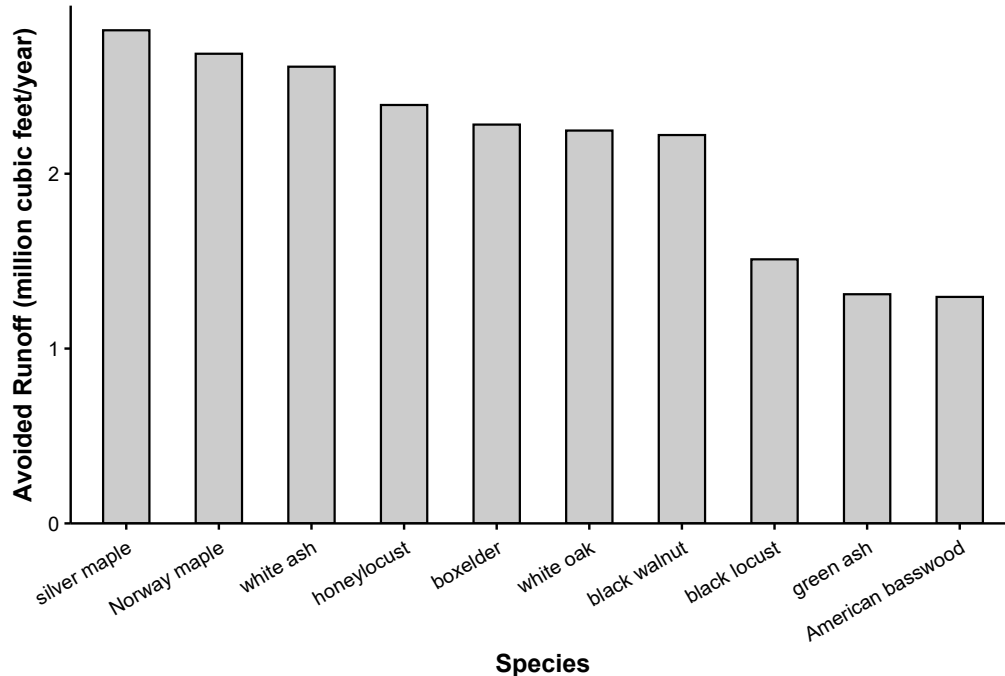


Figure 15.—Avoided runoff for the 10 tree species with the greatest leaf area, city of Madison, 2021.

Energy Conservation

Trees can affect building energy use by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months (cooling season) and can either increase or decrease building energy use in the winter months (heating season), depending on the location of the trees around the building (Heisler 1986, Nowak et al. 2017). Estimates of tree effects on energy use are based on field measurements of the tree distance and directions to space-conditioned residential buildings (McPherson and Simpson 1999; Nowak et al. 2008; Nowak 2024; U.S. EIA 2012a, b; U.S. EIA 2014a, b, c).

In Madison, interactions between buildings and trees 5.0 inches in diameter and greater are projected to annually decrease energy requirements by 225,000 gigajoules (GJ) during the heating and cooling seasons (an energy equivalent of 1.4 million gallons of home heating fuel oil) (Table 21), with an annual savings in energy costs of \$3.2 million (Table 22). Savings in residential energy costs were calculated based on state average 2012 costs for natural gas (U.S. EIA 2014b), 2012/2013 heating season fuel oil costs (U.S. EIA 2014a). Trees in the urban forest also are estimated to reduce carbon dioxide (CO₂) emissions from fossil-fuel-based power sources by 23,600 tons annually (6,400 tons of carbon; \$1,237,000), equivalent to the burning of over 16.5 million pounds of coal or roughly 49,855 barrels of oil (Hong and Slatick 1994, U.S. EPA 2020).

Table 21.—Annual energy savings due to live and standing dead trees 5.0+ inches in diameter near residential buildings during heating and cooling seasons, city of Madison, 2021

Reduced energy use and emissions	Cooling	Heating	Total
Carbon avoided (tons)	1,500	4,900	6,400
Energy effects (GJ)	39,000	186,000	225,000

Due to rounding, not all values will add up exactly.

To convert carbon estimates to carbon dioxide, multiply carbon value by 3.667.

GJ = gigajoule (one billion [10⁹] joules).

Table 22.—Annual monetary savings due to live and standing dead trees 5.0+ inches in diameter near residential buildings during heating and cooling seasons, city of Madison, 2021

Reduced energy use and emissions	Cooling (\$)	Heating (\$)	Total (\$)
Carbon avoided	296,000	942,000	1,240,000
Energy effects	1,590,000	1,640,000	3,230,000

Due to rounding, not all values will add up exactly.

Based on 2012 statewide energy costs (U.S. EIA 2012a, 2012b, 2014b, 2014c) and 2015 social cost of carbon (Interagency Working Group 2013, U.S. EIA 2015).

Carbon Storage and Sequestration

Climate change is an issue of global concern that threatens vulnerable species and ecosystems along with food production, water resources, and human health (Intergovernmental Panel on Climate Change 2014). Reductions in the amount of energy required to heat or cool residential buildings described in the energy conservation section of this report lead to reduced CO₂ emissions from fossil-fuel based power sources (Abdollahi et al. 2000). Trees can also help mitigate climate change by annually sequestering atmospheric carbon (in the form of CO₂) and storing carbon in their accumulated tissue (i.e., biomass). Although FIA volume and biomass models use species specific calculations, it is generally accepted that approximately half of the biomass in a tree is carbon (Westfall et al. 2024).

Carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose or are consumed in a fire event. Although tree maintenance practices (e.g., pruning) can contribute to carbon emissions, maintaining healthy trees helps to retain carbon stored in trees (Nowak et al. 2002b). Using removed trees for wood products is one way to help forestall carbon emissions related to wood decomposition. Wood from removed trees can also be used to produce energy (e.g., heat or cool buildings), helping to reduce fossil fuel-based carbon emissions. Trees in Madison store an estimated 420,000 tons of carbon (1.5 million tons of CO₂) valued at \$71.6 million (Table 23). Tree carbon values are based on the 2015 estimated social costs of carbon (\$170.60 per ton of carbon, Interagency Working Group on Social Cost of Carbon 2013, Intergovernmental Panel on Climate Change 2014). The social cost of carbon is a monetary value that encompasses the economic impact of increased carbon emissions on factors such as agricultural productivity, human health, and property damage. Carbon storage varies across the city (Fig. 16), among land uses, and by species. The species that store the most carbon are silver maple, white oak, and honeylocust (Fig. 17).

Table 23.—Aboveground and belowground carbon in live and standing dead trees by Forest Inventory and Analysis (FIA) land use class, city of Madison, 2021

FIA land use class	Aboveground in live trees (tons C)	Belowground in live trees (tons C)	Total in standing dead trees (tons C)	Total (tons C)	Standard error (tons C)
Forest land	132,000	22,000	9,500	164,000	40,000
Residential	134,000	18,000	1,400	153,000	40,000
Rights-of-way	55,000	8,600	130	63,000	14,000
Recreation/cemetery	16,000	2,500	29	18,000	7,300
Commercial/industrial	11,000	1,900	0	13,000	7,700
Multi-family residential	6,200	1,000	200	7,500	5,000
Agriculture	340	48	0	390	370
Natural lands	250	67	56	370	280
Total	354,000	55,000	11,000	420,000	–
Standard error	47,000	7,300	3,500	55,000	–

Due to rounding, not all values will add up exactly.

– = no value for cell.

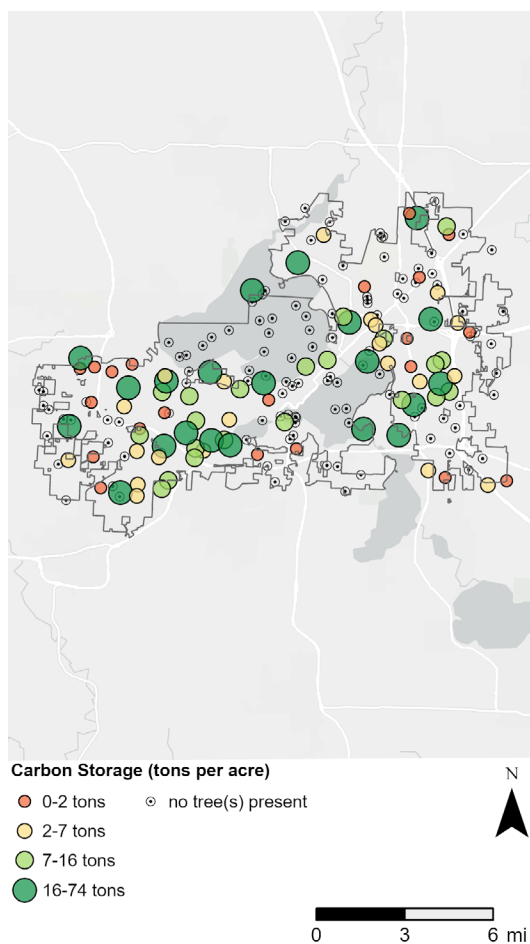


Figure 16.—Carbon storage per acre is shown for each Forest Inventory and Analysis (FIA) plot using approximate plot locations, city of Madison, 2021. The Light Gray Canvas basemap layer was provided by Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

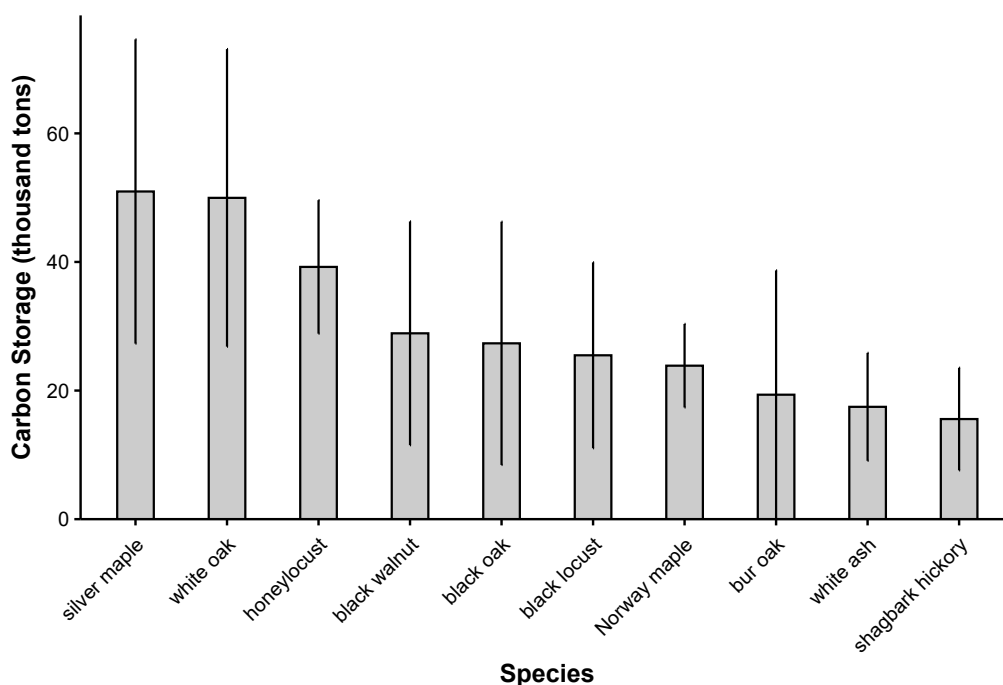


Figure 17.—Live and dead carbon storage for the 10 tree species with the greatest carbon storage, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

Figures 18 and 19 show the distribution of carbon storage and sequestration in trees by diameter class both as a proportion of the total amount of carbon stored and on a per tree basis.

In addition to carbon storage, which accounts for past carbon sequestration, healthy trees continue to annually sequester carbon in new tissue growth. Gross sequestration by urban trees in Madison is about 11,100 tons of carbon per year (41,000 tons per year of CO₂) with an associated value of \$1.9 million per year, which is roughly equivalent to the annual emissions associated with 8,000 passenger vehicles or energy usage by 4,400 homes (U.S. EPA 2020). Honeylocust is estimated to sequester the most carbon of all species in the urban forest (8.3 percent of all sequestered carbon) (Fig. 20).

Estimates of carbon storage and sequestration in developed and undeveloped land uses, along with evaluations of tree growth, removals, and mortality by ownership, can aid in assessing impacts of proposed land use changes and in developing climate change strategies and targets.

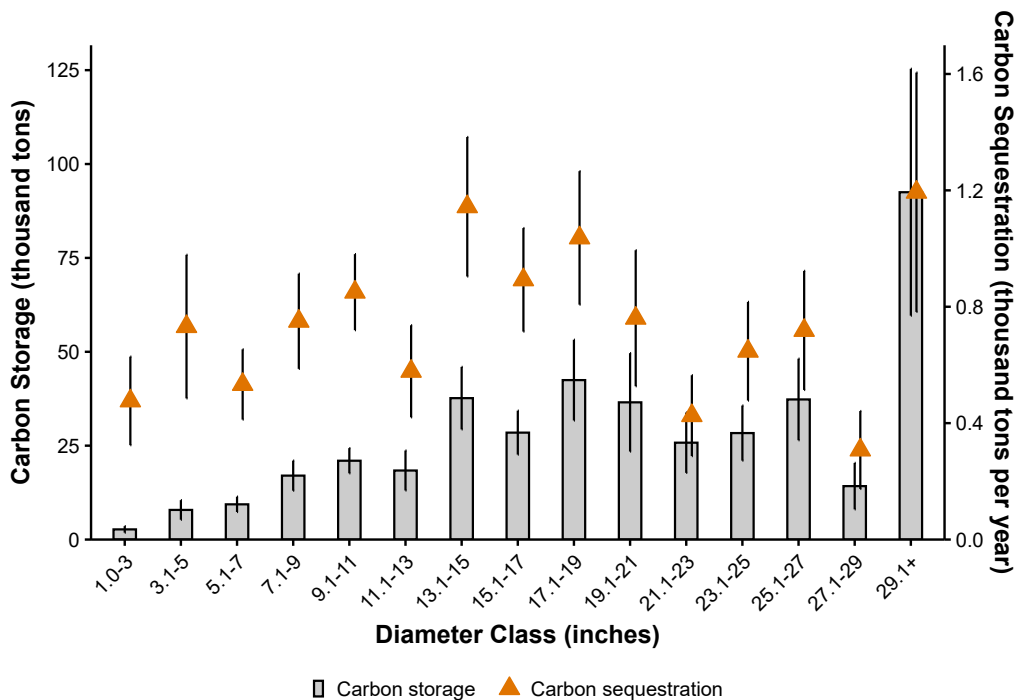


Figure 18.—Total live and dead carbon storage and sequestration by diameter class, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

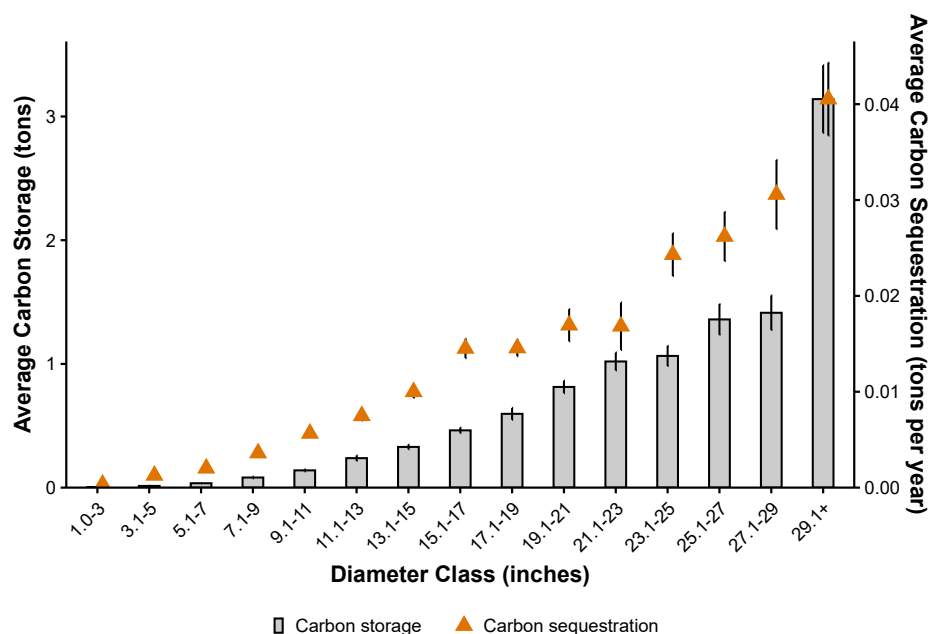


Figure 19.—Average per tree live and dead carbon storage and sequestration by diameter class, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

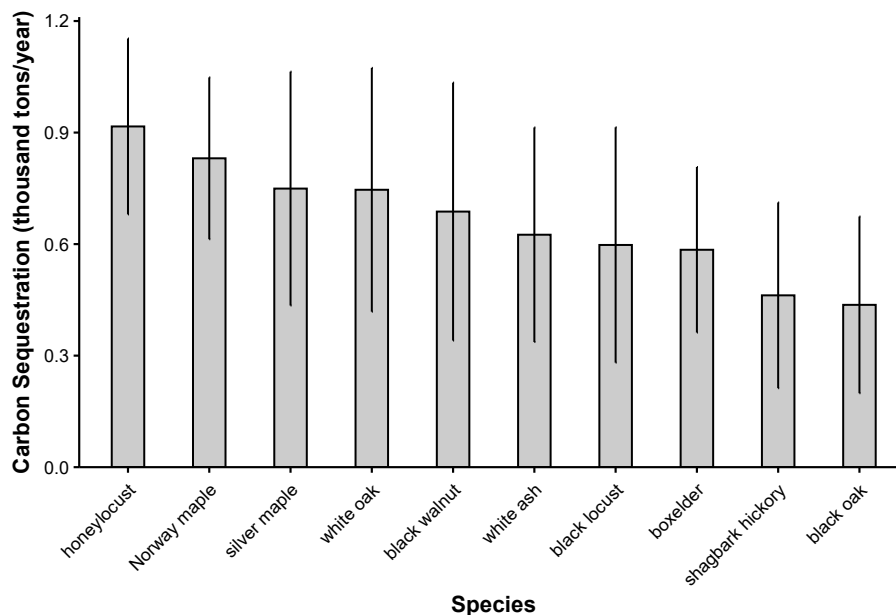


Figure 20.—Carbon sequestration for the 10 tree species with the greatest annual carbon sequestration, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated values.

Structural Values

The city's forest has a structural value that includes the compensatory value and carbon storage value of each tree. The compensatory value is an estimate of the value of the tree as a structural asset, which tends to increase with the size and health of the tree. For small trees, a replacement cost can be used; for larger trees, appraisal procedures are used (Council of Tree and Landscape Appraisers 2000, Nowak et al. 2002a). This appraisal is an estimate based on tree species, diameter, condition and location, and does not include many personal, social, functional or future values that may be ascribed to a tree (Nowak and Aevermann 2019). Note that **invasive** tree species have compensatory values because the methods used to estimate compensatory value do not account for whether the species is native, nonnative, or invasive. Additionally, invasive species can contribute some ecosystem services.

The compensatory value of the trees in Madison is estimated to be about \$1.33 billion. This compensatory value is a function of the number, health, diameter, and species of all trees measured, as well as the land use in which they were encountered. The species with the largest compensatory values in Madison are Norway maple, honeylocust, and bur oak (Fig. 21). The mean compensatory value per acre for all surveyed plots in Madison is \$20,280. For the 42.2 percent of these plots that contain trees, the mean compensatory value per acre is \$48,000 (Fig. 22). The structural value of urban trees in Madison is a combination of their compensatory value (estimated at \$1.33 billion) and the value associated with carbon storage by the trees (estimated at \$71.7 million).

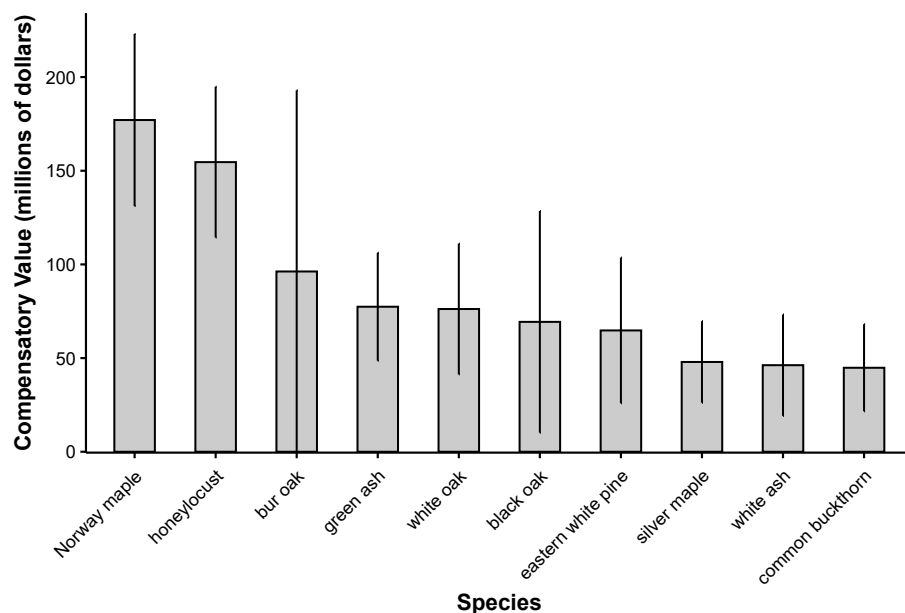


Figure 21.—The 10 tree species with the greatest compensatory value, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated values.

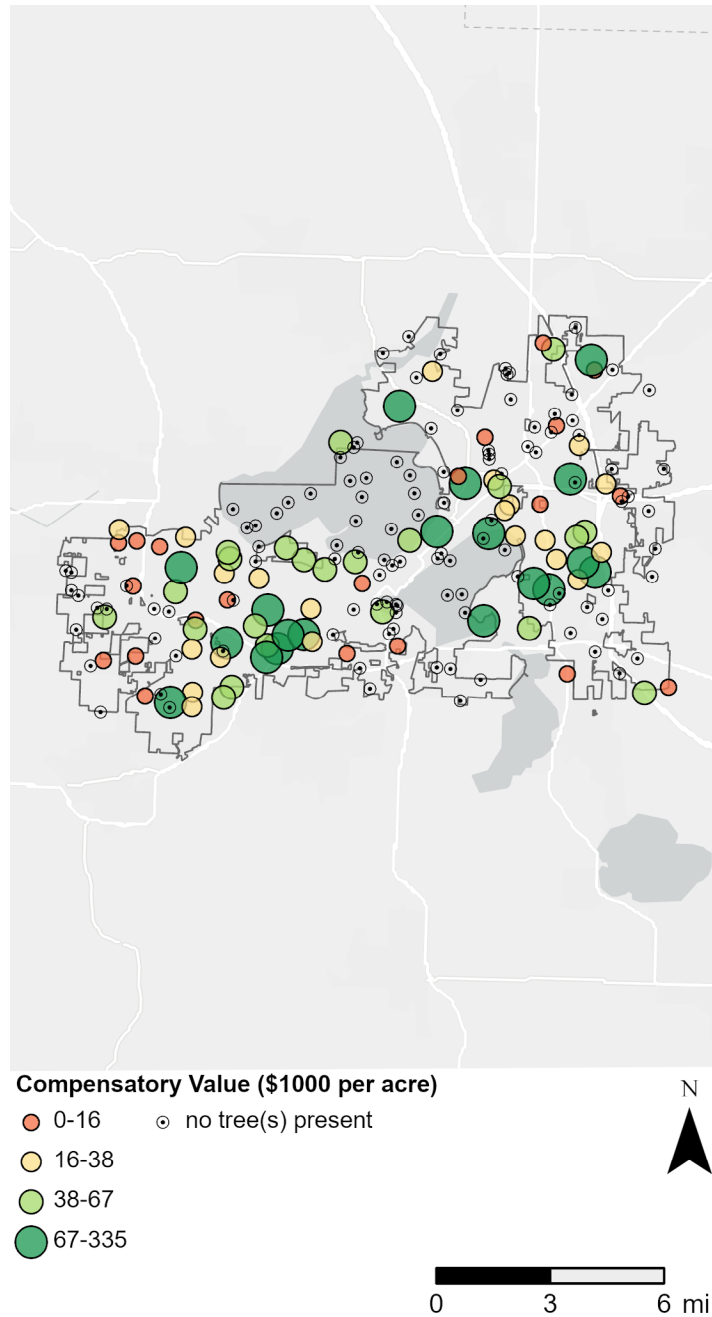


Figure 22.—Compensatory value per acre for each Forest Inventory and Analysis (FIA) plot using approximate plot locations, city of Madison, 2021. The Light Gray Canvas basemap layer was provided by Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community..

URBAN FOREST HEALTH



It can be a challenging life for an urban tree, such as this cottonwood. Courtesy photo by Brian Wahl, Wisconsin Department of Natural Resources.

A healthy urban forest provides greater benefits to society than an unhealthy one. This section highlights crown dieback, tree damage and rot, the number of standing dead trees, and the presence and prevalence of invasive plant species as indicators of urban forest health in Madison. Detailed methods of invasive species as indicators of urban forest health metrics are presented in the Urban FIA NRS Field Guide Version 7.1 (USDA Forest Service 2017).

Crown Dieback and Bole Rot

Tree crown condition 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. Crown dieback is one of the initial indications that a tree may be in a state of decline. Crown dieback is measured as a percentage of the crown volume with recent mortality of small fine branches and twigs in the upper and



outer portion of the tree's crown. Trees with more than 25 percent crown dieback may be in decline (Steinman 2000). High levels of dieback may indicate an insect, disease, or environmental problem associated with a particular tree, tree species, or group of trees. Of the tree species that have a minimum sample size of 10 trees and show evidence of dieback, green ash has the highest average dieback (11.6 percent) (Table 24). Additionally, approximately 9.1 percent of white ash display greater than 25 percent crown dieback, indicating that ash trees may have already been suffering from the emerald ash borer.

In addition to crown dieback, the amount of rot present in the trunk of a tree may indicate tree health issues and serve as a predictor of potential hazardous trees in urban areas. The percent of the main stem that is **rotten or cull** between 1 foot above the ground and approximately 4.0-inch top diameter outside of bark was recorded for all trees at least 5.0 inches in diameter. Of species with a minimum sample size of 10 trees, the species with the highest average rotten/cull amounts are hawthorn spp. and white oak (Table 25).

Table 24.—The 10 tree species with the greatest average dieback, city of Madison, 2021

Common name	Average dieback (percent)	Standard error (percent)	Trees with more than 25% dieback (percent)
green ash	11.6	4.5	8.8
white ash	10.7	6.7	9.1
black locust	5.4	1.6	0.0
hawthorn spp.	5.2	2.0	0.0
American elm	4.3	2.6	0.0
Siberian elm	3.3	1.1	0.0
Norway maple	3.2	1.2	0.0
white oak	2.3	0.6	0.0
silver maple	1.9	0.5	0.0
boxelder	1.5	0.4	0.3

Estimates are rounded.

Only species with minimum sample size of 10 live trees are included in this analysis to minimize effect of small sample size on percentage estimates.

Table 25.—The 10 tree species species with the greatest average rot, city of Madison, 2021

Common name	Average rot (percent)	Standard error (percent)	Trees with more than 15% rot (percent)
hawthorn spp.	4.3	0.6	0.8
white oak	2.5	1.8	2.1
apple spp.	2.5	1.1	0.4
green ash	2.4	1.5	1.9
boxelder	2.3	0.7	0.4
silver maple	2.3	0.7	0.0
black locust	1.6	0.4	0.0
Norway maple	1.2	0.4	0.0
black cherry	1.0	0.3	0.0
bur oak	0.6	0.4	0.0

Estimates are rounded.

Only species with minimum sample size of 10 live trees are included in this analysis to minimize effect of small sample size on percentage estimates.

Rot is only measured on trees 5.0+ inches in diameter.

Tree Damage and Potential Infrastructure Issues

Urban trees are susceptible to a wide range of insect, disease, and abiotic (e.g., soil compaction) damage agents that may affect tree survival, growth, and wood quality. Many damage agents are host specific and their impacts may vary by regional and local growing conditions. Live trees greater than 1.0-inch in diameter were examined for indications of several damage agents. Up to three damage agents were recorded per tree; each recorded agent was required to meet a minimum severity threshold (e.g., 20 percent of the foliage affected). If more than three damage agents were observed on a tree, the top three were prioritized according to their ability to: (1) prevent the tree from surviving more than 1–2 years, (2) reduce the tree’s growth in the near term, and (3) negatively affect a tree’s marketable wood products. The full list of potential damage agents is presented in the Urban FIA NRS Field Guide Version 7.1 (USDA Forest Service 2017). Stem decay and vine damage are the most common causes of damage, affecting 15.1 and 6.2 percent of trees, respectively (Table 26).

Table 26.—Percentage of trees with observed damage, by damage type, city of Madison, 2021

Damage type	Trees (percent)
Bark beetles	0.1
Black knot of cherry	0.2
Boring insects	1.5
Cankers	2.8
Defoliators	0.2
Dutch elm disease	0.8
Emerald ash borer	2.9
Foliage diseases	0.3
General insects	0.4
Human activities	2.4
Hypoxyton canker of aspen	0.1
Imbedded objects	1.9
Nectria canker	0.2
Shoot borer	0.1
Spongy moth	0.5
Stem decay	15.1
Vine damage	6.2
Wild animals	1.4
Other damages and symptoms	
Broken top	0.5
Dead top	1.2
Dieback	0.9
Foliage discoloration	0.1
Other damages and symptoms	5.0

Estimates are rounded.

In addition to damage agents, each live tree greater than 1.0-inch in diameter was evaluated for the presence of the following infrastructure issues that affect urban trees:

- bark inclusion,
- conflict with crown,
- conflict with roots
- excessive mulch
- improper planting
- root/stem girdling, and,
- topping/pruning

Bark inclusion is the most common issue, occurring in 20.4 percent of trees. Conflict with crown and topping/pruning are the second and third most common urban specific infrastructure issues, occurring in 3.7 and 1.0 percent of trees, respectively (Fig. 23).

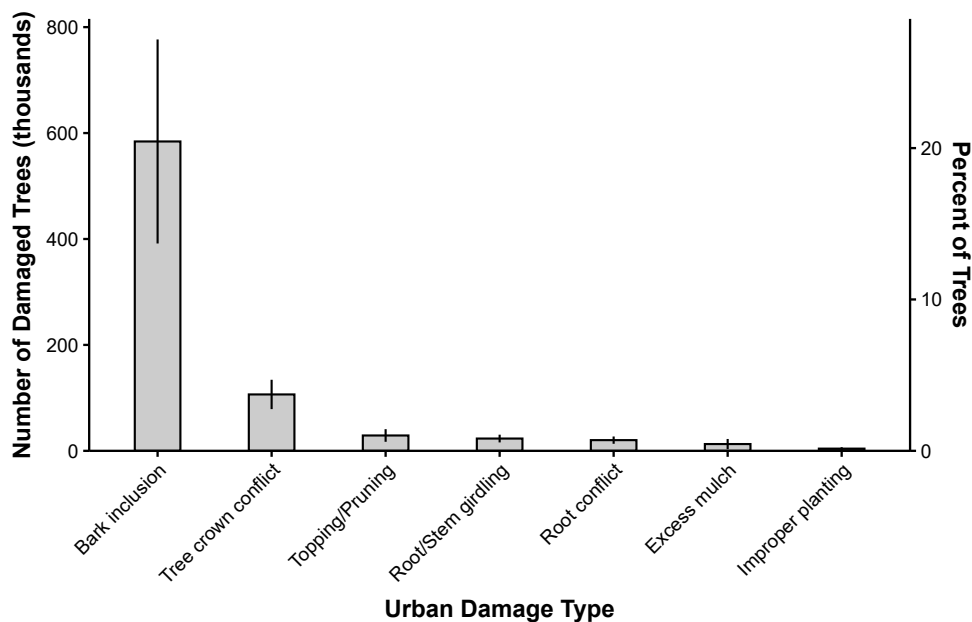


Figure 23.—Number and percentage of trees by urban infrastructure issue category, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

Differences exist in the prevalence of these issues among the FIA-designated land uses and may further inform forest health and management priorities. In Madison, bark inclusion occurs in 63.7 percent of trees on multi-family residential land, bark inclusion in 40.0 percent of trees on rights-of-way land, and bark inclusion in 36.0 percent of trees on recreation/cemetery land.

Of species with a minimum sample size of 10 trees, the species with the greatest proportion of their population affected by urban-specific damages are Siberian elm (61.9 percent affected by bark inclusion) and Norway maple (41.8 percent affected by bark inclusion) (Table 27).

Table 27.—Percentage of trees identified with damage, maintenance, and site issues, city of Madison, 2021

Common name	Number of trees	Standard error	Bark inclusion (percent)	Crown conflict (percent)	Excess mulch (percent)	Improper planting (percent)	Root conflict (percent)	Root/stem girdling (percent)	Topping/pruning (percent)
American elm	68,200	46,600	14.0	0.0	0.0	0.0	3.0	0.0	0.0
apple spp.	74,700	47,000	30.7	7.6	12.0	0.0	0.0	0.0	0.0
black cherry	99,400	52,500	6.1	0.0	0.0	0.0	0.0	0.0	0.0
black locust	105,900	51,800	16.9	0.0	0.0	0.0	0.0	0.0	0.0
black oak	24,000	12,800	0.0	0.0	0.0	0.0	0.0	0.0	0.0
black walnut	81,100	41,400	5.8	0.0	0.0	0.0	0.0	0.0	0.0
boxelder	272,600	153,100	26.5	0.0	0.0	0.0	0.0	0.7	0.0
bur oak	33,800	24,700	20.6	0.0	0.0	0.0	0.0	0.0	0.0
common buckthorn	870,700	400,500	23.2	0.4	0.0	0.0	0.0	0.0	0.0
eastern white pine	18,800	10,000	0.0	0.0	0.0	0.0	0.0	11.1	0.0
green ash	45,000	12,600	19.8	13.3	0.0	0.0	9.3	7.9	4.0
hawthorn spp.	58,500	36,300	20.8	0.0	0.0	0.0	0.0	0.0	0.0
honeylocust	43,700	12,400	14.3	29.9	4.8	0.0	4.8	4.8	12.3
northern white-cedar	99,500	42,600	33.2	20.9	0.0	0.0	0.0	0.0	0.0
Norway maple	56,200	12,700	41.8	34.5	0.0	7.0	14.8	21.2	3.2
shagbark hickory	40,500	22,800	12.6	0.0	0.0	0.0	0.0	0.0	0.0
Siberian elm	92,000	62,800	61.9	0.0	0.0	0.0	0.0	0.0	0.0
silver maple	26,000	12,900	28.1	22.7	0.0	0.0	0.0	0.0	9.8
white ash	230,700	106,500	0.0	0.8	0.0	0.0	0.0	0.0	0.8
white mulberry	24,600	14,300	25.4	25.4	0.0	0.0	0.0	0.0	0.0
white oak	30,200	13,200	0.0	5.8	0.0	0.0	0.0	0.0	0.0
white spruce	43,300	24,800	4.0	4.0	0.0	0.0	0.0	4.2	12.5

Estimates are rounded.

Only species with minimum sample size of 10 live trees are included in this analysis to minimize effect of small sample size on percentage estimates.

Standing dead

The number of standing dead trees serves as another measure of urban forest health and can be useful data for management planning. The extent to which a standing dead tree poses a threat to humans or infrastructure depends on the location of the tree. Standing dead trees in maintained areas where human activity is likely high, such as residential and institutional land uses or transportation corridors, will generally be considered hazardous trees and prioritized for removal. Conversely, standing dead trees in patches of forest away from heavy human use are of minimal risk but beneficial for wildlife habitat and their removal may be deemed undesirable. Because of the variability of removal rates among land use classes, caution is advised when interpreting forest health issues based on numbers of standing dead trees.

Standing dead trees are found on 16 plots in Madison. Of the total live and dead tree population, 8.0 percent are estimated to be standing dead trees. The tree species with the highest percentage of standing dead trees are Japanese tree lilac, black willow, and shagbark hickory (Table 28). The dead tree population is comprised mostly of black locust. (Table 29). Land uses with the highest estimated number of standing dead trees are forest land, residential, and multi-family residential (Fig. 24). The majority of standing dead trees are observed on unmaintained land in forest land uses.

Table 28.—Number of trees classified as standing dead by species, city of Madison, 2021

Common name	Standing dead trees (number)	Standard error (number)	Percent of species
Japanese tree lilac	26,000	25,000	92.6
black willow	2,600	2,200	50.0
shagbark hickory	27,000	23,000	39.9
black locust	69,000	40,000	39.4
white oak	11,000	5,500	27.6
apple spp.	26,000	25,000	25.9
American elm	19,000	12,000	21.6
sugar maple	1,700	1,800	20.0
red maple	1,700	1,800	16.9
Amur maple	1,700	1,800	11.1
boxelder	24,000	23,000	8.2
green ash	3,500	3,700	7.2
bur oak	1,700	1,800	4.9
black cherry	5,100	3,000	4.9
hawthorn spp.	2,100	2,000	3.4
Siberian elm	2,600	2,200	2.7
common buckthorn	22,000	23,000	2.4
white ash	2,600	2,200	1.1
Total	250,000	71,000	8.0

Due to rounding, not all values will add up exactly.

Table 29.—Proportion of the total population of trees that are standing dead by species, city of Madison, 2021

Common name	Standing dead trees (percent)	Common name	Standing dead trees (percent)
black locust	27.5	white ash	1.0
shagbark hickory	10.8	black willow	1.0
apple spp.	10.4	Siberian elm	1.0
Japanese tree lilac	10.4	hawthorn spp.	0.8
boxelder	9.8	red maple	0.7
common buckthorn	8.7	sugar maple	0.7
American elm	7.5	bur oak	0.7
white oak	4.6	Amur maple	0.7
black cherry	2.0	Total	100.0
green ash	1.4	Due to rounding, not all values will add up exactly.	

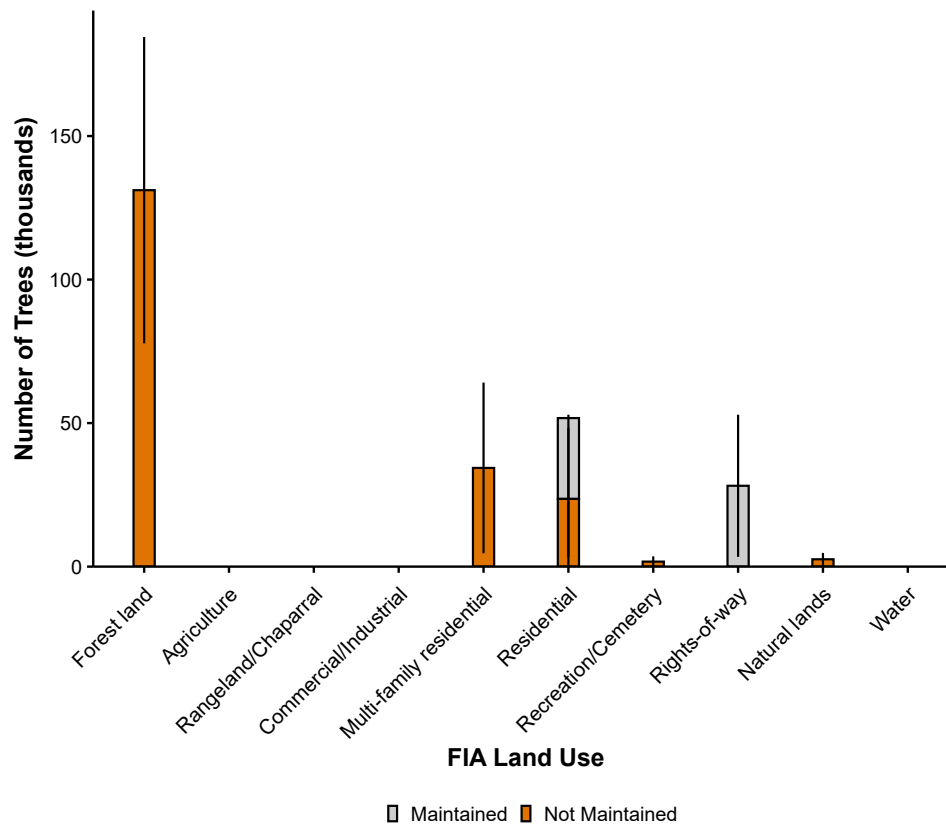


Figure 24.—Number of standing dead trees by Forest Inventory and Analysis (FIA) land use class on maintained and unmaintained land, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

Invasive Plant Species

Invasive plant species are often noted for their vigor, ability to adapt to novel environments, high reproduction capacity, and lack of natural enemies. These factors may enable them to displace native plants and threaten natural areas (Davis 2009, Simberloff 2013). Important considerations for invasive plant control efforts include weighing short- and long-term trade-offs in terms of ecosystem services provided or disrupted by invasive species. The removal of invasive species and loss of ecosystem services they provide may lead to a subsequent need to increase the abundance of desirable species to offset these losses. Field crews in Madison examined each plot for the presence of select invasive species based on the species list shown in Appendix 5. Of the 199 plots examined, invasive plant species were identified on 43.2 percent (86 plots).

Invasive species found in Madison are presented in Figure 25. Beyond noting simple presence or absence, crews noted the percentage of the plot area covered by the invasive species, allowing for the estimation of total area covered by each species within the city (Bechtold and Scott 2005). These estimated areas may offer insights into which species are having the greatest impact in the city. Of the invasive species recorded, common buckthorn (1,676 acres; 2.8 percent of the sampling area), Norway maple⁶ (1,561 acres; 2.6 percent of the sampling area), and reed canarygrass (1,184 acres; 2.0 percent of the sampling area) cover the largest area. Of particular concern is the potential for these and other invasive species to spread beyond their current distribution into the surrounding landscape, potentially displacing native species and altering local ecosystems (Pimentel et al. 2000).

Additional measurements are recorded in the field for most tree species. As some of the species on the invasive plants list for Madison are classified as trees, data on individual trees were collected in addition to descriptions of species cover on the plot. In Madison, tree data were collected for black locust, common buckthorn, Norway maple, and Siberian elm. Taken together, these invasive trees are estimated to account for 39.4 percent of all live trees surveyed (estimated total live trees: 1.1 million), and 16.7 percent of the total leaf area.

⁶ Norway maple is not listed as a regulated invasive species by the State of Wisconsin (WDNR 2024a).

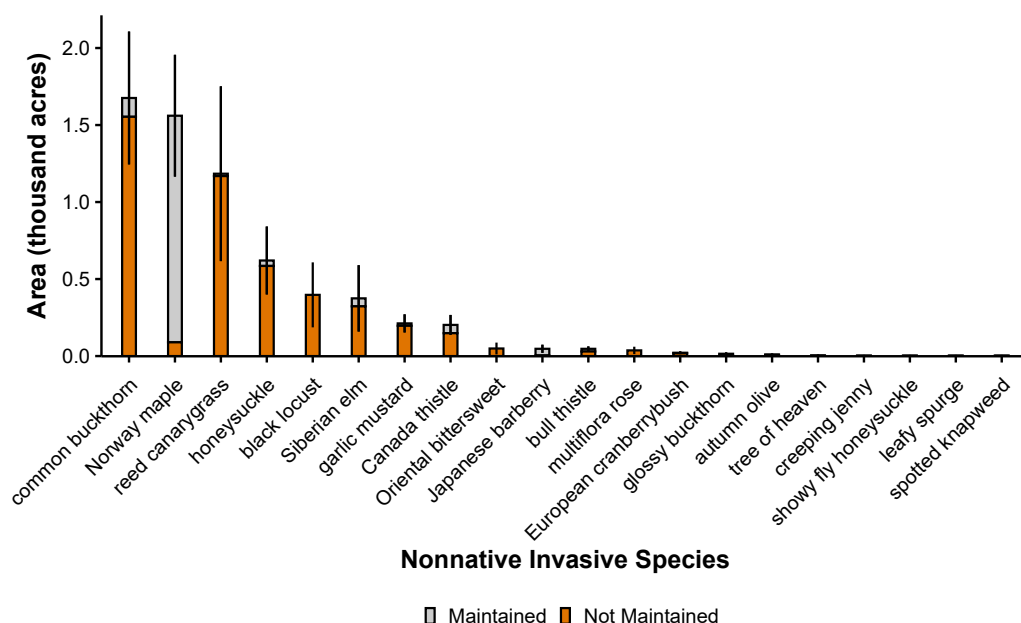


Figure 25.—Acres of nonnative invasive cover by species on maintained and unmaintained land, city of Madison, 2021. Error bars represent 68 percent confidence intervals around the estimated means.

Pests and Pathogens

Pathogens and insect pests can affect the health, sustainability, and benefits of urban forests. Identifying pathogens and pests⁷ of concern and their potential host-specific impacts allows managers to prioritize specific insects and diseases for monitoring and control measures. Using an i-Tree Eco analysis of the effects of 53 potential insects and diseases (Nowak 2024), we evaluated the data to quantify the possible impact on the Madison urban forest based on the number of host tree species and pest or pathogen proximity. Pest range maps (Nowak 2024, USDA Forest Service 2023; were used to determine the proximity of each pest and disease to Dane county. Of those pests and pathogens already present in Madison, spongy moth puts the most trees at risk (593,000), followed by emerald ash borer (276,000), Dutch elm disease (160,000), and oak wilt (118,000). As FIA crews did not attribute tree damage or mortality to specific pests or pathogens, it was not possible to identify what portion of each host tree's population is currently impacted by these pests and pathogens.

⁷ Common and scientific names for pests and pathogens evaluated for the 2021 Urban FIA inventory of Madison are in Appendix 6.

MANAGEMENT IMPLICATIONS



An arborist pauses to assess his next move atop a honeylocust tree in a Madison yard. Courtesy photo by Eric Tadsen, Tadsen Photography.

Urban trees are important and dynamic parts of Madison's character and its infrastructure. After sites are revisited, data from this project can help identify trends in the urban forest, and managers can better determine appropriate interventions or strategies. Though at this stage these data offer a “snapshot” in time; insights and implications can be gleaned for the future of Madison's trees. Some of these management implications include:

- The abundance of maple trees exposes the urban forest to risk.
- The high numbers of common buckthorn, particularly on forest land and other unmaintained spaces, present a challenge to regeneration of desired species.
- A focus on preserving large trees could help maintain the outsized benefits that they provide to communities.



Species Diversity

An increasingly important consideration in urban forestry is species diversity. Forests with more species variety and greater species evenness are more resilient to future disturbances, whether storms, pests, or climate change. Some planting rules are generally encouraged in the urban forestry world as ideals for public, maintained trees, such as those along streets or in high-use areas of parks. For example, the “30-20-10” planting rule or the Wisconsin Department of Natural Resource’s more aggressive “20-10-5” rule provide guidelines for how much of a managed tree population should be composed of any individual family, genus or species, respectively (Kendal et al. 2014, WDNR 2016). These were created to discourage dependence on a few types of trees in order to avoid catastrophic losses like those seen with Dutch elm disease and emerald ash borer. While there are no widely accepted diversity rules for the entire urban forest, assessing species diversity is an important way to project future problems.

While common buckthorn has the highest number of stems in the 2021 Urban FIA inventory of Madison, its small stature means that it does not currently dominate the urban canopy. However, this could change as larger, overstory trees die. The population of trees at least 5.0 inches in diameter typically provide much more canopy, and this assemblage is highly represented by the ash and maple genera (Appendix 2).

Unfortunately, observers throughout Madison may note that most untreated ash trees are now dead or dying. This development, due to emerald ash borer, is only hinted at in these data collected from 2015 through 2021. While only 5 percent of the ash trees at least 5.0 inches in diameter in Madison were dead when these plots were first established in the 2021 Urban FIA inventory, it is anticipated that those numbers will near 100 percent over the next decade. Indeed, in nearby Milwaukee, where emerald ash borer has been present longer, 60 percent of its ash trees were dead when Urban FIA plots were established over the same time period (Buckler et al. 2026).

As much as the city’s ash trees have been devastated by the emerald ash borer, the potential impact to Madison’s urban forest is greater should the maple genus be threatened by a serious pest or pathogen. There are high numbers of maple trees (including boxelder) across all ownerships (2 of the 10 most numerous species on both public and private lands) and size classes (1 of the 5 most numerous species in each size class). For trees at least 5.0 inches in diameter, maple makes up 20.6 percent. A 2012 i-Tree Eco study of the greater Madison urban area (as opposed to the city boundaries) also found that maples made up 21.2 percent of the area’s trees, finding also in a survey that almost 18 percent of the trees planted by industry professionals were maples (Slocum 2012).

For additional context, 28 percent of trees in Milwaukee (Buckler et al. 2026) at least 5.0 inches are maple, 25 percent in Minneapolis (Schanning et al. 2026), 33 percent in Chicago (Schanning et al. 2025), and 18 percent in Des Moines (Goff et al. 2026). Maple also represents 22.3 percent of Madison's street trees (WDNR 2024).

Though not radically different from other midwestern cities, this abundance of maple trees is noteworthy. Although no serious threats are currently detected, given these data, the future use of maples in planting regimes should be carefully considered. As Slocum noted in 2012, even though the species assemblage was shifting between what was historically versus currently planted, the trends remained similar, including the high percentage of maple. Maintaining the existing trees and the benefits they provide is critical, while also planning and planting for a more diverse future population.

As the planting of other species expands, close tracking and monitoring will allow managers to assess their success and potential in Madison, especially non-traditional, marginally hardy, and experimental species. For example, the City of Madison continues to experiment with new species and cultivars such as sweetgum (*Liquidambar styraciflua*), yellow poplar (*Liriodendron tulipifera*), and dawn redwood (*Metasequoia glyptostroboides*) to improve the long-term sustainability of the urban forest.

Planting

Recruitment of new trees into the urban forest can result from both natural regeneration and intentional planting. Every tree measured on Urban FIA plots is assigned a code to indicate whether it was planted, is natural regeneration, or whether the origin is unknown⁸. Since the number and size distribution of planted trees reflect intentional human effort toward development of the urban forest, close attention to these tree populations can provide information about how local interest, education, policy, and funding impact planting efforts over time.

Across all land uses including forest land and nonforest land, 78 percent of Madison's trees are naturally occurring, with 39 percent of those accounted for by sapling buckthorn. On Madison's nonforest land, planted trees account for 39 percent of the trees present. On private land, northern white cedar and white spruce are the most common planted species, accounting for 39 percent of the 330,000 planted trees. The most common of the planted species on public lands are apple species, Norway maple and honeylocust, which together make up 53 percent of the 235,000 planted trees. The survey results of the earlier study of the Madison urban area pointed to white cedar, white spruce, apple, and honeylocust being among the top 20 most commonly planted trees at that time, indicating that those species would continue to play a major role in the area (Slocum 2012).

⁸ In 2015 trees in forested areas were not evaluated for their planting status. In this report we have included those trees in the natural regeneration category.

Across public and private ownership, the size distribution of planted trees is evenly split with 33 percent saplings, 35 percent 5.0 to 11.0-inch diameter trees and 32 percent trees with diameters 11.0 inches or greater. Of the larger planted trees Norway maple and honeylocust represent 50 percent of the estimated population across all ownerships and account for 64 percent of all large, planted trees on public land.

As city foresters and local organizations work to manage and build the Madison urban forest, it will be useful to understand how the preferences and practices of private landowners differ from those of public land managers. City foresters looking to diversify the tree canopy will benefit from a clear understanding of what species are already heavily planted on private lands. Efforts aimed at increasing tree planting on private lands can take into consideration what species have been most popular. Providing outreach materials which recommend alternative species, while highlighting similar growth patterns or benefits to those more well known, popular species may encourage landowners to move beyond the species with which they are most familiar.

Buckthorn and Tomorrow's Urban Forest

While bigger trees loom larger in our collective impression of the urban forest, the invasive common buckthorn dominates the 1.0 to 5 inch size class (Table 12). It also has, by far, the most seedlings estimated in this study (11.1 million of the 25.3 million estimated total).

Because of its sheer quantity and its competitive advantages (e.g., it holds its leaves longer than native species and colonizes land rapidly), the invasive common buckthorn threatens the regeneration of desired species and puts the ecological function of some areas in jeopardy, especially forest land. While common buckthorn is present in significant numbers across multiple land uses, almost 40 percent of it is on forest land, a land use which only occupies 6.3 percent of the city's area, and 7.6 percent of its non-water area. Additionally, of the 1,676 acres of buckthorn coverage in Madison, 93 percent of it is in unmaintained areas. It is areas like these, and the native species within them, that are most threatened. Large proportions of the city's populations of trees like white oak, shagbark hickory, and sugar maple are in forest land.

Despite ongoing management efforts, buckthorn is not going to be eliminated. However, without continued additional efforts, buckthorn may threaten the regeneration of uncommon native trees in the remaining natural areas in Madison.

Pests and Pathogen Impacts

The introductions of Dutch elm disease and emerald ash borer have made the urban forestry community, and many others, painfully aware of the cultural and ecological trauma that pests and pathogens can wreak. Given the ongoing issues with species diversity, future insects or diseases invading Madison have the potential to cause massive amounts of damage.

Although 11 insects and diseases were noted as present in Dane County (of the 53 assessed) (Appendix 6), not all of the species are equally damaging. For example, emerald ash borer is a devastating insect, while pine shoot beetle is mostly a pest of current or abandoned Christmas tree farms. Spongy moth can be a significant damage agent periodically, while Dutch elm disease continues to impact untreated elm trees.

Of those other damage agents within the county, oak wilt is present and is always a concern, however, it should be manageable with the right protocols (e.g., oak pruning moratoriums). Other listed pests and diseases currently in Dane County could cause local damage or mortality on low vigor trees but are not expected to be major damage agents. Two wood boring insects not included in the i-Tree Eco analysis are also present in Madison: two-lined chestnut borer (*Agrilus bilineatus*; attacks oak trees) and bronze birch borer (*A. anxius*; attacks birch trees). These pests have the potential to cause damage when trees are already stressed by drought, construction, disease or other problems.

With a globalized economy and changing climate, new pests and diseases can be introduced and spread rapidly. An urban forest that is diversified across public and private lands will be more resilient against the potential damages of these pests and pathogens.

Other Forest Health Concerns

As noted above, it is anticipated that most ash trees across Madison will be dead or dying upon plot revisitation. Indeed, green and white ash were already the only species to have average dieback above 10 percent, with 9 percent of each species having more than 25 percent dieback. Only 27 percent of the city's standing dead trees were at least 5.0 inches in diameter, a size which could pose more risk to public health and infrastructure (though that number is rapidly increasing with the death of thousands of mature ash trees). American elm has the most standing dead trees at least 5.0 inches, and 48 percent of the species population at that size was dead. That is not altogether surprising with the ongoing presence of Dutch elm disease, a scourge of larger elm trees in particular. More concerning are the estimated 11,000 dead white oak trees at least 5.0 inches in diameter, a number that represents a quarter of all white oaks. However, there is significant statistical uncertainty with the number of dead trees of any species.

Maximizing Benefits

When considering benefits of trees assessed in the i-Tree protocol, bigger is almost always better. Larger diameter trees tend to have more volume, greater heights, wider canopies, and more leaf area. These all play a role in producing societal and ecological benefits. Among the trees with the highest carbon storage are silver maple, white oak, and honeylocust (Table 17, Figure 17). Despite not being in the top ten most common species in the city, these species play a significant role because many of them are larger. Protective measures and proactive maintenance can help ensure that these larger trees remain in the landscape.

A major reason why buckthorn is such a threat is that it could prevent the regeneration of species that play much greater ecological or functional roles. For example, despite having the most stems in the city, 25 other species store more carbon than buckthorn. When considering the carbon storage by crown area, 49 tree species (of the 52 tree species sampled in the 2021 inventory) store more carbon per acre of crown than buckthorn. Similarly, the leaf area coverage per acre of crown is much greater for other species. While buckthorn is estimated to have about 2 acres of leaf area for every acre of crown, some species have a leaf area to crown area ratio nearly five times that and 49 are larger than buckthorn. Leaf area is the dominant variable in ecosystem services such as air pollution removal and stormwater reduction so species that tend to have more of it play outsized roles in the benefits the urban forest provides.

Furthermore, forested areas play a significant role in carbon storage across the city. Though forest land is only 6.3 percent of the land area, 39 percent of the carbon stored in standing trees (living and dead) in Madison is in those spaces.

Although much of the discussion around trees' impact on energy savings has focused on the summer, Urban FIA results show that trees in Madison play a larger role reducing homes' energy footprint in the winter. This makes sense given how much longer people heat their homes through a year than cool them. Despite these modeled results, a study of Madison's canopy cover and energy usage showed tree presence associated with increased energy use (Erker and Townsend 2019). Further research would provide a better understanding of the interplay between trees and energy consumption.

One of the uses of Urban FIA data is to help project tree decline and mortality, which can be used to help predict availability of urban wood. Utilizing urban wood can redefine trees from waste products toward higher use products. Madison's urban tree removals generate significant biomass. Expanding urban wood utilization programs can provide economic and environmental benefits by repurposing removed trees for construction, furniture, or biomass energy. As plots are revisited, pairing tree health data and sawtimber volume could offer meaningful predictions of urban wood availability.

Land Use Opportunities

The commercial/industrial land use makes up 12.2 percent of Madison's land area but has tree cover percentage of 9.4, even lower than rights-of-way (Table 5, Table 8). Despite having a high amount of impervious surface in these areas, the large scale of commercial/industrial land creates a great opportunity for tree planting (Table 6).

Likewise, while it is no surprise that rights-of-way are predominantly covered by impervious surfaces, the low density of trees on this land use nonetheless suggests the potential for increased tree cover through improved streetscaping.

Ecological Role

The ecological role of trees is not significantly explored in this project, however they are of great importance. Forest land has significant shrub cover (71.3 percent tree canopy, 50 percent shrub/seedling cover) and thus has a fair amount of structural diversity that could support different wildlife species. While shrub species were not identified in this study, the fact that 46 percent of the seedlings in forest land were buckthorn, implies that much of the shrub/seedling understory could be buckthorn. However, 31.5 percent were sugar maple and 10.4 percent chokecherry. The percentage of shrub cover in forest land ranked far ahead of the next highest ranking land use, residential, which had a shrub cover of 4.7 percent (but with a robust 37.6 percent tree canopy cover). Though the relatively low shrub cover is expected in most developed spaces, it also presents an opportunity to introduce more shrubs and structural diversity across the city.

Plot data was processed through i-Tree Eco's Avian Habitat Suitability model, which produced a unitless value for eight different bird species indicating the suitability of habitat (Lerman et al. 2014). A score of 0, for example, indicated unsuitable habitat (i.e., the likelihood that a species is not present) while a score of 1 indicated that conditions likely exist to support the species. In addition to producing an overall suitability index value for the entire city (Table 30), the model was also applied to each NLCD land cover class (Appendix 1). Forest/shrub areas had the highest average score, and were likely to contain more favorable conditions, for five of the eight species (black-capped chickadee, northern cardinal, red-bellied woodpecker, scarlet tanager, and wood thrush). Baltimore oriole scored highest in lightly developed spaces due to its preference for large, well-spaced trees. Most land cover classes were equally accommodating to the American robin, befitting its reputation as an excellent generalist. The final species studied, the European starling, was more likely to be found in developed spaces.

Scarlet tanager and wood thrush had the lowest overall suitability score, due to their requirement for dense canopy and sensitivity to forest fragmentation. The supplementary material in Lerman et al. (2014) can provide insights into how habitat could be improved for individual bird species.

Table 30.—The overall suitability index values for eight bird species across all National Land Cover Database (NLCD) land cover classes using i-Tree Eco’s Avian Habitat Suitability model, city of Madison, 2021

Scientific name	Common name	Suitability index
<i>Turdus migratorius</i>	American robin	0.39
<i>Cardinalis cardinalis</i>	northern cardinal	0.18
<i>Icterus galbula</i>	Baltimore oriole	0.15
<i>Poecile atricapillus</i>	black-capped chickadee	0.15
<i>Melanerpes carolinus</i>	red-bellied woodpecker	0.10
<i>Sturnus vulgaris</i>	European starling	0.08
<i>Hylocichla mustelina</i>	wood thrush	0.04
<i>Piranga olivacea</i>	scarlet tanager	0.01

CONCLUSIONS



Lake Mendota is one of two lakes (along with Lake Monona) that squeezes the center of Madison into an isthmus. Courtesy photo by Eric Tadsen, Tadsen Photography

Madison's urban forest contributes to the city's environmental, economic, and societal well-being. Throughout the city, an estimated 2.9 million trees, representing 52 species, provide an estimated tree canopy cover of 19.3 percent. These trees provide a wide range of important environmental benefits including air pollution removal, reduced carbon emissions, carbon storage and sequestration, reduced energy use for buildings, stormwater capture, and many others.

There are several forces that may impact Madison's forest structure, health, and the environmental benefits provided to the city's residents in the future. These include insect and disease infestations, aging and loss of larger trees, the expansion of invasive species, changes in the management and use of the forest, and growth of the human population.

This analysis provides a baseline for future monitoring. While data from this report capture attributes of the current urban forest resource and associated ecosystem services and values, future monitoring will identify how the forest is changing over time. The plots measured in Madison will be re-measured on a 7-year cycle as part of the continuing Urban FIA program. Future analyses of the city's forest can be used to determine the role that natural and human forces play in shaping forest structure and composition.

For now, managers can use the data in this report to inform long-term management plans and policies to sustain a healthy urban tree population and ecosystem services for future generations. Planning and management of the urban forest resource can help sustain vital ecosystem services and values for current and future generations in Madison. In the future, change analyses can be used to evaluate the success of urban forest management programs.

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GLOSSARY OF TERMS

Definitions

Board-foot: A unit of measure indicating the amount of wood contained in an unfinished board 1.0-foot wide, 1.0-foot long, and 1.0-inch thick.

Bark inclusion: Bark inclusions are a sign of weak branch unions and 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. Trees with a tendency to form upright branches, such as elm and maple, often produce weak branch unions (USDA Forest Service 2017).

Conflict with roots: Damage to infrastructure such as sidewalks, driveways, roads, or other hardscapes directly caused by roots. Tree roots grow under sidewalks and asphalt. They do this in many instances because that is where the soil oxygen and moisture are located. Conflicts with curbs, driveways, or roads are all considered conflicts with roots (USDA Forest Service 2017).

Conflict with tree crown: Conflict with tree crown occurs when tree branches, foliage, or bole are within 5 feet of utility wires of any type, including drop lines that extend from the main line to a building. Conflict with overhead wires can cause problems for both trees and wires, creating maintenance problems and hazard situations (USDA Forest Service 2017).

Diameter: For timber species, diameter is measured at breast height (d.b.h.), which is usually measured at 4.5 feet above the ground line on the uphill side of the tree. For woodland species, if the tree has multiple stems, the diameter of each is taken and combined to establish total diameter for the tree. Woodland diameters are measured at the ground line or at the stem(s) root collar (d.r.c.), whichever is higher. (USDA Forest Service 2017). Timber species are listed in Appendix 2. There were no woodland species sampled in the 2021 Urban FIA inventory of Madison.

Excessive mulch: Excessive mulch is defined as mulch piled high around the stem to a depth greater than 3 inches and covering the root flare at the base of the trunk. Over mulching of landscape plants, sometimes to the extent of creating mountainous mulch “volcanoes”, can result in disease or death of the tree. Mulch can take the form of many different materials and is not limited to wood chips (USDA Forest Service 2017).

Improper planting: Improper planting occurs when burlap, twine, or root ball wire not removed prior to planting, or when the tree root flare is buried (USDA Forest Service 2017).

Forest/forest land/forested area: Land that has at least 10 percent crown cover by live trees or land formerly having such tree cover and is not currently developed for a nonforest use. The minimum area for classification as forest land is 1 acre and less than 120 feet in width. Unimproved roads and trails, streams and other bodies of water, or natural clearings in forested areas shall be included within surrounding forest conditions, if less than 120 feet in width and 1.0 acre in size (<30 feet wide for streams and rivers). Forest land is divided into timberland, reserved forest land, and other forest land (such as woodland). (USDA Forest Service 2023a)

Invasive species: A non-native species whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Executive Order 13112, 1999). A list of invasive plant species used in this inventory protocol is presented in Table 35.

Rights-of-way: Developed lands including improved and/or maintained roads, railways, power or gas line clearings, and maintained canals. (USDA Forest Service 2017)

Rotten or cull: Missing or rotten main stem or large branch volume caused by agents including cankers, punky knots, hollow sounding stems, or embedded metal in the wood (USDA Forest Service 2023a; 2017).

Sapling: Live trees 1.0 to 4.9 inches (2.5-12.5 cm) in diameter (d.b.h./d.r.c.) (USDA Forest Service 2023a).

Sawtimber: A live tree of commercial species containing at least a 12-foot sawlog or two noncontiguous sawlogs 8.0 feet or longer and meeting regional specifications for freedom from defect. Softwoods must be at least 9.0 inches d.b.h. Hardwoods must be at least 11.0 inches d.b.h. (USDA Forest Service 2023a).

Sawtimber volume: Net volume of the sawlog portion of live sawtimber in board feet, International 1/4-inch Rule (unless specified otherwise), from stump to a minimum 7.0 inches top diameter outside bark for softwoods and a minimum 9.0 inches top diameter outside bark for hardwoods. (USDA Forest Service 2023a).

Seedlings: Live tree species smaller than 1.0- inch (2.5 cm) d.b.h./d.r.c. that are at least 6 inches (15.2 cm) in height for softwoods and 12-inches (30.5 cm) in height for hardwoods (USDA Forest Service 2023a).

Severe topping or poor pruning: A tree is considered to have been severely topped when it has been reduced to a single “pole” due to severe over pruning and branch removal. Topping is the cutting of branches to stubs, or, if 25 percent or more at the main stem has been cut to reduce tree height. Topping usually results in a profusion of shoots rendering the tree more susceptible to wind damage. Poor pruning techniques include leaving stubs outside the branch collar or cutting into the branch collar. A tree with proper pruning may still maintain the look and shape of the tree, only it is shorter. (USDA Forest Service 2017).

Shannon-Wiener diversity index: An index of species diversity (also known as the Shannon diversity index) which takes into account both species richness (total number of species in a community) and species evenness (relative abundances among species in a community). Shannon diversity (H') is calculated as follows:

$$H' = - \sum_{i=1}^s p_i \ln(p_i)$$

where: S = the total number of species in the community (species richness) and p_i = proportion of the total assemblage of individuals represented by individuals of species i (Shannon 1948; Spellerberg and Fedor 2003).

Stem girdling: Stem girdling occurs when roots begin to grow around the main stem of the tree and cut off or restrict the movement of water, plant nutrients, and stored food reserves. Certain trees are more prone to this problem than others. Lindens, magnolias, pines, and maples (other than silver maple) are susceptible to root girdling (USDA Forest Service 2017).

Woodland: A subset of FIA-designated forest land that is dominated by woodland species (Dooley 2019).

Woodland Species: FIA classifies all tree species into either woodland or timber categories. Woodland species are typically small, slow-growing trees characterized by a multi-stemmed growth form; timber species generally grow from a single central stem (USDA Forest Service 2017). This difference in typical form induces some differences in data collection and calculation, such as how diameters are determined (see Diameter definition). There were no woodland tree species sampled in the 2021 Urban FIA inventory of Madison.

APPENDIX 1 – LAND COVER DESCRIPTIONS

Table 31.—National Land Cover Database (NLCD) land cover class descriptions, city of Madison, 2021

NLCD land cover class	NLCD code	Land cover description
Open water	11	Areas of open water generally with less than 25 percent of vegetation or soil.
Perennial ice/snow	12	Areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed-open space	21	Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed-low intensity	22	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 percent to 49 percent of total cover. These areas most commonly include single-family housing units.
Developed-medium intensity	23	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 percent to 79 percent of the total cover. These areas most commonly include single-family housing units.
Developed-high intensity	24	Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80 percent to 100 percent of the total cover.
Barren land (rock/sand/clay)	31	Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Deciduous forest	41	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen forest	42	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed forest	43	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Dwarf scrub	51	Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
Shrub/scrub	52	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Grassland/herbaceous	71	Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Sedge/herbaceous	72	Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
Lichens	73	Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
Moss	74	Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Pasture/hay	81	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
Cultivated crops	82	Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Woody wetlands	90	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent herbaceous wetlands	95	Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Source: Homer et al. 2015

APPENDIX 2 – TREE SPECIES COMPOSITION

Table 32.—List of live tree species and their characteristics, city of Madison, 2021

Genus	Species	Common name	1.0–4.9 in. diameter trees (number)	5.0–10.9 in. diameter trees (number)	11.0+ in. diameter trees (number)	Total (number)	Total (percent)	Total standard error (number)	Average diameter (in.)
<i>Acer</i>	<i>ginnala</i>	Amur maple	0	14,000	0	14,000	0.5	15,000	7.3
<i>Acer</i>	<i>negundo</i>	boxelder	168,000	83,000	21,000	273,000	9.5	153,000	5.2
<i>Acer</i>	<i>nigrum</i>	black maple	0	1,800	0	1,800	0.1	1,800	10.6
<i>Acer</i>	<i>platanooides</i>	Norway maple ^a	0	5,300	51,000	56,000	2.0	13,000	17.2
<i>Acer</i>	<i>rubrum</i>	red maple	0	3,500	5,100	8,600	0.3	5,700	11.8
<i>Acer</i>	<i>saccharinum</i>	silver maple	0	2,600	23,000	26,000	0.9	13,000	25.8
<i>Acer</i>	<i>saccharum</i>	sugar maple	0	1,700	5,200	7,000	0.2	7,300	13.0
<i>Acer</i>	<i>x freemanii</i>	Freeman maple	0	1,800	0	1,800	0.1	1,800	9.3
<i>Betula</i>	<i>nigra</i>	river birch	0	0	8,300	8,300	0.3	6,200	14.0
<i>Betula</i>	<i>papyrifera</i>	paper birch	22,000	7,800	0	30,000	1.1	27,000	5.2
<i>Carya</i>	<i>ovata</i>	shagbark hickory	0	21,000	20,000	41,000	1.4	23,000	11.1
<i>Celtis</i>	<i>occidentalis</i>	hackberry	0	2,200	11,000	13,000	0.5	4,900	14.7
<i>Cercidiphyllum</i>	<i>japonicum</i>	katsura tree	0	0	1,700	1,700	0.1	1,800	20.0
<i>Cercis</i>	<i>canadensis</i>	eastern redbud	0	4,200	2,100	6,200	0.2	4,400	9.1
<i>Crataegus</i>	spp.	hawthorn spp.	32,000	27,000	0	59,000	2.0	36,000	4.7
<i>Fraxinus</i>	<i>americana</i>	white ash	159,000	57,000	14,000	231,000	8.1	106,000	4.9
<i>Fraxinus</i>	<i>pennsylvanica</i>	green ash	0	25,000	20,000	45,000	1.6	13,000	12.7
<i>Ginkgo</i>	<i>biloba</i>	ginkgo, maidenhair tree	0	0	4,200	4,200	0.1	3,900	24.9
<i>Gleditsia</i>	<i>triacanthos</i>	honeylocust	0	1,800	42,000	44,000	1.5	12,000	20.8
<i>Juglans</i>	<i>nigra</i>	black walnut	27,000	16,000	38,000	81,000	2.8	41,000	10.4
<i>Juniperus</i>	<i>scopulorum</i>	Rocky Mountain juniper ^b	0	1,800	0	1,800	0.1	1,800	5.3
<i>Juniperus</i>	<i>virginiana</i>	eastern redcedar	0	8,300	0	8,300	0.3	6,200	10.2
<i>Malus</i>	spp.	apple spp.	45,000	22,000	7,600	75,000	2.6	47,000	5.7
<i>Morus</i>	<i>alba</i>	white mulberry	0	25,000	0	25,000	0.9	14,000	7.1
<i>Morus</i>	spp.	mulberry spp.	32,000	0	0	32,000	1.1	28,000	1.1
<i>Picea</i>	<i>abies</i>	Norway spruce	0	3,500	0	3,500	0.1	3,700	8.4

Continued on next page

Table 32. (continued)—List of live tree species and their characteristics, city of Madison 2021

Genus	Species	Common name	1.0–4.9 in. diameter trees (number)	5.0–10.9 in. diameter trees (number)	11.0+ in. diameter trees (number)	Total (number)	Total (percent)	Total standard error (number)	Average diameter (in.)
<i>Picea</i>	<i>glauca</i>	white spruce	22,000	16,000	5,700	43,000	1.5	25,000	6.1
<i>Picea</i>	<i>pungens</i>	blue spruce	0	0	6,200	6,200	0.2	4,400	16.6
<i>Pinus</i>	<i>resinosa</i>	red pine	0	4,200	4,300	8,400	0.3	6,300	8.9
<i>Pinus</i>	<i>strobus</i>	eastern white pine	0	2,100	17,000	19,000	0.7	10,000	16.4
<i>Platanus</i>	<i>hybrida</i>	London planetree	0	2,100	0	2,100	0.1	2,000	9.0
<i>Populus</i>	<i>alba</i>	silver poplar	0	0	1,700	1,700	0.1	1,800	15.4
<i>Populus</i>	<i>balsamifera</i>	balsam poplar	0	2,100	0	2,100	0.1	2,000	5.0
<i>Populus</i>	<i>tremuloides</i>	quaking aspen	0	5,400	0	5,400	0.2	4,100	7.1
<i>Prunus</i>	<i>serotina</i>	black cherry	54,000	32,000	13,000	99,000	3.5	53,000	5.8
<i>Prunus</i>	<i>virginiana</i>	chokecherry	191,000	2,100	0	193,000	6.8	165,000	1.3
<i>Pseudotsuga</i>	<i>menziesii</i>	Douglas-fir	0	0	3,900	3,900	0.1	2,700	19.6
<i>Pyrus</i>	<i>calleryana</i>	Callery pear	0	1,800	0	1,800	0.1	1,800	10.9
<i>Pyrus</i>	spp.	pear spp.	0	2,100	0	2,100	0.1	2,000	8.3
<i>Quercus</i>	<i>alba</i>	white oak	0	0	30,000	30,000	1.1	13,000	22.3
<i>Quercus</i>	<i>macrocarpa</i>	bur oak	0	9,100	25,000	34,000	1.2	25,000	15.9
<i>Quercus</i>	<i>rubra</i>	northern red oak	22,000	0	8,100	30,000	1.1	23,000	8.8
<i>Quercus</i>	<i>velutina</i>	black oak	0	10,000	14,000	24,000	0.8	13,000	17.8
<i>Rhamnus</i>	<i>cathartica</i>	common buckthorn ^a	859,000	12,000	0	871,000	30.5	400,000	1.9
<i>Robinia</i>	<i>pseudoacacia</i>	black locust ^a	32,000	33,000	41,000	106,000	3.7	52,000	8.9
<i>Salix</i>	<i>nigra</i>	black willow	0	0	2,600	2,600	0.1	2,200	13.5
<i>Syringa</i>	<i>reticulata</i>	Japanese tree lilac	0	2,100	0	2,100	0.1	2,000	5.3
<i>Thuja</i>	<i>occidentalis</i>	northern white-cedar	26,000	65,000	8,000	100,000	3.5	43,000	6.0
<i>Tilia</i>	<i>americana</i>	American basswood	0	5,100	4,600	9,700	0.3	5,200	17.8
<i>Tilia</i>	<i>cordata</i>	littleleaf linden	0	1,800	3,200	5,000	0.2	3,100	15.6
<i>Ulmus</i>	<i>americana</i>	American elm	48,000	10,000	9,900	68,000	2.4	47,000	5.5
<i>Ulmus</i>	<i>pumila</i>	Siberian elm ^a	54,000	31,000	7,200	92,000	3.2	63,000	5.8
Total			1,790,000	586,000	479,000	2,860,000	100.0	603,000	6.0

Due to rounding, not all values will add up exactly.

Diameter measurements were taken at breast height (d.b.h.).

^a Tree species included on the list of invasive plants monitored during the inventory of Madison, 2021 (see Appendix 5).

APPENDIX 3 – TREE CHARACTERISTICS WITHIN NLCD LAND COVER CLASS GROUPS AND FIA LAND USE

Table 33.—Estimates of total number of trees, basal area, and average diameter by National Land Cover Database (NLCD) land cover class group, city of Madison, 2021

NLCD land cover class group	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Crop	black cherry	8,723	1.0	9.4
	black walnut	35,887	0.8	4.0
	boxelder	38,068	1.1	3.1
	bur oak	6,542	0.3	5.8
	common buckthorn	271,646	2.0	2.2
	hackberry	2,181	< 0.1	5.8
	red pine	2,181	0.3	11.0
	white mulberry	13,084	0.7	6.5
Developed-low	American basswood	2,081	1.2	41.1
	American elm	28,163	0.2	3.5
	apple spp.	10,405	0.5	11.4
	balsam poplar	2,081	< 0.1	5.0
	blue spruce	6,243	0.6	16.6
	boxelder	4,162	0.2	11.1
	bur oak	2,081	< 0.1	11.6
	chokecherry	2,081	< 0.1	6.2
	common buckthorn	4,162	< 0.1	5.9
	Douglas-fir	2,081	0.2	14.5
	eastern redbud	6,243	0.2	9.1
	eastern redcedar	8,324	0.3	10.2
	eastern white pine	8,324	0.8	15.5
	ginkgo, maidenhair tree	4,162	0.9	24.9
	green ash	12,485	2.1	21.0
	hackberry	4,162	0.4	16.0
	hawthorn spp.	24,971	0.5	7.2
	honeylocust	31,214	5.5	21.8
	Japanese tree lilac	2,081	< 0.1	5.3
	London planetree	2,081	< 0.1	9.0
	northern red oak	2,081	0.3	21.7
	northern white-cedar	65,620	1.1	5.6
	Norway maple	31,214	4.0	18.5
	paper birch	4,162	< 0.1	7.4

Estimates are rounded.

Continued on next page

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

Table 33. (continued)—Estimates of total number of trees, basal area, and average diameter by National Land Cover Database (NLCD) land cover class group, city of Madison, 2021

NLCD land cover class group	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Developed-low (cont.)	pear spp.	2,081	< 0.1	8.3
	red pine	6,243	0.2	8.2
	river birch	8,324	0.6	14.0
	shagbark hickory	2,081	0.2	16.2
	Siberian elm	2,081	0.2	17.1
	silver maple	6,243	3.4	38.2
	white ash	4,162	0.9	25.1
	white mulberry	6,243	0.2	9.0
	white oak	6,243	1.0	21.4
	white spruce	2,081	0.2	17.2
Developed-medium/high	apple spp.	60,815	0.6	4.3
	black maple	1,798	< 0.1	10.6
	boxelder	1,798	< 0.1	6.9
	Callery pear	1,798	< 0.1	10.9
	common buckthorn	25,912	0.1	3.1
	Douglas-fir	1,798	0.5	25.6
	Freeman maple	1,798	< 0.1	9.3
	green ash	12,588	0.6	9.5
	honeylocust	10,790	1.4	16.4
	littleleaf linden	1,798	< 0.1	5.7
	northern red oak	22,315	0.1	3.7
	northern white-cedar	25,176	0.6	7.4
	Norway maple	17,983	1.6	14.1
	paper birch	25,912	0.3	4.8
	quaking aspen	5,395	0.1	7.1
	Rocky Mountain juniper	1,798	< 0.1	5.3
	Siberian elm	22,315	0.1	3.6
	white ash	1,798	< 0.1	6.9
	white spruce	8,992	0.5	11.2
Developed-open	American elm	37,526	1.2	6.1
	Amur maple	13,939	0.5	7.3

Estimates are rounded.

Continued on next page

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

Table 33. (continued)—Estimates of total number of trees, basal area, and average diameter by National Land Cover Database (NLCD) land cover class group, city of Madison, 2021

NLCD land cover class group	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Developed-open (cont.)	apple spp.	3,485	0.4	12.5
	black cherry	41,011	1.2	6.1
	black oak	8,712	5.0	26.6
	black walnut	1,742	0.7	24.4
	boxelder	140,583	2.5	4.4
	bur oak	22,652	6.6	20.0
	common buckthorn	89,118	0.4	2.2
	eastern white pine	10,455	2.2	17.1
	green ash	5,227	1.1	15.9
	hawthorn spp.	1,742	< 0.1	8.9
	honeylocust	1,742	1.2	30.7
	katsura tree	1,742	0.5	20.0
	littleleaf linden	1,742	0.4	18.8
	northern red oak	3,485	2.1	28.6
	northern white-cedar	8,712	0.2	5.3
	Norway maple	6,970	2.1	19.2
	Norway spruce	3,485	0.2	8.4
	red maple	3,485	< 0.1	6.1
	shagbark hickory	5,227	0.3	8.2
	silver maple	6,970	6.5	35.9
	silver poplar	1,742	0.3	15.4
	sugar maple	6,970	0.9	13.0
	white ash	1,742	< 0.1	6.8
	white mulberry	5,227	0.1	6.2
	white oak	3,485	1.2	21.8
	white spruce	27,071	0.4	3.4
Forest/shrub	American basswood	7,664	1.3	11.5
	American elm	2,555	0.8	17.8
	black cherry	49,706	2.4	4.9
	black locust	105,910	12.3	8.9
	black oak	15,328	3.0	12.7

Estimates are rounded.

Continued on next page

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

Table 33. (continued)—Estimates of total number of trees, basal area, and average diameter by National Land Cover Database (NLCD) land cover class group, city of Madison, 2021

NLCD land cover class group	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Forest/shrub (cont.)	black walnut	43,430	10.7	15.0
	black willow	2,555	0.5	13.5
	boxelder	88,027	5.2	7.1
	bur oak	2,555	0.2	9.8
	chokecherry	190,940	0.3	1.3
	common buckthorn	479,906	1.5	1.6
	green ash	10,219	0.5	7.2
	hackberry	5,109	1.1	14.4
	hawthorn spp.	31,823	0.2	2.5
	mulberry spp.	31,823	< 0.1	1.1
	northern red oak	2,555	0.7	16.1
	red maple	5,109	1.3	15.8
	shagbark hickory	33,211	4.6	11.2
	Siberian elm	67,589	3.3	6.2
	silver maple	12,774	2.6	14.3
	white ash	222,985	6.8	4.5
	white oak	20,438	11.1	22.6
	white spruce	5,109	0.2	6.5
Herbaceous	green ash	4,435	0.4	7.6
	hackberry	1,478	1.4	25.5
	littleleaf linden	1,478	1.2	23.8

Estimates are rounded.

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

Table 34.—Estimates of total number of trees, basal area and average diameter by Forest Inventory and Analysis (FIA) land use class, city of Madison, 2021

FIA land use class	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Forest land	American basswood	7,664	1.8	11.5
	American elm	37,526	2.5	6.1
	black cherry	90,343	5.6	5.3
	black locust	53,649	16.8	14.1
	black oak	18,813	5.8	13.4
	black walnut	76,763	16.3	10.2
	boxelder	199,578	7.3	4.6
	bur oak	9,097	0.7	6.9
	chokecherry	190,940	0.5	1.3
	common buckthorn	340,078	0.9	1.3
	green ash	13,841	1.5	8.2
	hackberry	5,109	1.6	14.4
	hawthorn spp.	31,823	0.3	2.5
	mulberry spp.	31,823	< 0.1	1.1
	northern red oak	2,555	1.0	16.1
	red maple	8,594	2.1	11.8
	shagbark hickory	38,439	7.2	10.8
	Siberian elm	5,109	0.6	8.7
	silver maple	5,109	1.8	15.6
	silver poplar	1,742	0.6	15.4
	sugar maple	6,970	1.8	13.0
	white ash	222,985	10.0	4.5
	white mulberry	1,742	< 0.1	6.1
	white oak	22,180	17.2	22.4
Agriculture	boxelder	35,887	0.7	2.5
Commercial/industrial	apple spp.	12,476	0.7	7.9
	black cherry	6,542	0.5	10.2
	boxelder	2,181	0.3	13.2
	common buckthorn	271,646	1.2	2.2
	green ash	10,678	1.1	9.8
	hackberry	2,181	< 0.1	5.8
	honeylocust	2,081	1.1	26.4

Estimates are rounded.

Continued on next page

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

Table 34. (continued)—Estimates of total number of trees, basal area and average diameter by Forest Inventory and Analysis (FIA) land use class, city of Madison, 2021

FIA land use class	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Commercial/industrial (cont.)	white ash	4,162	2.0	25.1
	white mulberry	13,084	0.4	6.5
Multi-family residential	black locust	44,597	1.5	3.2
	blue spruce	2,081	1.0	14.0
	boxelder	7,664	1.8	8.8
	common buckthorn	127,294	1.1	1.8
	green ash	2,555	0.3	7.3
	northern white-cedar	25,176	3.4	7.4
	Siberian elm	54,816	6.4	6.0
	white spruce	1,798	0.5	10.7
Residential	American elm	26,082	< 0.1	2.6
	apple spp.	14,001	0.8	10.8
	balsam poplar	2,081	< 0.1	5.0
	black maple	1,798	< 0.1	10.6
	black oak	5,227	2.9	33.6
	black walnut	1,742	0.5	24.4
	boxelder	9,445	0.7	11.7
	bur oak	24,733	4.4	19.3
	Callery pear	1,798	< 0.1	10.9
	chokecherry	2,081	< 0.1	6.2
	common buckthorn	72,951	0.3	2.8
	Douglas-fir	3,879	0.8	19.6
	eastern redbud	6,243	0.3	9.1
	eastern redcedar	8,324	0.4	10.2
	eastern white pine	8,324	1.1	15.5
	green ash	7,758	1.4	17.8
	hackberry	2,081	0.3	18.1
	honeylocust	7,985	2.8	27.3
	katsura tree	1,742	0.3	20.0
	littleleaf linden	1,742	0.3	18.8
	northern red oak	27,881	2.0	8.2
	northern white-cedar	74,332	1.5	5.5
	Norway maple	9,162	1.0	13.9

Estimates are rounded.

Continued on next page

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

Table 34. (continued)—Estimates of total number of trees, basal area and average diameter by Forest Inventory and Analysis (FIA) land use class, city of Madison, 2021

FIA land use class	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Residential (cont.)	Norway spruce	3,485	0.1	8.4
	paper birch	30,073	0.4	5.2
	pear spp.	2,081	< 0.1	8.3
	quaking aspen	5,395	0.1	7.1
	red pine	8,423	0.3	8.9
	river birch	8,324	0.8	14.0
	Rocky Mountain juniper	1,798	< 0.1	5.3
	shagbark hickory	2,081	0.3	16.2
	Siberian elm	2,081	0.3	17.1
	silver maple	20,877	9.4	28.3
	white mulberry	9,728	0.3	8.0
	white oak	7,985	1.8	21.9
	white spruce	37,631	0.7	5.1
Recreation/cemetery	Amur maple	13,939	1.0	7.3
	blue spruce	4,162	1.7	18.0
	eastern white pine	10,455	3.9	17.1
	hackberry	3,559	1.7	18.8
	hawthorn spp.	1,742	0.2	8.9
	honeylocust	8,992	3.0	15.1
	littleleaf linden	1,478	1.0	23.8
	Norway maple	3,485	2.3	22.7
	white ash	1,742	0.1	6.8
	white spruce	3,823	1.0	13.8
Rights-of-way	American basswood	2,081	1.5	41.1
	American elm	4,636	0.5	16.7
	apple spp.	48,226	0.3	3.6
	black cherry	2,555	0.1	11.8
	black locust	7,664	< 0.1	5.2
	black walnut	2,555	< 0.1	6.8
	boxelder	17,883	0.9	11.1
	common buckthorn	58,774	0.3	3.0
	Freeman maple	1,798	< 0.1	9.3

Estimates are rounded.

Continued on next page

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

Table 34. (continued)—Estimates of total number of trees, basal area and average diameter by Forest Inventory and Analysis (FIA) land use class, city of Madison, 2021

FIA land use class	Common name	Trees (number)	Basal area (sq ft per ac)	Average diameter (inches)
Rights-of-way (cont.)	ginkgo, maidenhair tree	4,162	1.1	24.9
	green ash	10,122	1.7	19.6
	hawthorn spp.	24,971	0.5	7.2
	honeylocust	24,688	4.4	20.3
	Japanese tree lilac	2,081	< 0.1	5.3
	littleleaf linden	1,798	< 0.1	5.7
	London planetree	2,081	< 0.1	9.0
	Norway maple	43,519	5.8	17.4
	Siberian elm	29,979	0.2	4.2
	white ash	1,798	< 0.1	6.9
Natural lands	black willow	2,555	1.5	13.5

Estimates are rounded.

Basal area is the cross-sectional area of the tree stems measured at the diameter.

Diameter measurements were taken at breast height (d.b.h.).

APPENDIX 4 – SPECIES COMPOSITION IN MAINTAINED AREAS

Table 35.—Tree species composition in maintained areas, city of Madison, 2021

Common name	Number of trees	Common name	Number of trees
northern white-cedar	83,000	quaking aspen	5,400
Norway maple	54,000	black oak	5,200
honeylocust	44,000	littleleaf linden	5,000
white spruce	43,000	ginkgo, maidenhair tree	4,200
apple spp.	30,000	Douglas-fir	3,900
paper birch	30,000	common buckthorn	3,600
American elm	28,000	Norway spruce	3,500
northern red oak	28,000	shagbark hickory	2,100
hawthorn spp.	27,000	balsam poplar	2,100
Siberian elm	24,000	American basswood	2,100
silver maple	23,000	Japanese tree lilac	2,100
green ash	23,000	London planetree	2,100
eastern white pine	13,000	pear spp.	2,100
river birch	8,300	Rocky Mountain juniper	1,800
white ash	7,700	boxelder	1,800
eastern redcedar	6,200	black maple	1,800
blue spruce	6,200	Freeman maple	1,800
eastern redbud	6,200	Callery pear	1,800
white mulberry	6,200	katsura tree	1,700
white oak	6,200	hackberry	1,500
bur oak	5,600		

Estimates are rounded.

APPENDIX 5 – LIST OF INVASIVE PLANT SPECIES

Table 36.—Invasive species list used in the Urban FIA inventory protocol for the city of Madison, 2021

Scientific name	Common name	Scientific name	Common name
<i>Acer platanoides</i>	Norway maple	<i>Lonicera morrowii</i>	Morrow's honeysuckle
<i>Ailanthus altissima</i>	tree of heaven	<i>Lonicera tatarica</i>	Tatarian honeysuckle
<i>Albizia julibrissin</i>	mimosa	<i>Lysimachia nummularia</i>	creeping jenny
<i>Alliaria petiolata</i>	garlic mustard	<i>Lythrum salicaria</i>	purple loosestrife
<i>Berberis thunbergii</i>	Japanese barberry	<i>Melia azedarach</i>	Chinaberrytree
<i>Berberis vulgaris</i>	common barberry	<i>Melaleuca quinquenervia</i>	melaleuca
<i>Celastrus orbiculatus</i>	Oriental bittersweet	<i>Microstegium vimineum</i>	Nepalese browntop
<i>Centaurea stoebe</i> ssp. <i>micranthos</i>	spotted knapweed	<i>Phalaris arundinacea</i>	reed canarygrass
<i>Cirsium arvense</i>	Canada thistle	<i>Phragmites australis</i>	common reed
<i>Cirsium vulgare</i>	bull thistle	<i>Polygonum cuspidatum</i>	Japanese knotweed
<i>Cynanchum louiseae</i>	Louise's swallow-wort	<i>Polygonum sachalinense</i>	giant knotweed
<i>Cynanchum rossicum</i>	European swallow-wort	<i>Rhamnus cathartica</i>	common buckthorn
<i>Elaeagnus angustifolia</i>	Russian olive	<i>Rosa multiflora</i>	multiflora rose
<i>Elaeagnus umbellata</i>	autumn olive	<i>Robinia pseudoacacia</i>	black locust
<i>Euphorbia esula</i>	leafy spurge	<i>Spiraea japonica</i>	Japanese meadowsweet
<i>Frangula alnus</i>	glossy buckthorn	<i>Tamarix ramosissima</i>	saltcedar
<i>Hedera helix</i>	English ivy	<i>Triadica sebifera</i>	Chinese tallow
<i>Hesperis matronalis</i>	dames rocket	<i>Ulmus pumila</i>	Siberian elm
<i>Ligustrum vulgare</i>	European privet	<i>Viburnum opulus</i>	European cranberrybush
<i>Lonicera</i> spp.	honeysuckle spp.	<i>Lonicera maackii</i>	Amur honeysuckle
<i>Lonicera x bella</i>	showy fly honeysuckle	<i>Paulownia tomentosa</i>	paulownia
<i>Lonicera japonica</i>	Japanese honeysuckle	<i>Polygonum x bohemicum</i>	Bohemian knotweed

APPENDIX 6 – LIST OF PESTS AND PATHOGENS

Table 37.—List of pests and pathogens assessed in the Urban FIA inventory protocol for the city of Madison, 2021

Scientific name	Common name	Scientific name	Common name
<i>Acleris gloverana</i>	western blackheaded budworm	<i>Leptographium wageneri</i>	black stain root disease
<i>Adelges piceae</i>	balsam woolly adelgid	<i>Leptographium wageneri</i> var. <i>ponderosum</i>	pine black stain root disease ^a
<i>Adelges tsugae</i>	hemlock woolly adelgid ^a	<i>Leptographium wageneri</i> var. <i>pseudotsugae</i>	Douglas-fir black stain root disease
<i>Agrilus auroguttatus</i>	goldspotted oak borer ^a	<i>Litylenchus crenatae mccannii</i>	beech leaf disease ^a
<i>Agrilus planipennis</i>	emerald ash borer	<i>Lycorma delicatula</i>	spotted lanternfly
<i>Anoplophora glabripennis</i>	Asian longhorned beetle	<i>Lymantria dispar</i>	spongy moth
<i>Armillaria</i> spp.	Armillaria root disease	<i>Malacosoma disstria</i>	forest tent caterpillar
<i>Bretziella fagacearum</i>	oak wilt	<i>Matsucoccus resinosae</i>	red pine scale
<i>Choristoneura conflictana</i>	large aspen tortrix	NA - multiple pests	western five-needle pine mortality ^a
<i>Choristoneura fumiferana</i>	spruce budworm	NA - multiple pests	subalpine fir mortality ^a
<i>Choristoneura occidentalis</i>	western spruce budworm	<i>Neodiprion tsugae</i>	hemlock sawfly ^a
<i>Choristoneura pinus</i>	jack pine budworm	<i>Neodothiora populina</i>	aspen running canker
<i>Cronartium quercuum</i> f. sp. <i>Fusiforme</i>	fusiform rust	<i>Neonectria faginata</i>	beech bark disease ^a
<i>Cronartium ribicola</i>	white pine blister rust	<i>Operophtera brumata</i>	winter moth
<i>Cryphonectria parasitica</i>	chestnut blight ^a	<i>Ophiostoma novo-ulmi</i>	Dutch elm disease
<i>Dendroctonus brevicomis</i>	western pine beetle ^a	<i>Phyllocnistis populiella</i>	aspen leafminer
<i>Dendroctonus frontalis</i>	southern pine beetle	<i>Phytophthora lateralis</i>	Port-Orford-cedar root disease
<i>Dendroctonus jeffreyi</i>	Jeffrey pine beetle ^a	<i>Phytophthora ramorum</i>	sudden oak death
<i>Dendroctonus ponderosae</i>	mountain pine beetle	<i>Raffaelea lauricola</i>	laurel wilt ^a
<i>Dendroctonus pseudotsugae</i>	Douglas-fir Beetle	<i>Scolytus ventralis</i>	fir engraver
<i>Dendroctonus rufipennis</i>	spruce beetle	<i>Sirex noctilio</i>	sirex wood wasp
<i>Discula destructiva</i>	dogwood anthracnose ^a	<i>Sirococcus clavignenti juglandacearum</i>	butternut canker
<i>Dryocoetes confusus</i>	western balsam bark beetle ^a	<i>Tomicus piniperda</i>	pine shoot beetle
<i>Euproctis chrysorrhoea</i>	browntail moth	<i>Tubakia iowensis</i>	bur oak blight
<i>Euwallacea</i> nov. sp.	polyphagous shot hole borer	<i>Xyleborus monographus</i>	Mediterranean oak borer
<i>Geosmithia morbida</i>	thousand canker disease		
<i>Heterobasidion irregulare/occidentale</i>	Heterobasidion root disease		
<i>Ips perturbatus</i>	northern spruce engraver		

^aThe pest or pathogen does not pose a risk to the tree species sampled in the 2021 Urban FIA inventory of Madison

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