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**Northern
Research Station**

Resource Bulletin NRS-37

Assessing Urban Forest Effects and Values

Chicago's Urban Forest

Northern
RESEARCH STATION
USDA Forest Service

UFORE
Urban Forest Effects Model

Abstract

An analysis of trees in Chicago, IL, reveals that this city has about 3,585,000 trees with canopies that cover 17.2 percent of the area. The most common tree species are white ash, mulberry species, green ash, and tree-of-heaven. Chicago's urban forest currently stores about 716,000 tons of carbon valued at $14.8 million. In addition, these trees remove about 25,200 tons of carbon per year ($521,000 per year) and about 888 tons of air pollution per year ($6.4 million per year). Trees in Chicago are estimated to reduce annual residential energy costs by $360,000 per year. The structural, or compensatory, value is estimated at $2.3 billion. Information on the structure and functions of the urban forest can be used to inform urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Chicago area.

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David Nowak, U.S. Forest Service

Urban forests provide numerous benefits to society, yet relatively little is known about this important resource.

In 2007, the UFORE model was used to survey and analyze Chicago's urban forest.

The calculated environmental benefits of the urban forest are significant, yet many environmental and social benefits still remain to be quantified.

Executive Summary

Trees in cities can contribute significantly to human health and environmental quality. Unfortunately, little is known about the urban forest resource and what it contributes to the local and regional society and economy. To better understand the urban forest resource and its numerous values, the U.S. Forest Service, Northern Research Station, developed the Urban Forest Effects (UFORE) model. Results from this model are used to advance the understanding of the urban forest resource, improve urban forest policies, planning and management, provide data to support the potential inclusion of trees within environmental regulations, and determine how trees affect the environment and consequently enhance human health and environmental quality in urban areas.

Forest structure is a measure of various physical attributes of the vegetation, including tree species composition, number of trees, tree density, tree health, leaf area, biomass, and species diversity. Forest functions, which are determined by forest structure, include a wide range of environmental and ecosystem services such as air pollution removal and cooler air temperatures. Forest values are an estimate of the economic worth of the various forest functions.

To help determine the vegetation structure, functions, and values of the urban forest in Chicago, a vegetation assessment was conducted during the summer of 2007. For this assessment, one-tenth acre field plots were sampled and analyzed using the UFORE model. This report summarizes results and values of:

- Forest structure
- Potential risk to forest from insects or diseases
- Air pollution removal
- Carbon storage
- Annual carbon removal (sequestration)
- Changes in building energy use

Chicago Urban Forest Summary

Feature	Measure
Number of trees	3,585,000
Tree cover	17.2%
Most common species	white ash, mulberry, green ash, tree-of-heaven
Percentage of trees < 6-inches diameter	61.2%
Pollution removal	888 tons/year ($6.4 million/year)
Carbon storage	716,000 tons ($14.8 million)
Carbon sequestration	25,200 tons/year ($521,000/year)
Building energy reduction	$360,000/year
Increased carbon emissions	-$25,000/year
Structural value	$2.3 billion
Ton – short ton (U.S.) (2,000 lbs)	

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Benefits ascribed to urban trees include:

- Air pollution removal
- Air temperature reduction
- Reduced building energy use
- Absorption of ultraviolet radiation
- Improved water quality
- Reduced noise
- Improved human comfort
- Increased property value
- Improved physiological & psychological well-being
- Aesthetics
- Community cohesion

Urban Forest Effects Model and Field Measurements

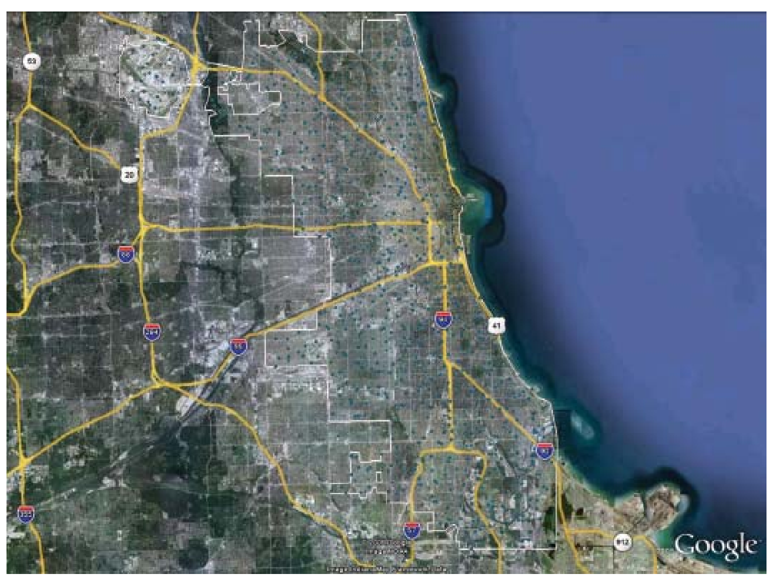
Though urban forests have many functions and values, currently only a few of these attributes can be assessed due to a limited ability to quantify all of these values thorugh standard data analyses. To help assess the city's urban forest, data from 745 field plots located throughout the city were analyzed using the Forest Service's Urban Forest Effects (UFORE) model.[1]

UFORE is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects, including:

- Urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<10 microns).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Compensatory value of the forest, as well as the value of air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetles, emerald ash borers, gypsy moth, or Dutch elm disease.

For more information go to http://www.ufore.org

In the field, one-tenth acre plots were selected based on a randomized grid-based pattern at a density of approximately 1 plot for every 198 acres. The study is broken into smaller areas by using zoning maps. The plots were divided among the following zoning districts: downtown (14 plots; 1.5 percent of city area), industrial (145 plots; 18.8 percent), open space (53 plots; 7.4 percent), planned developed (65 plots; 11.7 percent), residential multi-family unit (85 plots; 10.6 percent), residential single family (311 plots; 40.9 percent), and shopping (72 plots; 9.1 percent).



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Field Survey Data

Plot Information

- Land use type
- Percent tree cover
- Percent shrub cover
- Percent plantable
- Percent ground cover types

Tree parameters

- Species
- Stem diameter
- Total height
- Height to crown base
- Crown width
- Percent foliage missing
- Percent dieback
- Crown light exposure
- Distance and direction to buildings from trees

A cooperative effort among the U.S. Forest Service, and City of Chicago Department of Environment, Greencorps Chicago, Chicago Park District, Chicago Department of Street and Sanitation's Bureau of Forestry, and WRD Environmental designed, supervised and collected the data for analysis; data collection took place during the leaf-on season to properly assess tree canopies. Within each plot, data included land-use, ground and tree cover, shrub characteristics, and individual tree attributes of species, stem diameter at breast height (d.b.h.; measured at 4.5 ft.), tree height, height to base of live crown, crown width, percentage crown canopy missing and dieback, and distance and direction to residential buildings.[2]

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations.[3] To adjust for this difference, biomass results for open-grown urban trees are multiplied by 0.8.[3] No adjustment is made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models.[4, 5] As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[6, 7] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere.[8]

Seasonal effects of trees on residential building energy use were calculated based on procedures described the literature[9] using distance and direction of trees from residential structures, tree height, and tree condition data.

Compensatory values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information.[10]

To learn more about UFORE methods[11] visit:
http://www.nrs.fs.fed.us/tools/UFORE/ or www.ufore.org

David Nowak, U.S. Forest Service

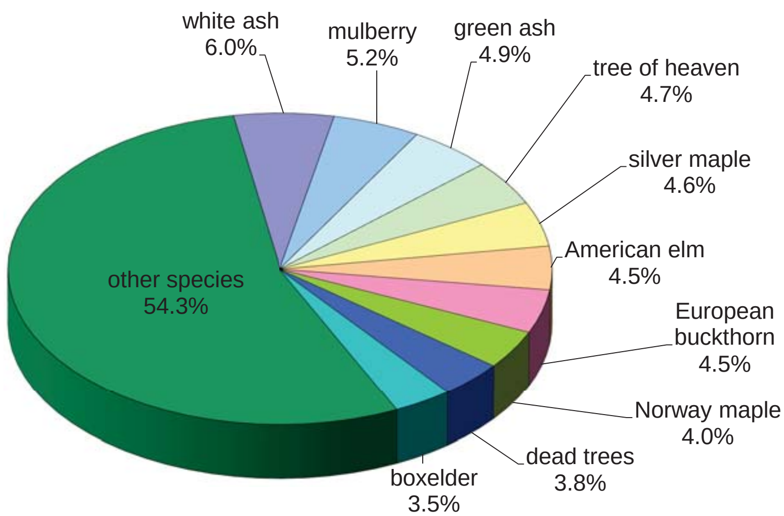
There are an estimated 3.6 million trees in Chicago with canopies that cover 17.2 percent of the city.

The 10 most common species account for 45.7 percent of the total number of trees.

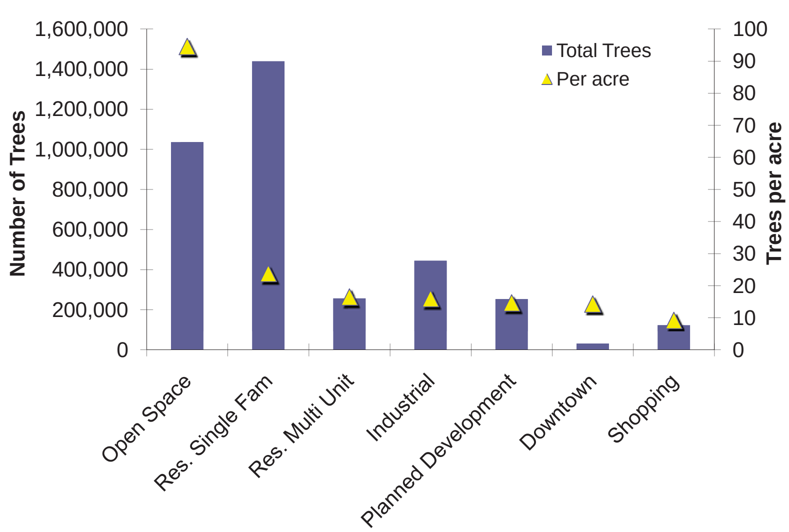
Tree density is highest in open space, and lowest in shopping areas.

Tree Characteristics of the Urban Forest

The urban forest of Chicago has an estimated 3,585,000 trees with a standard error (SE) of 344,000. Tree cover in Chicago is estimated at 17.2 percent based on digital cover mapping of 2008 imagery.[12] The four most common species in the urban forest are white ash (6.0 percent), mulberry (5.2 percent), green ash (4.9 percent), and tree-of-heaven (4.7 percent). The 10 most common species, including unidentified dead trees, account for 45.7 percent of all trees; their relative abundance is illustrated below. In total, 103 tree species were sampled in Chicago; these species and their relative abundance are presented in Appendix IV.



The highest density of trees occurs in the open space (94.5 trees/acre), followed by the residential single family (23.8 trees/acre) and the residential multi-family unit (16.5 trees/acre). The overall tree density in Chicago is 24.3 trees/acre, which is comparable to other city tree densities (Appendix I) that range between 14.4 to 119.2 trees/acre. Trees that have diameters less than 6 inches account for 61.2 percent of the population. Land uses that contain the most leaf area are single family residential (50.5 percent of total tree leaf area), open space (24.7 percent) and multi-family residential (10.1 percent).



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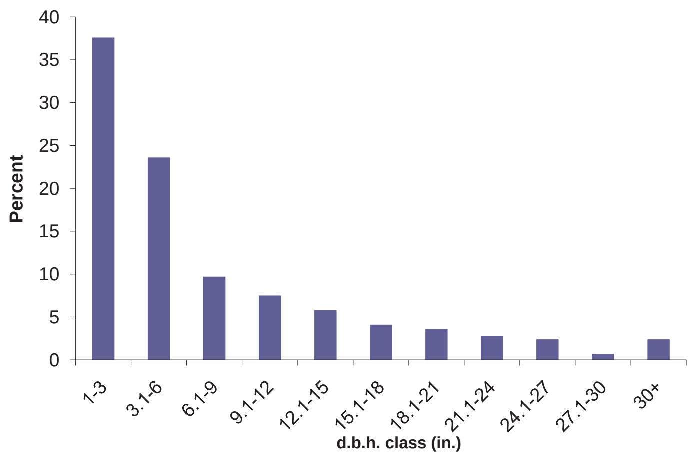
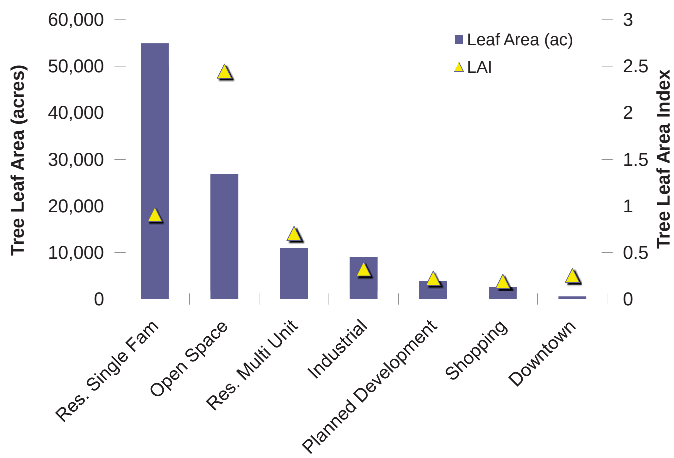
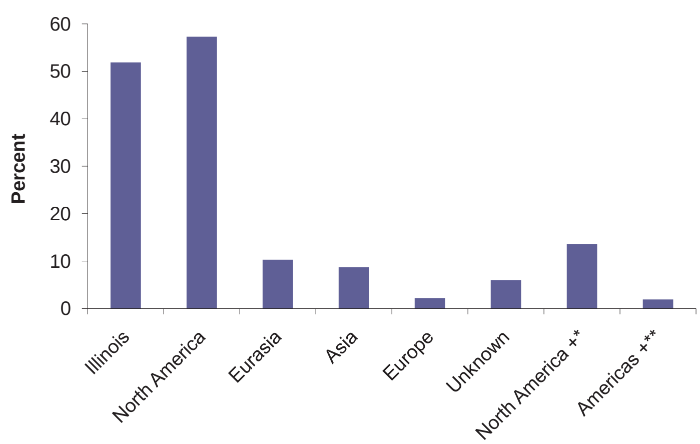
Nearly 51.9 percent of the tree species in Chicago are native to Illinois.

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means.

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. An increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but the increase in the number of exotic plants can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. In Chicago, about 51.9 percent of the trees are from species native to Illinois. Trees with a native origin outside of North America are mostly from Eurasia (10.3 percent of the species).







* native to North America and one other continent, excluding South America
** native to North America and South America, and one other continent

David Nowak, U.S. Forest Service

Healthy leaf area equates directly to tree benefits provided to the community.

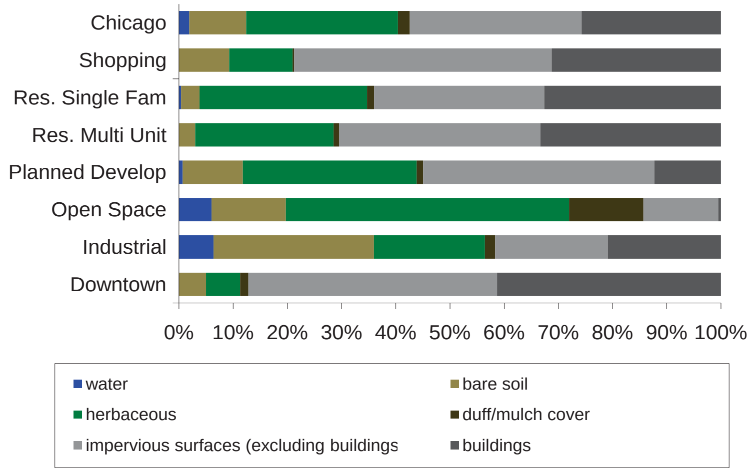
Silver maple is currently the most dominant species in Chicago's urban forest based on relative leaf area and relative population.

Common Name	% Pop[a]	% LA[b]	IV[c]
silver maple	4.6	12.5	17.1
Norway maple	4.0	11.4	15.4
green ash	4.9	7.5	12.4
mulberry	5.2	5.6	10.8
white ash	6.0	3.9	9.9
American elm	4.5	3.9	8.4
tree-of-heaven	4.7	2.6	7.3
littleleaf linden	1.5	5.0	6.5
honeylocust	3.3	2.6	5.9
European buckthorn	4.5	0.7	5.2

[a] percent of population
[b] percent of leaf area
[c] Percent Pop + Percent LA

Urban Forest Cover and Leaf Area

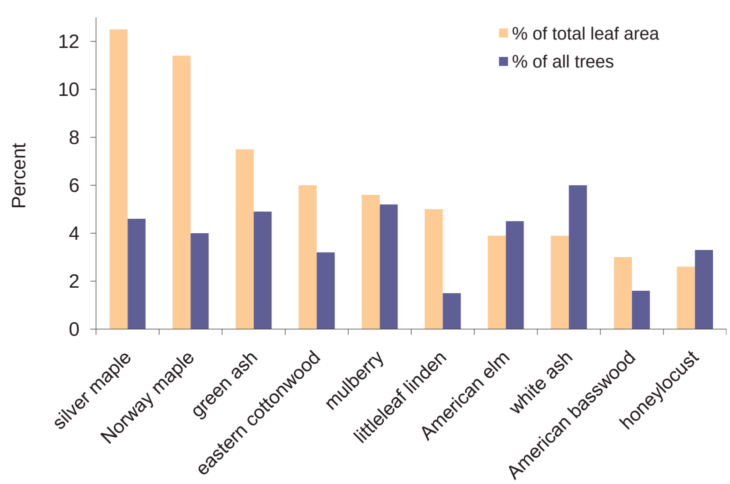
Dominant ground cover types include impervious surfaces (excluding buildings) (31.7 percent), herbaceous (28.0 percent), and buildings (25.7 percent).



Many tree benefits are linked directly to the amount of healthy leaf surface area of the plant. In Chicago trees that dominate in terms of leaf area are silver maple, Norway maple, and green ash.

Tree species with relatively large individuals contributing leaf area to the population (species with percent of leaf area much greater than percent of total population) are littleleaf linden, Norway maple, and silver maple. Smaller trees in the population are European buckthorn, northern white cedar, and viburnum species (species with percent of leaf area much less than percent of total population). A species must also constitute at least 1 percent of the total population to be considered as relatively large or small trees in the population.

The importance values (IV) are calculated using a formula that takes into account the relative leaf area and relative abundance. The most important species in the urban forest, according to calculated IVs, are silver maple, Norway maple, and green ash. High importance values do not mean that these trees should necessarily be used in the future, rather that these species currently dominate the urban forest structure.



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The urban forest of Chicago removes approximately 888 tons of pollutants each year, with a societal value of $6.4 million/year.

General urban forest management recommendations to improve air quality are given in Appendix II.

Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to human health problems, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduce air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation.[13]

Chicago water tower from Hancock.

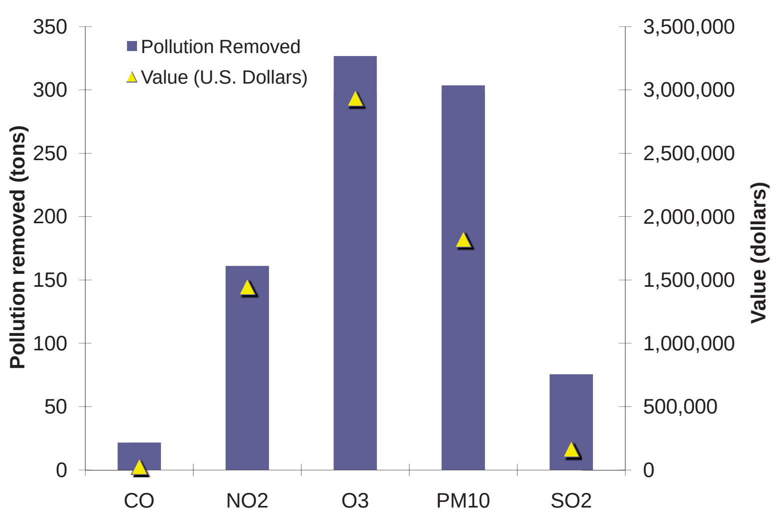
Pollution removal by trees in Chicago was estimated using the UFORE model in conjunction with field data and hourly pollution and weather data for the year 2000. Pollution removal was greatest for ozone (O_3), followed by particulate matter less than ten microns (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). It is estimated that trees remove 888 tons of air pollution (CO, NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $6.4 million (based on estimated 2007 national median externality costs associated with pollutants[14]).

The average percentage of air pollution removal during the daytime, in-leaf season was estimated to be:

- O_3 0.45%
- SO_2 0.44%
- CO 0.002%
- PM_{10} 0.40%
- NO_2 0.27%

Peak 1-hour air quality improvements during the in-leaf season for heavily-treed areas were estimated to be:

- O_3 13.4%
- SO_2 14.1%
- CO 0.05%
- PM_{10} 9.9%
- NO_2 6.3%



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Carbon storage:

Carbon currently held in tree tissue (roots, stems, and branches).

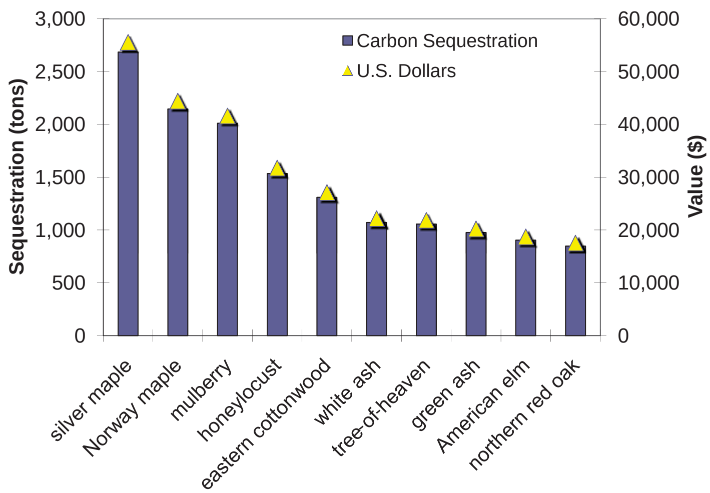
Carbon sequestration:

Estimated amount of carbon removed annually by trees. Net carbon sequestration can be negative if emission of carbon from decomposition is greater than amount sequestered by healthy trees.

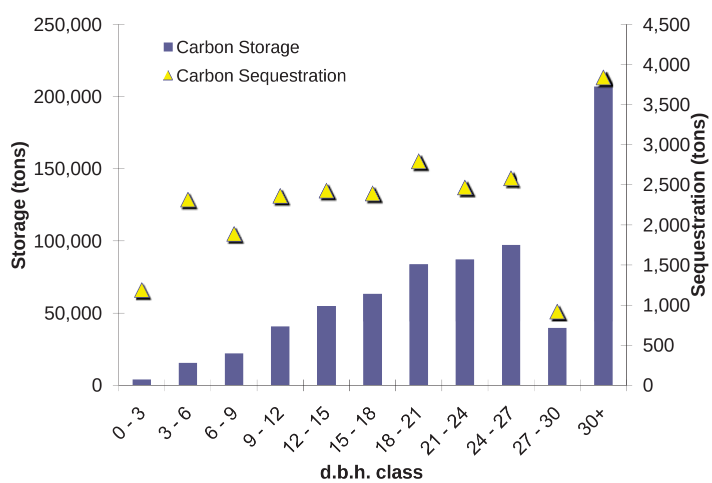
Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power plants.[15]

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth every year. The amount of carbon annually sequestered is increased with healthier trees and larger diameter trees. Gross sequestration by trees in Chicago is about 25,200 tons of carbon per year with an associated value of $521,000. Net carbon sequestration in the Chicago urban forest is estimated at about 17,700 tons.



Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees and when trees die, utilizing the wood in long-term wood products or to help heat buildings or produce energy will help reduce carbon emissions from wood decomposition or from power plants. Trees in Chicago are estimated to store 716,000 tons of carbon ($14.8 million). Of all the species sampled, silver maple stores and sequesters the most carbon (approximately 14.8% of the total carbon stored and 10.7% of all sequestered carbon).



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Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds.

Interactions between buildings and trees are estimated to reduce residential heating and cooling costs by $360,000 per year.

Trees Affect Energy Use in Buildings

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space-conditioned residential buildings.[9]

Dennis Haugen, U.S. Forest Service, bugwood.org

Based on average state energy costs in February 2009, trees in Chicago are estimated to reduce energy costs from residential buildings by $360,000 annually. Trees are estimated to slightly increase the amount of carbon released by fossil-fuel based power plants. However, this estimated increase in emissions (1,200 tons) is more than offset by annual carbon sequestration by trees (25,200 tons).

Annual energy savings due to trees near residential buildings.
Note: negative numbers indicate an increase in energy use or carbon emissions.

	Heating	Cooling	Total
MBTU[a]	-198,400	n/a	-198,400
MWH[b]	-1,700	20,600	18,900
Carbon avoided (t)	-3,600	2,400	-1,200

[a]Million British Thermal Units
[b]Megawatt-hour

Annual savings[c] (U.S. $) in residential energy expenditures during heating and cooling seasons. Note: negative numbers indicate a cost due to increased energy use or carbon emissions

	Heating	Cooling	Total
MBTU[a]	-1,808,000	n/a	-1,808,000
MWH[b]	-190,000	2,360,000	2,170,000
Carbon avoided	-75,100	50,400	-24,700

[a]Million British Thermal Units
[b]Megawatt-hour
[c]Based on state-wide energy costs

Richard Webb, self-employed horticulturist, bugwood.org

Urban forests have a structural value based on the tree itself.

Urban forests also have functional values based on the functions the tree performs.

Large, healthy, long-lived trees provide the greatest structural and functional values.

A map of priority planting locations for Chicago is found in Appendix IV.

A list of tree species found in Chicago is in Appendix V.

Structural and Functional Values

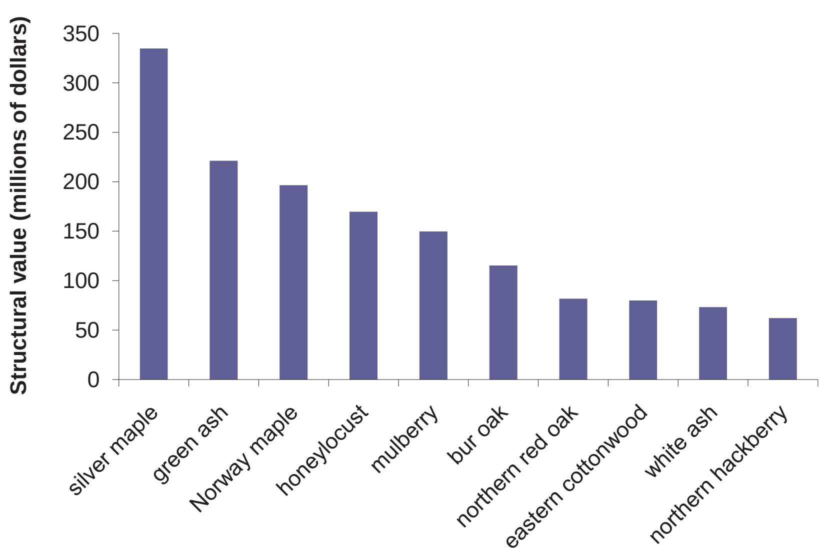
Urban forests have a structural value based on the tree itself (e.g., the cost of having to replace the tree with a similar tree). The structural value[10] of the urban forest in Chicago is about $2.3 billion. The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees.

Urban forests also have functional values (either positive or negative) based on the functions the tree performs. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. There are many other functional values of the urban forest, though they are not quantified here (e.g., reduction in air temperatures and ultra-violet radiation, improvements in water quality). Through proper management, urban forest values can be increased. However, the values and benefits also can decrease as the amount of healthy tree cover declines.

Structural values:
- Structural value: $2.3 billion
- Carbon storage: $14.8 million

Annual functional values:
- Carbon sequestration: $521,000
- Pollution removal: $6.4 million
- Reduced energy costs: $360,000

More detailed information on the urban forest in Chicago can be found at http://nrs.fs.fed.us/data/urban. Additionally, information on other urban forest values can be found in Appendix I and information comparing tree benefits to estimates of average carbon emissions in the city, average automobile emissions, and average household emissions can be found in Appendix III.



Asian longhorned beetle

Kenneth R. Law
USDA APHIS PPQ
(www.invasive.org)

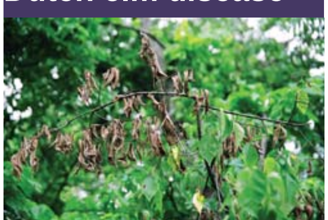
Gypsy moth

USDA Forest Service Archives
(www.invasive.org)

Emerald ash borer

David Cappaert
Michigan State University
(www.invasive.org)

Dutch elm disease

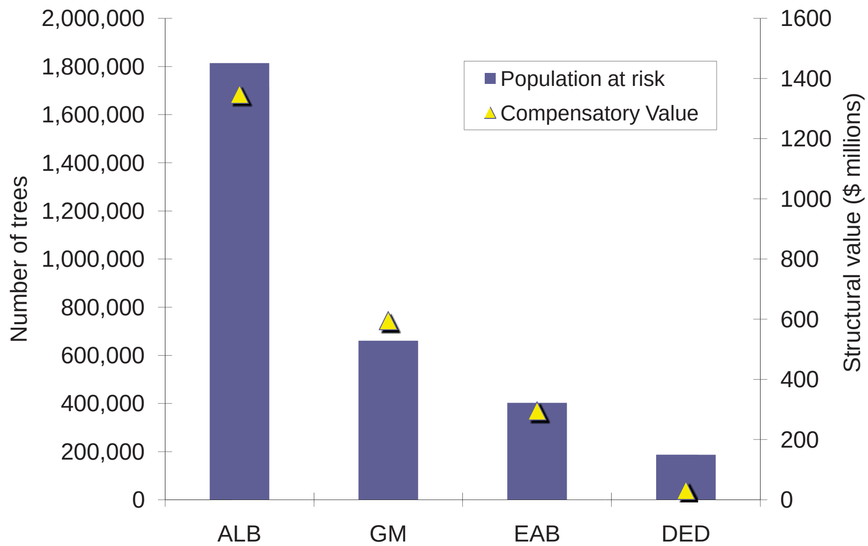


USDA Forest Service

Potential Insect and Disease Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As various pests have differing tree hosts, the potential damage or risk of each pest will differ. Four exotic pests were analyzed for their potential impact: Asian longhorned beetle, gypsy moth, emerald ash borer, and Dutch elm disease.

The Asian longhorned beetle (ALB)[16] is an insect that bores into and kills a wide range of hardwood species. This beetle, which has recently reappeared in the Chicago region after having been eradicated, represents a potential loss to the Chicago urban forest of $1.3 billion in structural value (53.6 percent of live tree population).



The gypsy moth (GM)[17] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest could potentially result in damage to or a loss of $595 million in structural value of Chicago's trees (19.5 percent of live tree population).

Emerald ash borer (EAB)[18] has killed thousands of ash trees in Michigan, Ohio, and Indiana. EAB has the potential to affect 11.9 percent of Chicago's live tree population ($295 million in structural value).

American elm, one of the most important street trees in the 20th century, has been devastated by Dutch elm disease (DED). Since first reported in the 1930s, it has killed more than 50 percent of the native elm population in the United States.[19] Although some elm species have shown varying degrees of resistance, Chicago possibly could lose 5.5 percent of its trees to this disease ($31 million in structural value).

Chicago Parks contain:

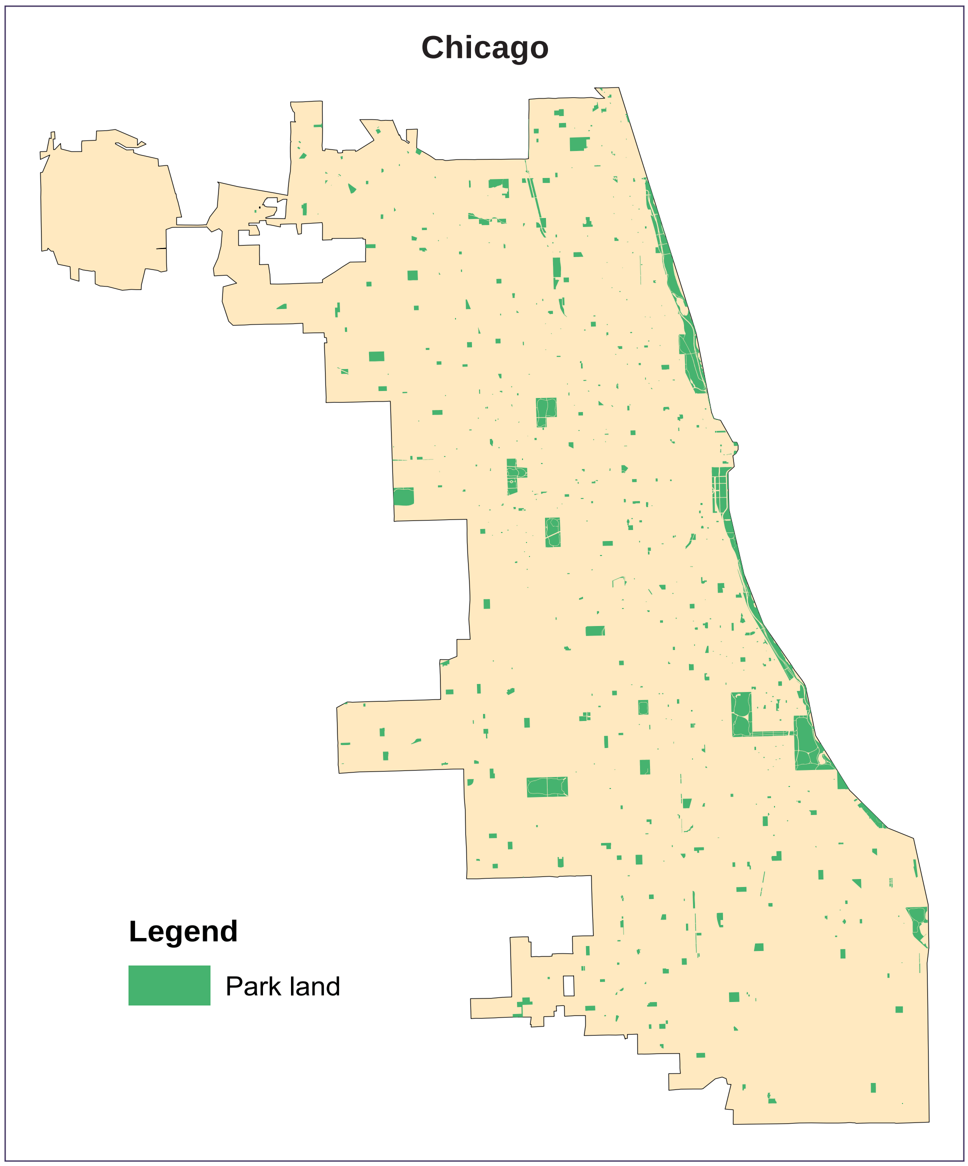
- **274,000 trees**
- **Tree density of 43.2 trees per acre**
- **At least 58 different species of trees**

Most common tree species in Chicago Parks

- **Green ash**
- **European buckthorn**
- **Hawthorn**

Chicago Parks

To help understand more about the trees in Chicago's park land, which currently encompass approximately 7,700 acres, a separate analysis was conducted for parks in the city. For this analysis, only 6,300 acres of park land were sampled due to recent increases in park land and differences in GIS park boundary files at the time of the field sample selection. Thus current park trees benefits are likely about 20 percent higher than reported here. During the sampling of the city of Chicago, 53 of the 745 plots sampled fell within park land. Additional plots were sampled to bring the sample total in parks to 158 plots.



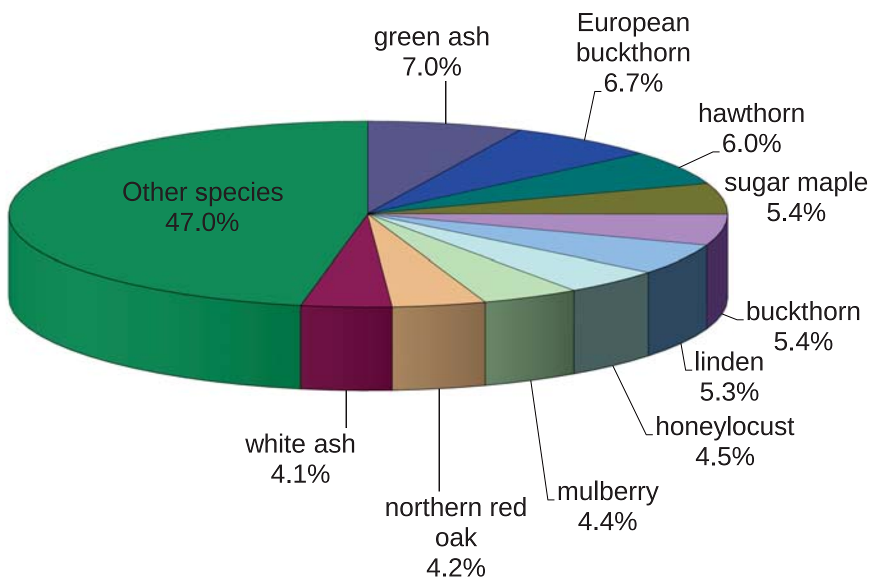
David Cappaert, Michigan State University, bugwood.org, 5110042

The ten most common species account for 53.0 percent of the total park tree population.

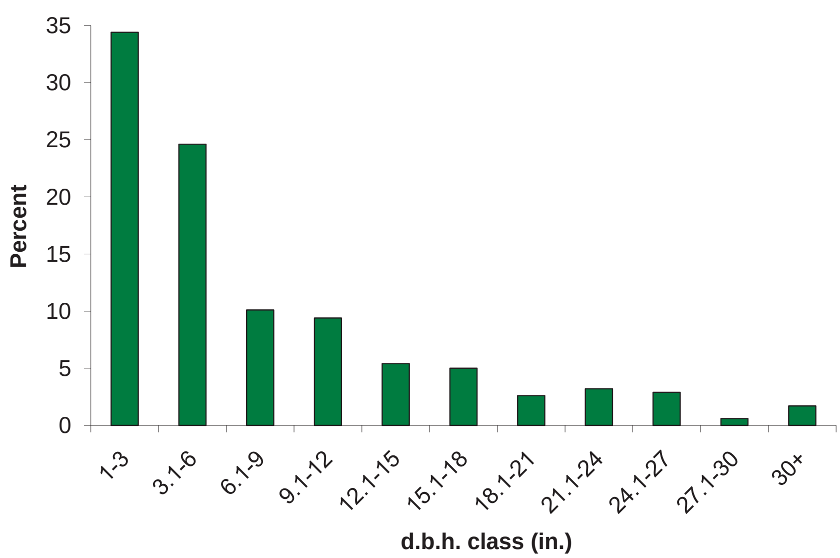
Park tree cover is estimated at 31.6 percent.

Park trees less than 6 inches in diameter account for 59.0 percent of the population.

Based on this sample, parks in Chicago are estimated to contain 274,000 trees (7.6 percent of the city's tree population) with an average tree density of 43.2 trees per acre. The most common live trees in parks are green ash (7.0 percent) followed by European buckthorn (6.7 percent) and hawthorn species (6.0 percent), however standing dead trees comprise 7.3 percent of the population. There were a total of 58 different species of trees sampled.



Park tree cover is estimated at 31.6 percent with an overall leaf area index (LAI) of 1.3. The majority of the trees were less than or equal to 6 inches in diameter (59.0 percent). The leaf surface area of parks trees is equal to 12.5 square miles.



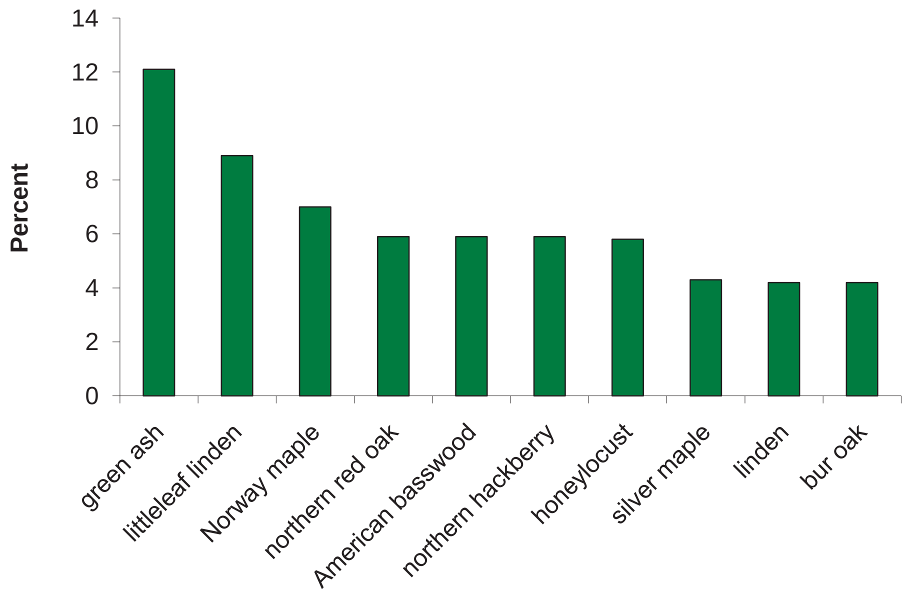
David Nowak, U.S. Forest Service

Tree species that contribute the most leaf surface area in parks are:

- **green ash**
- **littleleaf linden**
- **Norway maple**

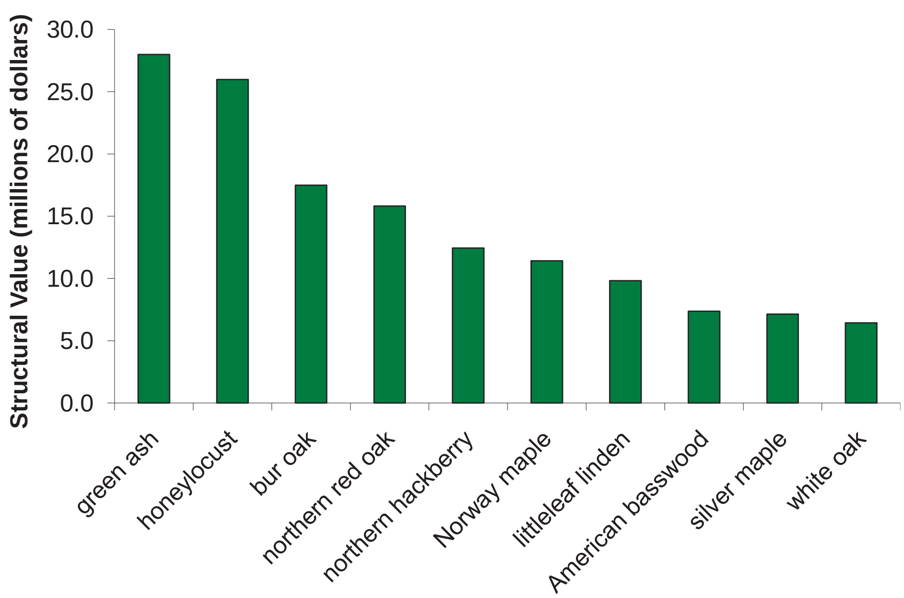
Park trees remove about 1,600 tons of carbon per year and about 64 tons of air pollution per year.

Leaf area has a strong correlation with benefits that the trees produce for the ecosystem, such as pollution removal. Green ash contributes 12.1 percent of the leaf area in parks, followed by littleleaf linden (8.9 percent) and Norway maple (7.0 percent).



Park trees have an estimated structural value of $192 million. Additional functional benefits provided by park trees are:

Carbon storage: 52,700 tons ($1.1 million)
Carbon sequestration: 1,600 tons/year ($32,800/year)
Air pollution removal: 64 tons/year ($344,000/year)



Pennsylvania Department of Conservation and Natural Resources, Forestry Archive, bugwood.org, 5017015

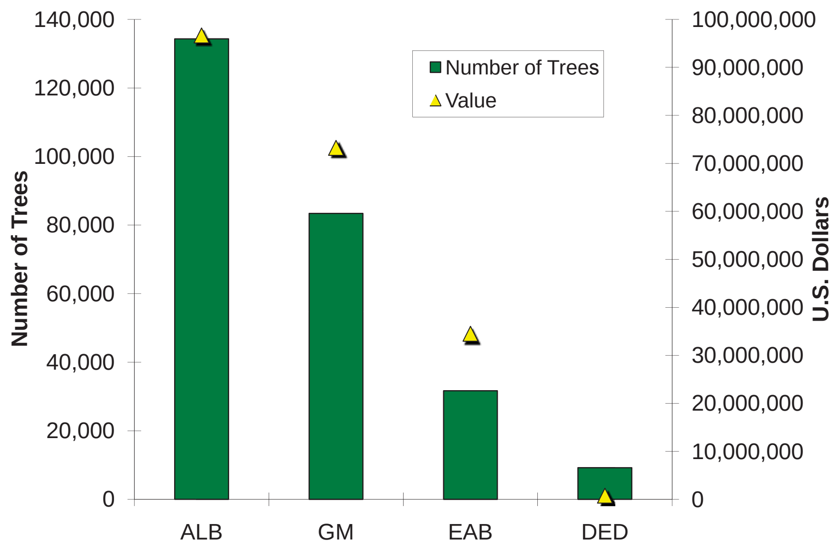
Asian longhorned beetle is a potential threat to 49.0 percent of the park trees.

Tree species with the greatest structural value are:

- **green ash**
- **honeylocust**
- **bur oak**

The risk to park trees from various pests and diseases are:

- Asian longhorned beetle – potential threat to 134,300 trees (49.0 percent of park trees)
- Gypsy moth – potential threat to 83,400 trees (30.5 percent of park trees)
- Emerald ash borer – potential threat to 31,700 trees (11.6 percent of park trees)
- Dutch elm disease – potential threat to 9,200 trees (3.4 percent of park trees)



Data from this report provide the basis for a better understanding of the urban forest resource and the ecosystem services and values provided by this resource. Managers and citizens can use these data to help develop improved long-term management plans and policies to sustain a healthy urban tree population and ecosystem services for future generations. Improved planning and management to sustain healthy tree populations can lead to improved environmental quality and quality of life for Chicago's residents.

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Millennium Park in Chicago.

David Nowak, U.S. Forest Service

Efforts made since 1989 to improve and expand Chicago's urban forest:

- **Commissioned the Chicago Urban Forest Climate Project**
- **Established the Bureau of Forestry to plant and maintain parkway trees**
- **Acted to limit the impact of invasive species**
- **Developed Chicago's Urban Forest Agenda 2009**

Chicago's Urban Forestry Efforts

Mayor Richard M. Daley has made it a priority to improve and expand Chicago's urban forest. Since 1989, Chicago has taken many steps toward this goal, including: commissioning the Chicago Urban Forest Climate Project to better understand the effects of vegetation influences local climate, energy use, and air quality; establishing the Bureau of Forestry within the Department of Streets and Sanitation to plant and maintain the over 540,000 parkway trees; taking aggressive action to limit the impact of harmful invasive species such as the Asian longhorned beetle, preventing the loss of more than half of our city trees; and developing a plan, Chicago's Urban Forest Agenda 2009, to address future challenges and set sustainable landscape goals for the city. These efforts reflect the city's strong commitment to protect and improve the quality of the urban forest and make Chicago a more livable city.

This report contributes to the significant research efforts made to understand the role of the urban forest in mitigating and adapting to climate change. In 2008, Chicago released its Climate Action Plan outlining 26 strategies to reduce greenhouse gas emissions by 80 percent below 1990 levels by 2050, with the midterm reduction target of 15.1 million metric tons of CO_2 equivalents, or 25 percent below 1990 levels by 2020 (CO_2 equivalent is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas). Tree related strategies include expanding the tree canopy to mitigate emissions and adaptation actions to prepare the urban forest for a changing climate. For more information about the Chicago Climate Action Plan, visit www.chicagoclimateaction.org

A view toward the Sears Tower down Wentworth Avenue in Chicago.

Appendix I. Comparison of Urban Forests

A commonly asked question is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the UFORE model.

I. City totals, trees only

City	% Tree cover	Number of trees	Carbon storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (tons/yr)	Pollution value U.S. $
Calgary, Canada[a]	7.2	11,889,000	445,000	21,400	326	2,357,000
Atlanta, GA[b]	36.7	9,415,000	1,344,000	46,400	1,663	12,213,000
Toronto, Canada[c]	20.5	7,542,000	992,000	40,300	1,212	8,952,000
New York, NY[b]	20.9	5,212,000	1,350,000	42,300	1,677	11,834,000
Chicago, IL[d]	17.2	3,585,000	716,000	25,200	888	6,398,000
Baltimore, MD[e]	21.0	2,627,000	597,000	16,200	430	3,123,000
Philadelphia, PA[b]	15.7	2,113,000	530,000	16,100	576	4,150,000
Washington, DC[f]	28.6	1,928,000	526,000	16,200	418	2,858,000
Boston, MA[b]	22.3	1,183,000	319,000	10,500	284	2,092,000
Woodbridge, NJ[g]	29.5	986,000	160,000	5,560	210	1,525,000
Minneapolis, MN[h]	26.4	979,000	250,000	8,900	306	2,242,000
Syracuse, NY[e]	23.1	876,000	173,000	5,420	109	836,000
San Francisco, CA[a]	11.9	668,000	194,000	5,100	141	1,018,000
Morgantown, WV[i]	35.5	658,000	93,000	2,890	72	489,000
Moorestown, NJ[g]	28.0	583,000	117,000	3,760	118	841,000
Jersey City, NJ[g]	11.5	136,000	21,000	890	41	292,000
Freehold, NJ[g]	34.4	48,000	20,000	545	22	162,000

II. Per acre values of tree effects

City	No. of trees	Carbon Storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (lbs/yr)	Pollution value U.S. $
Calgary, Canada[a]	66.7	2.5	0.12	3.7	13.2
Atlanta, GA[b]	111.6	15.9	0.55	39.4	144.8
Toronto, Canada[c]	48.3	6.4	0.26	15.5	57.3
New York, NY[b]	26.4	6.8	0.21	17.0	59.9
Chicago, IL[d]	24.3	4.8	0.17	12.0	43.3
Baltimore, MD[e]	50.8	11.6	0.31	16.6	60.4
Philadelphia, PA[b]	25.1	6.3	0.19	13.6	49.2
Washington, DC[f]	49.0	13.4	0.41	21.3	72.7
Boston, AM[b]	33.5	9.1	0.30	16.1	59.3
Woodbridge, NJ[g]	66.5	10.8	0.38	28.4	102.9
Minneapolis, MN[h]	26.2	6.7	0.24	16.4	60.1
Syracuse, NY[e]	54.5	10.8	0.34	13.5	52.0
San Francisco, CA[a]	22.5	6.6	0.17	9.5	34.4
Morgantown, WV[i]	119.2	16.8	0.52	26.0	87.8
Moorestown, NJ[g]	62.1	12.4	0.40	25.1	89.5
Jersey City, NJ[g]	14.4	2.2	0.09	8.6	30.8
Freehold, NJ[g]	38.3	16.0	0.44	34.9	130.1

Data collection group

[a] City personnel
[b] ACRT, Inc.
[c] University of Toronto
[d] Various Departments of the City of Chicago
[e] U.S. Forest Service
[f] Casey Trees Endowment Fund
[g] New Jersey Department of Environmental Protection
[h] Davey Resource Group
[i] West Virginia University

Appendix II. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment. Four main ways that urban trees affect air quality are:

Temperature reduction and other microclimatic effects
Removal of air pollutants
Emission of volatile organic compounds (VOC) and tree maintenance emissions
Energy conservation in buildings and consequent power plant emissions

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the overall impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities. Local urban forest management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include:

Strategy	Reason
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

Appendix III. Relative Tree Effects

The urban forest in Chicago provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate a relative value of these benefits, tree benefits were compared to estimates of average carbon emissions in the city[20], average passenger automobile emissions[21], and average household emissions.[22]

General tree information:

Average tree diameter (d.b.h.) = 7.7 in.
Median tree diameter (d.b.h.) = 4.3 in.
Average number of trees per person = 1.3
Number of trees sampled = 1,697
Number of species sampled = 103

Average tree effects by tree diameter:

	Carbon storage			Carbon sequestration			Pollution removal	
D.b.h. Class (inch)	(lbs)	($)	(miles) [a]	(lbs/yr)	($/yr)	(miles)[a]	(lbs)	($)
1-3	6	0.06	20	1.8	0.02	6	0.05	0.17
3-6	37	0.38	130	5.5	0.06	20	0.2	0.60
6-9	127	1.32	470	10.9	0.11	40	0.4	1.56
9-12	304	3.15	1,110	17.6	0.18	65	0.7	2.65
12-15	538	5.56	1,970	23.8	0.25	87	1.1	3.99
15-18	859	8.89	3,150	32.4	0.34	119	1.2	4.48
18-21	1,286	13.31	4,710	42.8	0.44	157	1.7	5.95
21-24	1,709	17.68	6,260	48.3	0.50	177	1.5	5.50
24-27	2,258	23.36	8,270	60.0	0.62	220	1.8	6.48
27-30	3,116	32.24	11,410	72.0	0.75	264	2.7	9.81
30+	5,160	53.38	18,900	95.7	0.99	350	2.7	9.86

[a] miles = number of automobile miles driven that produces emissions equivalent to tree effect

The Chicago urban forest provides:

Carbon storage equivalent to:
Amount of carbon (C) emitted in city in 15 days or
Annual carbon emissions from 430,000 automobiles or
Annual C emissions from 215,700 single family houses

Carbon monoxide removal equivalent to:
Annual carbon monoxide emissions from 86 automobiles or
Annual carbon monoxide emissions from 400 single family houses

Nitrogen dioxide removal equivalent to:
Annual nitrogen dioxide emissions from 10,200 automobiles or
Annual nitrogen dioxide emissions from 6,800 single family houses

Sulfur dioxide removal equivalent to:
Annual sulfur dioxide emissions from 110,400 automobiles or
Annual sulfur dioxide emissions from 1,900 single family houses

Particulate matter less than 10 micron (PM_{10}) removal equivalent to:
Annual PM_{10} emissions from 809,000 automobiles or
Annual PM_{10} emissions from 78,100 single family houses

Annual C sequestration equivalent to:
Amount of C emitted in city in 0.5 days or
Annual C emissions from 15,100 automobiles or
Annual C emissions from 7,600 single family homes

Appendix IV. Tree Planting Index Map

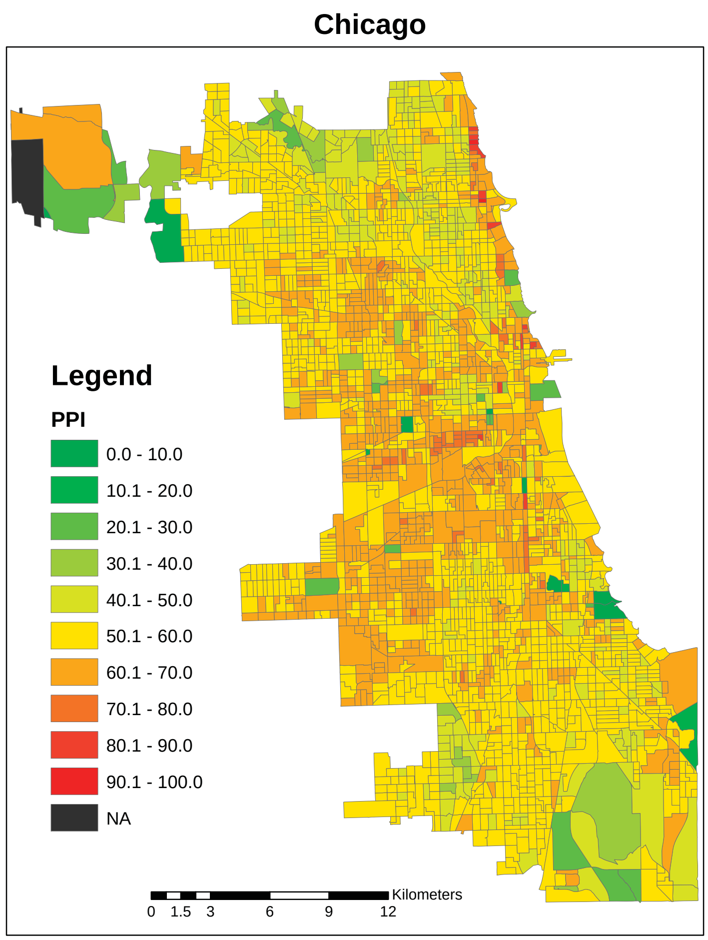
To determine the best locations to plant trees, high resolution tree canopy and impervious cover maps from Chicago[12] were used in conjunction with 2000 U.S. Census data to produce an index of priority planting areas. Index values were produced for each census block group with the higher the index value, the higher the priority of the area for tree planting. This index is a type of "environmental equity" index with areas with higher human population density and lower tree cover tending to get the higher index value. The criteria used to make the index were:

- Population density: the greater the population density, the greater the priority for tree planting
- Tree stocking levels: the lower the tree stocking level (the percent of available greenspace (tree, grass, and soil cover areas) that is occupied by tree canopies), the greater the priority for tree planting
- Tree cover per capita: the lower the amount of tree canopy cover per capita (m^2/capita), the greater the priority for tree planting

Each criteria was standardized[23] on a scale of 0 to 1 with 1 representing the census block group with the highest value in relation to priority of tree planting (i.e., the census block group with highest population density, lowest stocking density or lowest tree cover per capita were standardized to a rating of 1). Individual scores were combined and standardized based on the following formula to produce an overall priority planting index (PPI) value between 0 and 100:

$$PPI = (PD * 40) + (TS * 30) + (TPC * 30)$$

Where PPI = index value, PD is standardized population density, TS is standardized tree stocking, and TPC is standardized tree cover per capita.



Appendix V. List of Species Sampled in Chicago

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest [b] ALB	GM	EAB	DED
Acer	*negundo*	Boxelder	3.5	1.3	4.8	✦			
Acer	*palmatum*	Japanese maple	0.3	0.1	0.4	✦			
Acer	*platanoides*	Norway maple	4.0	11.4	15.4	✦			
Acer	*rubrum*	Red maple	0.7	1.0	1.7	✦			
Acer	*saccharinum*	Silver maple	4.6	12.5	17.1	✦			
Acer	*saccharum*	Sugar maple	2.2	2.4	4.6	✦			
Acer	*species*	Maple	0.1	0.2	0.3	✦			
Aesculus	*species*	Buckeye species	0.1	0.1	0.2	✦			
Ailanthus	*altissima*	Tree of heaven	4.7	2.6	7.3				
Amelanchier	*arborea*	Downy serviceberry	0.1	<0.1	0.1				
Amelanchier	*species*	Serviceberry	0.3	<0.1	0.3				
Betula	*nigra*	River birch	0.5	0.1	0.6	✦	✦		
Betula	*papyrifera*	Paper birch	0.1	0.2	0.3	✦	✦		
Betula	*populifolia*	Gray birch	0.1	<0.1	0.1	✦	✦		
Carpinus	*caroliniana*	American hornbeam	0.1	<0.1	0.1				
Carya	*ovata*	Shagbark hickory	0.1	<0.1	0.1				
Carya	*species*	Hickory	0.2	0.1	0.3				
Catalpa	*species*	Catalpa	0.2	0.3	0.5				
Catalpa	*speciosa*	Northern catalpa	0.4	0.3	0.7				
Celtis	*occidentalis*	Northern hackberry	1.7	2.2	3.9				
Celtis	*occidentalis*	Common hackberry	0.2	<0.1	0.2				
Celtis	*species*	Hackberry	0.2	<0.1	0.2				
Cercis	*canadensis*	Eastern redbud	0.3	0.1	0.4				
Cornus	*florida*	Flowering dogwood	0.1	<0.1	0.1				
Cornus	*species*	Dogwood	0.1	<0.1	0.1				
Cotinus	*coggygria*	Smoke tree	0.1	<0.1	0.1		✦		
Crataegus	*crus-galli*	Cockspur hawthorn	0.3	<0.1	0.3		✦		
Crataegus	*phaenopyrum*	Washington hawthorn	0.3	0.3	0.6		✦		
Crataegus	*species*	Hawthorn	3.3	1.7	5.0		✦		
Elaeagnus	*angustifolia*	Russian olive	0.1	0.1	0.2	✦			
Euonymus	*atropurpureus*	Eastern wahoo	0.1	<0.1	0.1				
Fraxinus	*americana*	White ash	6.0	3.9	9.9	✦		✦	
Fraxinus	*nigra*	Black ash	0.1	0.1	0.2	✦		✦	
Fraxinus	*pennsylvanica*	Green ash	4.9	7.5	12.4	✦		✦	
Fraxinus	*species*	Ash	0.3	<0.1	0.3	✦		✦	
Ginkgo	*biloba*	Ginkgo	0.1	0.1	0.2				
Gleditsia	*triacanthos*	Honeylocust	3.3	2.6	5.9				

Continued

Appendix V continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest[b] ALB	GM	EAB	DED
Gymnocladus	*dioicus*	Kentucky coffeetree	0.2	<0.1	0.2				
Hamamelis	*virginiana*	Witch hazel	0.1	<0.1	0.1		✦		
Hibiscus	*syriacus*	Rose-of-sharon	0.5	<0.1	0.5	✦			
Juglans	*nigra*	Black walnut	0.4	1.4	1.8				
Juniperus	*species*	Juniper	0.9	0.1	1.0				
Juniperus	*virginiana*	Eastern red cedar	0.8	0.3	1.1				
Ligustrum	*species*	Privet	0.4	<0.1	0.4				
Ligustrum	*vulgare*	Common privet	0.2	<0.1	0.2				
Liquidambar	*styraciflua*	Sweetgum	0.2	0.1	0.3		✦		
Lonicera	*species*	Honeysuckle	0.1	<0.1	0.1				
Magnolia	*denudata*	Chinese magnolia	0.2	0.1	0.3				
Magnolia	*species*	Magnolia	0.1	0.1	0.2				
Malus	*pumila*	Apple	0.1	0.1	0.2	✦	✦		
Malus	*species*	Crabapple	1.3	1.3	2.6	✦	✦		
Morus	*alba*	White mulberry	0.1	0.5	0.6				
Morus	*rubra*	Red mulberry	0.3	0.2	0.5				
Morus	*species*	Mulberry	5.2	5.6	10.8				
Other	*species*	Other species	0.6	0.6	1.2				
Picea	*abies*	Norway spruce	0.3	0.8	1.1				
Picea	*pungens*	Blue spruce	1.0	0.8	1.8				
Picea	*species*	Spruce	0.5	0.7	1.2				
Pinus	*resinosa*	Red pine	0.1	<0.1	0.1				
Pinus	*species*	Pine	0.4	0.1	0.5				
Pinus	*strobus*	Eastern white pine	0.4	0.1	0.5				
Platanus	*occidentalis*	American sycamore	0.2	1.3	1.5	✦			
Populus	*alba*	White poplar	0.2	0.1	0.3	✦			
Populus	*deltoides*	Eastern cottonwood	3.2	6.0	9.2	✦			
Populus	*species*	Aspen	0.4	0.3	0.7	✦	✦		
Populus	*tremuloides*	Quaking aspen	0.1	0.1	0.2	✦	✦		
Prunus	*cerasifera*	Cherry plum	0.1	0.1	0.2	✦			
Prunus	*persica*	Nectarine	0.2	<0.1	0.2	✦			
Prunus	*serotina*	Black cherry	1.3	1.2	2.5	✦			
Prunus	*serrulata*	Kwanzan cherry	0.4	0.4	0.8	✦			
Prunus	*species*	Cherry	1.6	0.6	2.2	✦			
Prunus	*virginiana*	Common chokecherry	0.2	<0.1	0.2	✦			
Pyrus	*calleryana*	Callery pear	0.2	<0.1	0.2	✦			
Pyrus	*species*	Pear	0.3	0.1	0.4	✦			

Continued

Appendix V continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest [b]			
						ALB	GM	EAB	DED
Quercus	*alba*	White oak	0.8	1.0	1.8		✦		
Quercus	*macrocarpa*	Bur oak	0.4	1.8	2.2		✦		
Quercus	*muehlenbergii*	Chinkapin oak	0.1	<0.1	0.1		✦		
Quercus	*palustris*	Pin oak	0.2	0.5	0.7		✦		
Quercus	*rubra*	Northern red oak	1.7	2.5	4.2		✦		
Quercus	*x macnabiana*	McNab's oak	0.2	0.2	0.4		✦		
Rhamnus	*cathartica*	European buckthorn	4.5	0.7	5.2				
Rhamnus	*species*	Buckthorn	2.3	0.6	2.9				
Rhododendron	*species*	Rhododendron	0.2	<0.1	0.2				
Rhus	*typhina*	Staghorn sumac	0.1	<0.1	0.1		✦		
Robinia	*pseudoacacia*	Black locust	0.5	0.8	1.3	✦			
Salix	*exigua*	Sandbar willow	0.1	<0.1	0.1	✦	✦		
Salix	*species*	Willow	0.1	<0.1	0.1	✦	✦		
Syringa	*reticulata*	Japanese tree lilac	0.2	<0.1	0.2				
Syringa	*species*	Lilac	0.9	0.1	1.0				
Taxus	*species*	Yew	1.7	0.4	2.1				
Thuja	*occidentalis*	Northern white cedar	3.0	0.5	3.5				
Tilia	*americana*	American basswood	1.6	3.0	4.6	✦	✦		
Tilia	*cordata*	Littleleaf linden	1.5	5.0	6.5	✦	✦		
Tilia	*species*	Linden	2.0	1.8	3.8	✦	✦		
Tilia	*tomentosa*	Silver linden	0.1	0.2	0.3	✦	✦		
Ulmus	*americana*	American elm	4.5	3.9	8.4	✦			✦
Ulmus	*parvifolia*	Chinese elm	0.4	0.8	1.2	✦	✦		
Ulmus	*pumila*	Siberian elm	1.6	1.4	3.0	✦			
Ulmus	*rubra*	Slippery elm	0.1	<0.1	0.1	✦			✦
Ulmus	*species*	Elm	0.7	0.2	0.9	✦			✦
Viburnum	*prunifolium*	Black haw	0.4	0.1	0.5				
Viburnum	*species*	Viburnum	1.0	0.2	1.2				
Viburnum	*trilobum*	High-bush cranberry	0.1	<0.1	0.1				

[a] IV = importance value (% population + % leaf area)

[b] ALB = Asian longhorned beetle; GM = gypsy moth; EAB = emerald ash borer; DED = Dutch elm disease

Note: 3.8 percent of the population was classified as dead and is not included in this table

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Explanation of Calculations of Appendix III and IV

20 Total city carbon emissions were based on 2003 U.S. per capita carbon emissions, calculated as total U.S. carbon emissions (Energy Information Administration, 2003, Emissions of Greenhouse Gases in the United States 2003. http://www.eia.doe.gov/oiaf/1605/1605aold.html) divided by 2003 total U.S. population (www.census.gov). Per capita emissions were multiplied by Minneapolis population to estimate total city carbon emissions.

21 Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Carbon dioxide emissions from automobiles assumed 6 pounds of carbon per gallon of gasoline with energy costs of refinement and transportation included (Graham, R.L.; Wright, L.L.; Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO_2 emissions. Climatic Change. 22: 223-238.)

22 Average household emissions based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household from:

Energy Information Administration. Total Energy Consumption in U.S. Households by Type of Housing Unit, 2001 www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html.

CO_2, SO_2, and NOx power plant emission per KWh from:

U.S. Environmental Protection Agency. U.S. power plant emissions total by year www.epa.gov/cleanenergy/egrid/samples.htm.

CO emission per kWh assumes one-third of 1 percent of C emissions is CO based on:

Energy Information Administration. 1994. Energy use and carbon emissions: non-OECD countries. DOE/EIA-0579(94). Washington, DC: Department of Energy, Energy Information Administration. http://tonto.eia.doe.gov/bookshelf

PM_{10} emission per kWh from:

Layton, M. 2004. 2005 Electricity environmental performance report: electricity generation and air emissions. Sacramento, CA: California Energy Commission.
http://www.energy.ca.gov/2005_energypolicy/documents/2004-11-15_workshop/2004-11-15_03-A_LAYTON.PDF

CO_2, NOx, SO_2, PM_{10}, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from:

Abraxas energy consulting. http://www.abraxasenergy.com/emissions/

CO_2 and fine particle emissions per Btu of wood from:

Houck, J.E.; Tiegs, P.E.; McCrillis, R.C.; Keithley, C.; Crouch, J. 1998. Air emissions from residential heating: the wood heating option put into

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CO, NOx and SOx emission per Btu of wood based on total emissions from wood burning (tonnes) from:

Residential Wood Burning Emissions in British Columbia. 2005. http://www.env.gov.bc.ca/air/airquality/pdfs/wood_emissions.pdf.

Emissions per dry tonne of wood converted to emissions per Btu based on average dry weight per cord of wood and average Btu per cord from:

Kuhns, M.; Schmidt, T. 1988. Heating with wood: species characteristics and volumes I. NebGuide G-88-881-A. Lincoln, NE: University of Nebraska, Institute of Agriculture and Natural Resources, Cooperative Extension.

23 Standardized value for population density was calculated as PD = (n – m)/r, where PD is the value (0-1), n is the value for the census block (population / km^2), m is the minimum value for all census blocks, and r is the range of values among all census blocks (maximum value – minimum value). Standardized value for tree stocking was calculated as TS = 1 – [t/(t+g)], where TS is the value (0-1), t is percent tree cover, and g is percent grass cover. Standardized value for tree cover per capita was calculated as TPC = 1 – [(n – m)/r], where TPC is the value (0-1), n is the value for the census block (m^2/capita), m is the minimum value for all census blocks, and r is the range of values among all census blocks (maximum value – minimum value).

Nowak, David J.; Hoehn, Robert E. III; Crane, Daniel E.; Stevens, Jack C.; Leblanc Fisher, Cherie. 2010. **Assessing urban forest effects and values, Chicago's urban forest.** Resour. Bull. NRS-37. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 27 p.

An analysis of trees in Chicago, IL, reveals that this city has about 3,585,000 trees with canopies that cover 17.2 percent of the area. The most common tree species are white ash, mulberry species, green ash, and tree-of-heaven. Chicago's urban forest currently stores about 716,000 tons of carbon valued at $14.8 million. In addition, these trees remove about 25,200 tons of carbon per year ($521,000 per year) and about 888 tons of air pollution per year ($6.4 million per year). Trees in Chicago are estimated to reduce annual residential energy costs by $360,000 per year. The structural, or compensatory, value is estimated at $2.3 billion. Information on the structure and functions of the urban forest can be used to inform urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Chicago area.

KEY WORDS: urban forestry, ecosystem services, air pollution removal, carbon sequestration, tree value

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