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Research Station**

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Assessing Urban Forest Effects and Values

Minneapolis' Urban Forest

Northeastern Research Station
USDA Forest Service

UFORE
Urban Forest Effects Model

Abstract

An analysis of trees in Minneapolis, MN, reveals that the city has about 979,000 trees with canopies that cover 26.4 percent of the area. The most common tree species are green ash, American elm, and boxelder. The urban forest currently stores about 250,000 tons of carbon valued at $4.6 million. In addition, these trees remove about 8,900 tons of carbon per year ($164,000 per year) and trees and shrubs combined remove about 384 tons of air pollution per year ($1.9 million per year). The structural, or compensatory, value is estimated at $756 million. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Minneapolis area.

The Authors

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

In 2004, the UFORE model was used to survey and analyze Minneapolis' urban forest.

The calculated environmental benefits of the Minneapolis 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 USDA Forest Service, Northeastern 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 for 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, such as 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 Minneapolis, a vegetation assessment was conducted during the summer of 2004. 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
- Risk of insect pests and diseases
- Air pollution removal
- Carbon storage
- Annual carbon removal (sequestration)
- Changes in building energy use

More detailed information can be found at: www.fs.fed.us/ne/syracuse/Data/data.htm.

Minneapolis Urban Forest Summary

Feature	Measure
Number of trees	979,000
Tree cover	26.4%
Most common species	green ash, American elm, boxelder
Percentage of trees < 6-inches diameter	47.3%
Pollution removal	384 tons/year ($1.9 million/year)
Carbon storage	250,000 tons ($4.6 million)
Carbon sequestration	8,900 tons/year ($164,000/year)
Building energy reduction	$216,000/year
Avoided carbon emissions	$16,000/year
Structural values	$756 million

Ton – short ton (U.S.) (2,000 lbs)

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

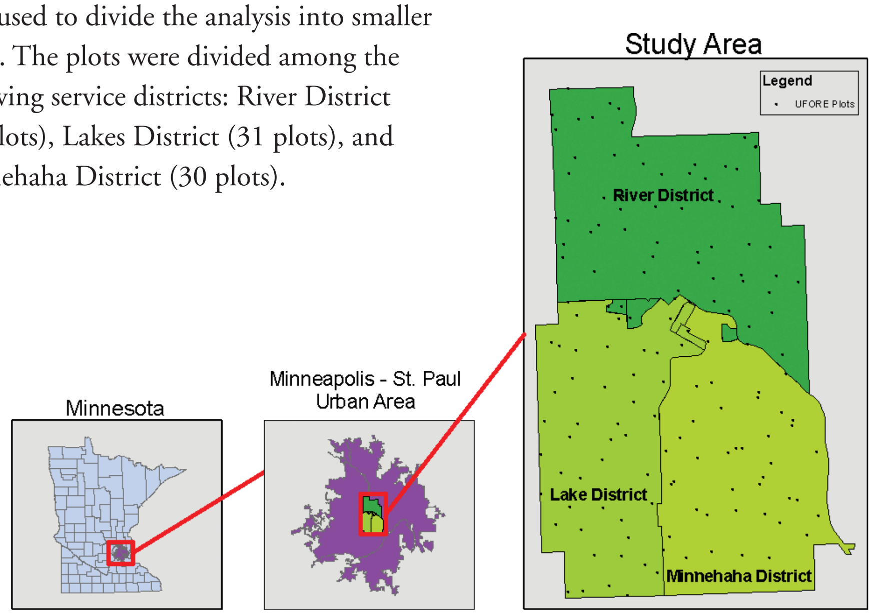
Though urban forests have many functions and values, currently only a few of these attributes can be assessed. To help assess the city's urban forest, data from 110 field plots located throughout the city were analyzed using the Forest Service's Urban Forest Effects (UFORE) model.[1]

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 energy use in buildings and consequent effects on carbon dioxide emissions from power plants.
- Compensatory value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetles, emerald ash borers, gypsy moth, and Dutch elm disease.

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

In the field, one-tenth acre plots were randomly located within a grid pattern at a density of approximately one plot every 340 acres. In Minneapolis, service districts were used to divide the analysis into smaller zones. The plots were divided among the following service districts: River District (49 plots), Lakes District (31 plots), and Minnehaha District (30 plots).



Field Survey Data

Plot Information

- Land use type
- Percent tree cover
- Percent shrub cover
- Percent plantable
- Percent ground cover types
- Shrub species / dimensions

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

Field data were collected by Davey Resource Group 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 energy use in residential building was 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.fs.fed.us/ne/syracuse/Data/data.htm or www.ufore.org

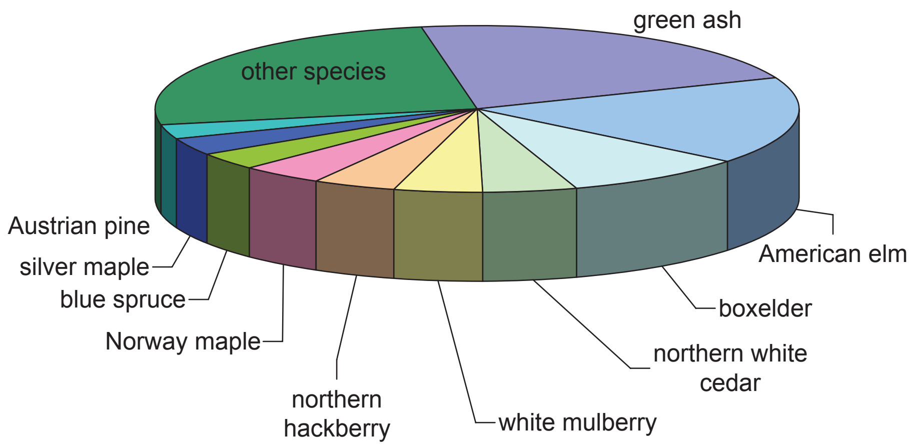
There are an estimated 979,000 trees in Minneapolis with canopies that cover 26.4 percent of the city.

The 10 most common species account for 75 percent of the total number of trees.

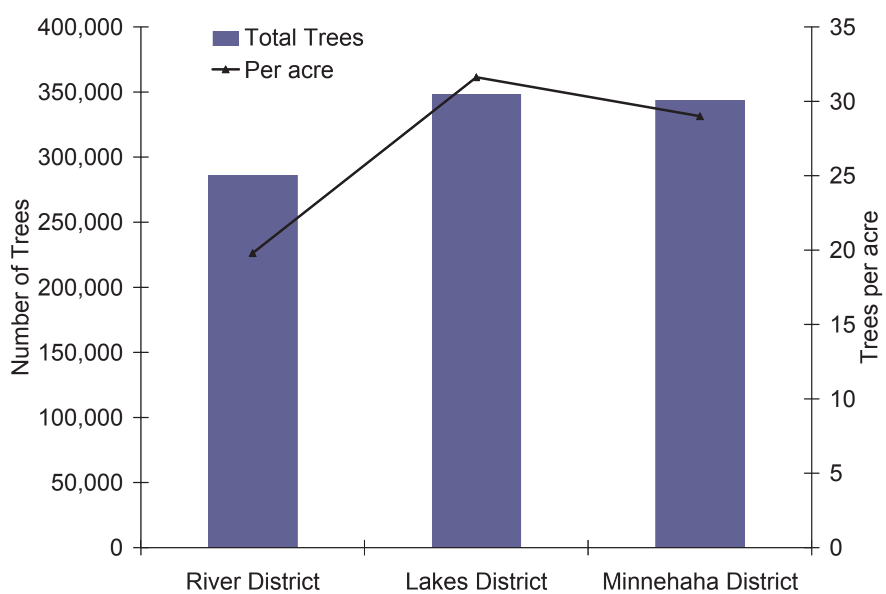
Tree density is highest in the Lakes District, lowest in the River District.

Tree Characteristics of the Urban Forest

The urban forest of Minneapolis has an estimated 979,000 trees and a tree cover of 26.4 percent. Trees with diameters less than 6 inches account for 47.3 percent of the population. The three most common species are green ash (21.6 percent), American elm (17.1 percent), and boxelder (9.1 percent). The 10 most common species account for 75 percent of all trees; their relative abundance is illustrated below.

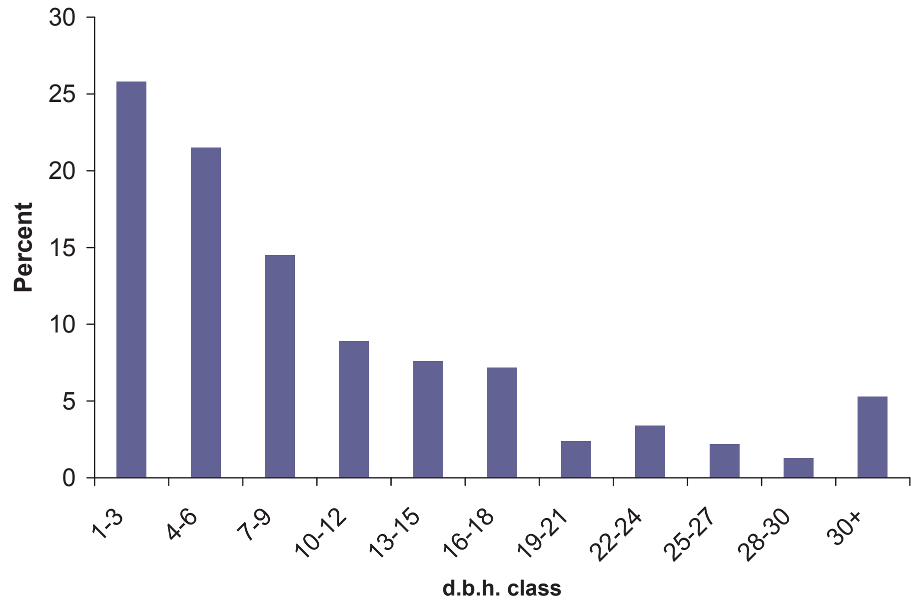


The highest density of trees occurs in the Lakes District (31.6 trees/acre), followed by the Minnehaha District (29.0 trees/acre) and the River District (19.8 trees/acre). The overall tree density in Minneapolis is 26.2 trees/acre, which is within the range of other city tree densities (Appendix I), of 14.4 to 119.2 trees/acre.

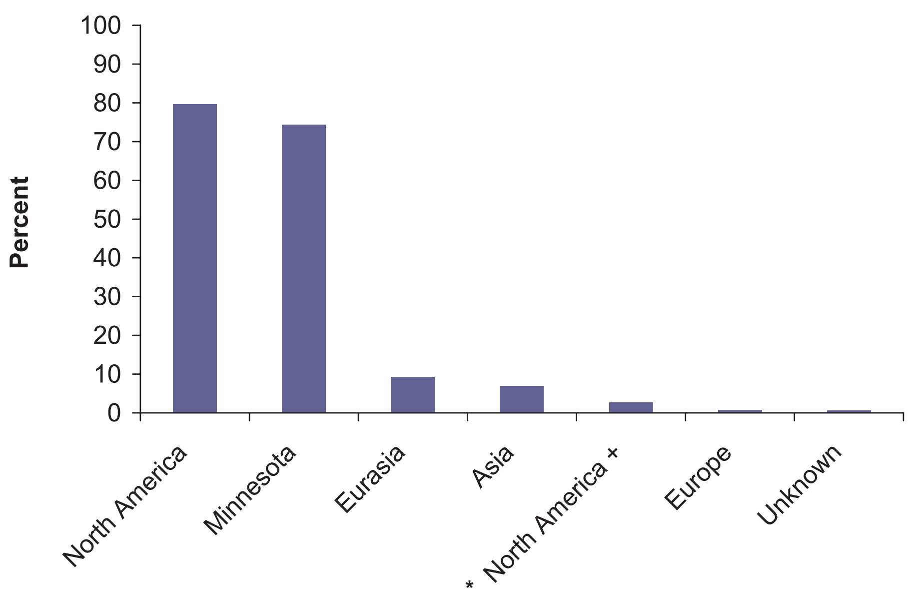


Nearly three-quarters of the tree species in Minneapolis are native to Minnesota.

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.



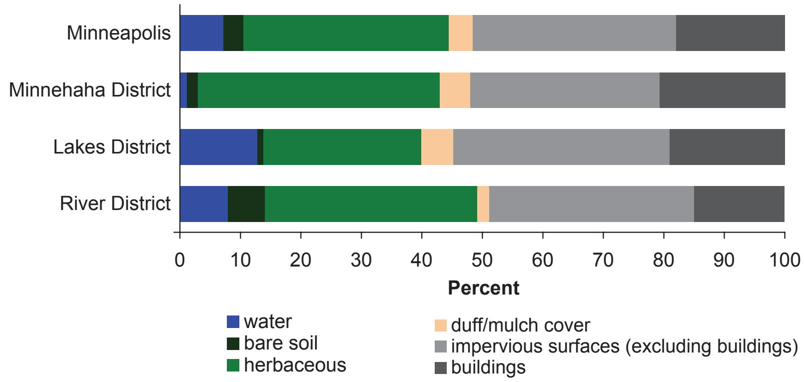
Urban forests are a mix of native trees species that existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. An increased tree diversity can minimize 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 exotics species are invasive plants that can potentially out-compete and displace native species. In Minneapolis, about 80 percent of the trees are species native to North America, while 74 percent are native to the state. Species exotic to Minnesota make up 26 percent of the population. Most exotic tree species have an origin from Eurasia (9.2 percent of the species).



*North America + refers to tree species that are native to North America and one other continent.

Urban Forest Cover and Leaf Area

Trees cover about 26.4 percent of Minneapolis and shrubs cover 6 percent of the city. Dominant ground cover types include herbaceous (e.g., grass, gardens) (34.0 percent), impervious surfaces (excluding buildings) (e.g., driveways, sidewalks, parking lots) (33.6 percent), and buildings (18.0 percent).



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

Green ash has the greatest importance to the Minneapolis urban forest based on relative leaf area and relative population.

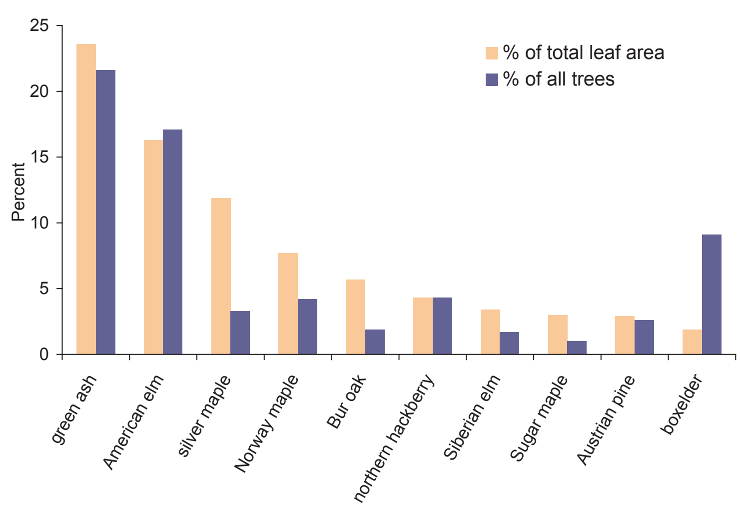
Many tree benefits are linked directly to the amount of healthy leaf surface area of the plant. In Minneapolis, trees that dominate in terms of leaf area are green ash, American elm, and silver maple.

Tree species with relatively large individuals contributing leaf area to the population (species with percentage of canopy much greater than percentage of population) are silver maple, bur oak, and sugar maple. Smaller trees in the population are American basswood, northern white cedar, and boxelder (species with percentage of canopy much less than percentage of 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.

Tree importance values (IV) are calculated using a formula that takes into account the relative leaf area and relative composition. The most important species in the urban forest, according to calculated IVs, are green ash, American elm, and silver maple.

Common Name	% Pop[a]	% LA[b]	IV[c]
green ash	21.6	24.8	46.4
American elm	17.1	16.1	33.2
silver maple	3.3	10.5	13.8
Norway maple	4.2	7.6	11.8
boxelder	9.1	1.4	10.5
northern hackberry	4.3	4.0	8.3
bur oak	1.9	5.4	7.3
white mulberry	4.3	1.2	5.5
northern white cedar	4.8	0.9	5.7

[a]Percent population
[b]Percent leaf area
[c]Importance value (%Pop + %LA)



The urban forest of Minneapolis removes about 384 tons of pollutants each year, with a value to society of $1.9 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 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.[12]

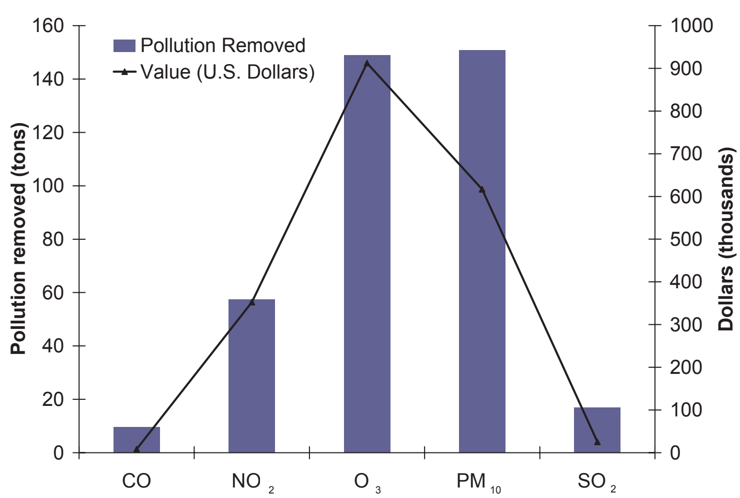
Pollution removal by trees and shrubs in Minneapolis was estimated using field data and hourly pollution and weather data for 2000. Pollution removal was greatest for particulate matter less than ten microns (PM_{10}), followed by ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). It is estimated that trees and shrubs remove 384 tons of air pollution (CO, NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $1.9 million (based on estimated national median externality costs associated with pollutants[13]). Trees remove about four times more air pollution than shrubs in Minneapolis.

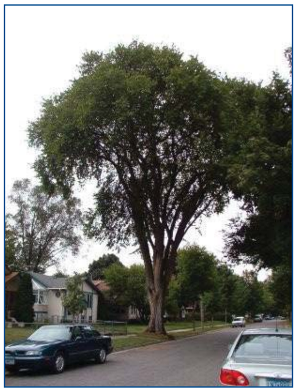
The average percentage of air pollution removal during the daytime, in-leaf season was estimated to be:

- O_3 0.58%
- PM_{10} 0.57%
- SO_2 0.57%
- NO_2 0.36%
- CO 0.002%

Peak 1-hour air quality improvements during the in-leaf season for heavily-treed areas (100% tree cover) was estimated to be:

- O_3 14.9%
- PM_{10} 11.1%
- SO_2 15.5%
- NO_2 7.2%
- CO 0.05%





Carbon storage:

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

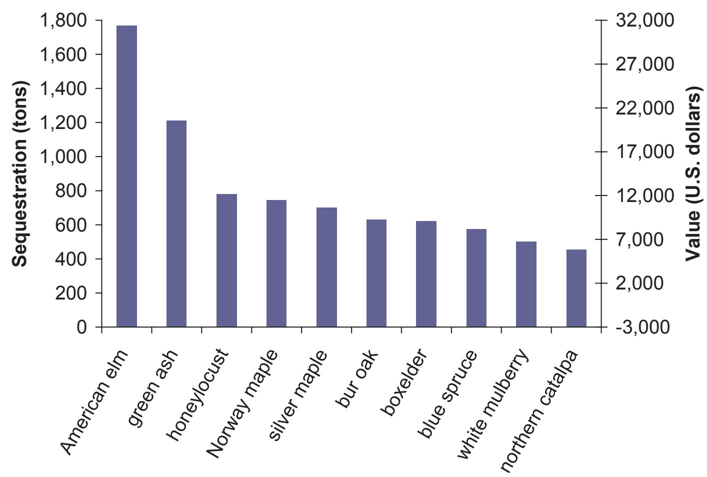
Carbon sequestration:

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.

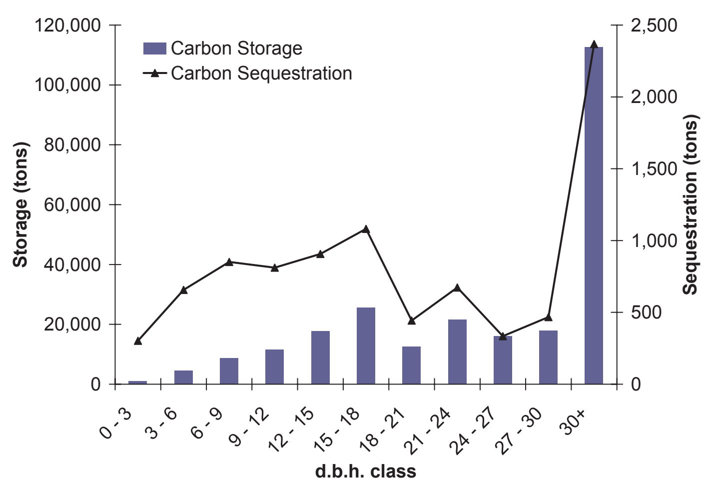
Carbon Storage and Sequestration

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, consequently reducing carbon dioxide emissions from fossil-fuel based power plants.[14]

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. Minneapolis' trees gross sequestration is about 8,900 tons of carbon per year with an associated value of $164,000. Net carbon sequestration in the Minneapolis urban forest is about 4,200 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 into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in Minneapolis are estimated to store 250,000 tons of carbon ($4.6 million). Of all the species sampled, American elm stores and sequesters the most carbon (about 18.6 percent of the total carbon stored and 19.2 percent of all sequestered carbon).



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

Interactions between buildings and trees save an estimated $221,000 in heating and cooling costs.

Lower energy use in residential buildings reduced carbon emissions from power plants by 900 tons ($15,900).

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]

Based on 2002 energy costs, trees in Minneapolis are estimated to reduce energy costs from residential buildings by $221,000 annually. Trees also provide an additional $15,900 in value by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 900 tons of carbon emissions).

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]	-174,000	n/a	-174,000
MWH[b]	-1,100	17,900	16,800
Carbon avoided (t)	-3,100	4,000	900

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

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

	Heating	Cooling	Total
MBTU[a]	-1,182,000	n/a	-1,182,000
MWH[b]	-96,000	1,499,000	1,403,000
Carbon avoided	-57,500	73,400	15,900

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

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 urban forest in Minneapolis is about $756 million. 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.

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.

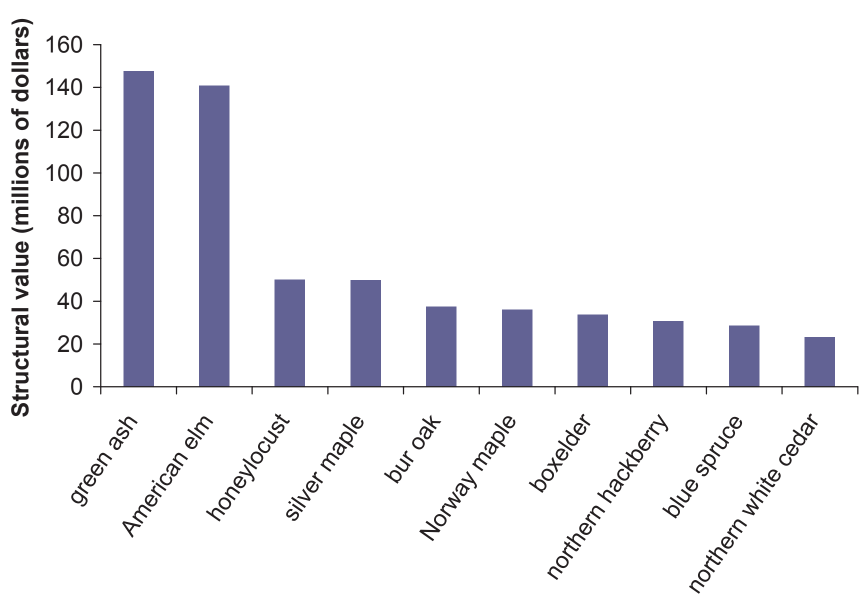
Structural values:

- Structural value: $756 million
- Carbon storage: $4.6 million

Annual functional values:

- Carbon sequestration: $164,000
- Pollution removal: $1.9 million
- Lower energy costs and carbon emission reductions: $237,000

More detailed information on the urban forest in Minneapolis can be found at www.fs.fed.us/ne/syracuse/Data/data.htm. Additionally, information on other urban forest values can be found in Appendix I and information comparing tree benefits to estimates of average carbons 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)

Emerald ash borer

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

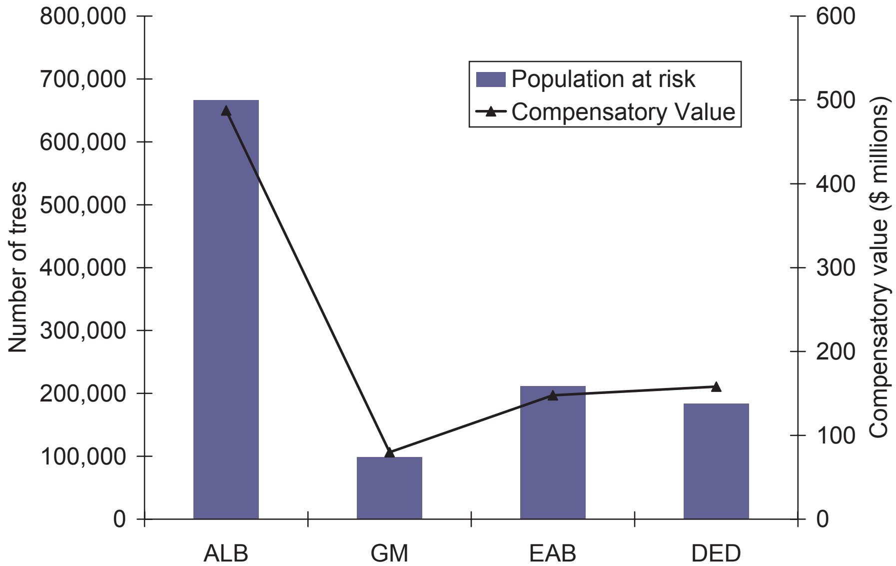
Gypsy moth

USDA Forest Service Archives
(www.invasive.org)

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)[15] is an insect that bores into and kills a wide range of hardwood species. ALB represents a potential loss to the Minneapolis urban forest of $487 million in structural value (68.1 percent of the tree population).



The gypsy moth (GM)[16] 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 a loss of $80 million in structural value (10.1 percent of the tree population).

Emerald ash borer (EAB)[17] has killed thousands of ash trees in Michigan, Ohio, and Indiana. EAB has the potential to affect 22.0 percent of the population ($148 million in structural value).

American elm, one of the most important street trees in the 20th century, has been devastated by the 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.[18] Although some elm species have shown varying degrees of resistance, Minneapolis possibly could lose 17.1 percent of its trees to this disease ($141 million in structural value).

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	1,611,000
Atlanta, GA[b]	36.7	9,415,000	1,344,000	46,400	1,663	8,321,000
Toronto, Canada[c]	20.5	7,542,000	992,000	40,300	1,212	6,105,000
New York, NY[b]	20.9	5,212,000	1,350,000	42,300	1,677	8,071,000
Baltimore, MD[d]	21.0	2,627,000	597,000	16,200	430	2,129,000
Philadelphia, PA[b]	15.7	2,113,000	530,000	16,100	576	2,826,000
Washington, DC[e]	28.6	1,928,000	523,000	16,100	418	1,956,000
Boston, MA[b]	22.3	1,183,000	319,000	10,500	284	1,426,000
Woodbridge, NJ[f]	29.5	986,000	160,000	5,560	210	1,037,000
Minneapolis, MN[g]	26.4	979,000	250,000	8,900	306	1,527,000
Syracuse, NY[d]	23.1	876,000	173,000	5,420	109	568,000
San Francisco, CA[a]	11.9	668,000	194,000	5,100	141	693,000
Morgantown, WV[h]	35.5	658,000	93,000	2,890	72	333,000
Moorestown, NJ[f]	28.0	583,000	117,000	3,760	118	576,000
Jersey City, NJ[f]	11.5	136,000	21,000	890	41	196,000
Freehold, NJ[f]	34.4	48,000	20,000	545	22	110,000

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	9.0
Atlanta, GA[b]	111.6	15.9	0.55	39.4	98.6
Toronto, Canada[c]	48.3	6.4	0.26	15.5	39.1
New York, NY[b]	26.4	6.8	0.21	17.0	40.9
Baltimore, MD[d]	50.8	11.6	0.31	16.6	41.2
Philadelphia, PA[b]	25.1	6.3	0.19	13.6	33.5
Washington, DC[e]	49.0	13.3	0.41	21.3	49.7
Boston, MA[b]	33.5	9.1	0.30	16.1	40.4
Woodbridge, NJ[f]	66.5	10.8	0.38	28.4	70.0
Minneapolis, MN[g]	26.2	6.7	0.24	16.4	40.9
Syracuse, NY[d]	54.5	10.8	0.34	13.5	35.4
San Francisco, CA[a]	22.5	6.6	0.17	9.5	23.4
Morgantown, WV[h]	119.2	16.8	0.52	26.0	60.3
Moorestown, NJ[f]	62.1	12.4	0.40	25.1	61.3
Jersey City, NJ[f]	14.4	2.2	0.09	8.6	20.7
Freehold, NJ[f]	38.3	16.0	0.44	34.9	88.2

Data collection group

[a] City personnel
[b] ACRT, Inc.
[c] University of Toronto
[d] U.S. Forest Service
[e] Casey Trees Endowment Fund
[f] New Jersey Department of Environmental Protection
[g] Davey Resource Group
[h] 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 Minneapolis 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 city[19], average passenger automobile emissions[20], and average household emissions.[21]

General tree information:

Average tree diameter (d.b.h.) = 10.3 in.
Median tree diameter (d.b.h.) = 6.7 in.
Average number of trees per person = 2.6
Number of trees sampled = 278
Number of species sampled = 41

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	8	0.08	30	2.4	0.02	9	0.4	0.86
3-6	44	0.40	160	6.2	0.06	23	0.4	0.95
6-9	124	1.15	460	12.0	0.11	44	0.6	1.34
9-12	268	2.47	980	18.7	0.17	69	0.8	1.86
12-15	483	4.45	1,770	24.5	0.23	90	0.8	1.81
15-18	721	6.64	2,640	30.3	0.28	111	0.9	2.01
18-21	1,068	9.84	3,910	37.7	0.35	138	0.8	1.84
21-24	1,303	12.00	4,770	40.7	0.37	149	0.9	1.99
24-27	1,516	13.97	5,550	31.4	0.29	115	1.7	3.75
27-30	2,883	26.55	10,560	75.3	0.69	276	0.7	1.69
30+	4,338	39.96	15,890	91.2	0.84	334	1.1	2.51

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

The Minneapolis urban forest provides:

Carbon storage equivalent to:
Amount of carbon (C) emitted in city in 40 days or
Annual C emissions from 150,000 automobiles or
Annual C emissions from 75,500 single family houses

Carbon monoxide removal equivalent to:
Annual carbon monoxide emissions from 31 automobiles or
Annual carbon monoxide emissions from 100 single family houses

Nitrogen dioxide removal equivalent to:
Annual nitrogen dioxide emissions from 2,900 automobiles or
Annual nitrogen dioxide emissions from 1,900 single family houses

Sulfur dioxide removal equivalent to:
Annual sulfur dioxide emissions from 19,900 automobiles or
Annual sulfur dioxide emissions from 300 single family houses

Particulate matter less than 10 micron (PM_{10}) removal equivalent to:
Annual PM10 emissions from 315,600 automobiles or
Annual PM10 emissions from 30,500 single family houses

Annual C sequestration equivalent to:
Amount of C emitted in city in 1.4 days or
Annual C emissions from 5,300 automobiles or
Annual C emissions from 2,700 single family homes

Appendix IV. List of Species Sampled in Minneapolis

Genus	Species	Common Name	% Population	% Leaf Area	IV [a]	Potential pest [b]			
						ALB	GM	EAB	DED
Abies	concolor	white fir	0.3	0.9	1.2				
Acer	negundo	boxelder	9.1	1.4	10.5	🌲			
Acer	platanoides	Norway maple	4.2	7.6	11.8	🌲			
Acer	saccharinum	silver maple	3.3	10.5	13.8	🌲			
Acer	saccharum	sugar maple	1.0	3.5	4.5	🌲			
Acer	rubrum	red maple	1.0	1.0	2.0	🌲			
Aesculus	pavia	red buckeye	0.4	1.2	1.6	🌲			
Aesculus	hippocastanum	horsechestnut	0.3	0.4	0.7	🌲			
Betula	papyrifera	paper birch	1.1	1.4	2.5	🌲	🌲		
Betula	pendula	European white birch	0.6	0.2	0.8	🌲	🌲		
Catalpa	speciosa	northern catalpa	0.7	1.2	1.9				
Celtis	occidentalis	northern hackberry	4.3	4.0	8.3				
Fraxinus	pennsylvanica	green ash	21.6	24.8	46.4	🌲		🌲	
Gleditsia	triacanthos	honeylocust	2.2	1.3	3.5				
Juglans	nigra	black walnut	0.9	0.2	1.1				
Juniperus	species	juniper	0.3	0.5	0.8				
Malus	species	crabapple	2.6	0.8	3.4				
Morus	alba	white mulberry	4.3	1.2	5.5	🌲			
Other	species	other species	0.9	0.3	1.2				
Picea	pungens	blue spruce	3.3	1.9	5.2				
Picea	glauca	white spruce	1.4	1.4	2.8				
Pinus	nigra	Austrian pine	2.6	3.1	5.7				
Pinus	strobus	eastern white pine	0.7	0.8	1.5				
Pinus	resinosa	red pine	0.4	0.7	1.1				
Pinus	sylvestris	Scotch pine	0.4	0.1	0.5				
Populus	nigra	black poplar	0.6	0.1	0.7	🌲	🌲		
Populus	balsamifera	balsam poplar	0.4	0.0	0.4	🌲	🌲		
Populus	deltoides	eastern cottonwood	0.3	0.2	0.5	🌲	🌲		
Prunus	serrulata	Kwanzan cherry	0.8	0.1	0.9	🌲			
Prunus	serotina	black cherry	0.4	0.0	0.4	🌲			

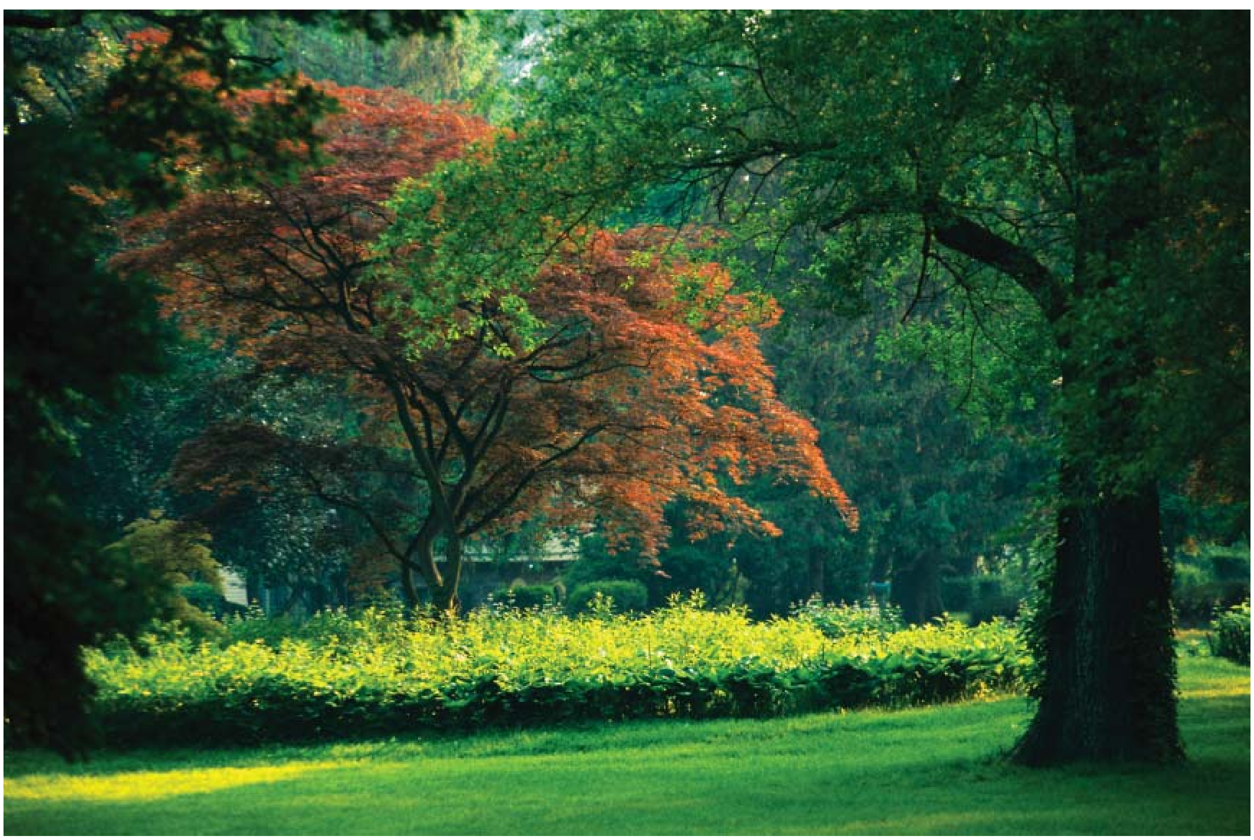
Continued

Appendix IV continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest[b]			
						ALB	GM	EAB	DED
Prunus	x cistena	purpleleaf sand cherry	0.4	0.0	0.4	🌲			
Pseudotsuga	menziesii	douglas fir	0.4	0.3	0.7				
Quercus	macrocarpa	bur oak	1.9	5.4	7.3	🌲	🌲		
Quercus	alba	white oak	0.4	1.1	1.5	🌲	🌲		
Quercus	rubra	northern red oak	0.4	0.1	0.5	🌲	🌲		
Sorbus	aucuparia	European mountain ash	0.4	0.1	0.5				
Thuja	occidentalis	northern white cedar	4.8	0.9	5.7				
Tilia	americana	American basswood	1.3	0.2	1.5	🌲	🌲		
Tilia	cordata	littleleaf linden	1.0	1.6	2.6	🌲	🌲		
Ulmus	americana	American elm	17.1	16.1	33.2	🌲			🌲
Ulmus	pumila	Siberian elm	1.7	3.3	5.0	🌲			

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

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



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Explanation of Calculations of Appendix III

19 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.

20 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.)

21 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:

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

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PM_{10} emission per kWh from:

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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:

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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:

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Nowak, David J.; Hoehn, Robert E. III, Crane, Daniel E.; Stevens, Jack C.; Walton, Jeffrey T. 2006. **Assessing urban forest effects and values, Minneapolis' urban forest.** Resour. Bull. NE-166. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 20 p.

An analysis of trees in Minneapolis, MN, reveals that the city has about 979,000 trees with canopies that cover 26.4 percent of the area. The most common tree species are green ash, American elm, and boxelder. The urban forest currently stores about 250,000 tons of carbon valued at $4.6 million. In addition, these trees remove about 8,900 tons of carbon per year ($164,000 per year) and trees and shrubs combined remove about 384 tons of air pollution per year ($1.9 million per year). The structural, or compensatory, value is estimated at $756 million. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Minneapolis area.

Keywords: urban forestry; ecosystem services; air pollution removal; carbon sequestration; tree value

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