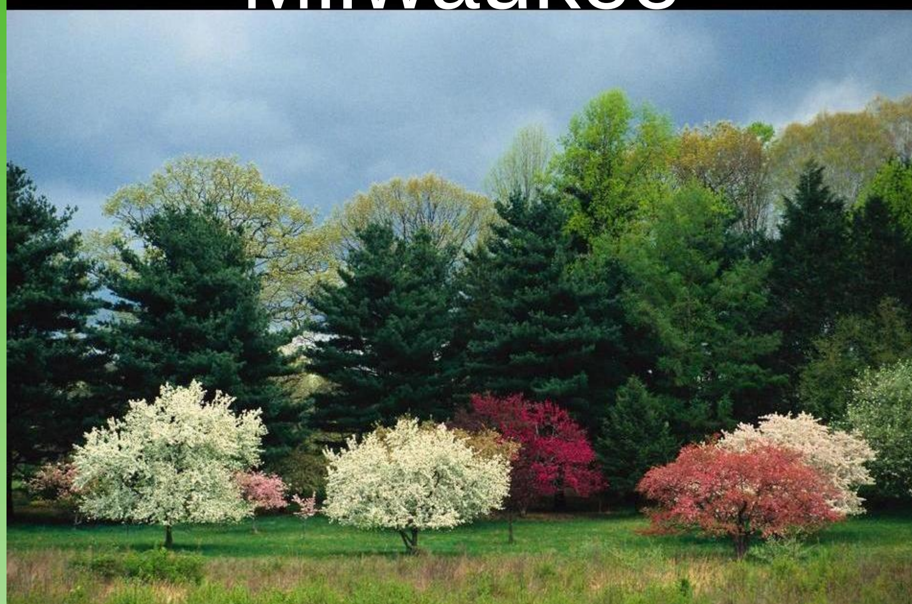
# i-Tree
# Ecosystem Analysis

## Milwaukee



Urban Forest Effects and Values
September 2008

i-Tree

UFORE
Urban Forest Effects Model

# Summary

Understanding an urban forest's structure, function and value can promote management decisions that will improve human health and environmental quality. An assessment of the vegetation structure, function, and value of the Milwaukee urban forest was conducted during 2008. Data from collected 216 field plots (out of total 220 plots) located throughout Milwaukee were analyzed using the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service, Northern Research Station.

<u>Key findings</u>

- Number of trees: 3,377,000
- Tree cover: 21.6%
- Most common species: European buckthorn, Green ash, Boxelder
- Percentage of trees less than 6" (15.2 cm) diameter: 67.3%
- Pollution removal: 496 tons/year ($2.59 million/year)
- Carbon storage: 434,000 tons ($8.97 million)
- Carbon sequestration: 15,500 tons/year ($321 thousand/year)
- Building energy savings: $864 thousand / year
- Avoided carbon emissions: $39.1 thousand / year
- Structural values: $1.43 billion

Ton: short ton (U.S.) (2,000 lbs)
Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation
Carbon sequestration: the removal of carbon dioxide from the air by plants through photosynthesis
Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree)

For an overview of UFORE methodology, see Appendix I. Data collection quality is determined by the local data collectors, over which i-Tree has no control. Additionally, some of the plot and tree information may not have been collected, so not all of the analyses may have been conducted for this report.

# Table of Contents

# I. Tree Characteristics of the Urban Forest

The urban forest of Milwaukee has an estimated 3,377,000 trees with a tree cover of 21.6 percent. Trees that have diameters less than 6-inches constitute 67.3 percent of the population. The three most common species are European buckthorn (23.30 percent), Green ash (12.70 percent), and Boxelder (11.00 percent).

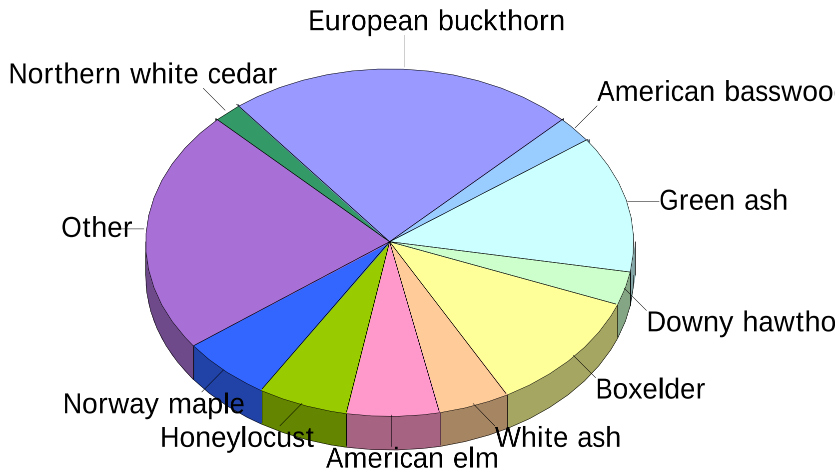



**Figure 1. Tree species composition in Milwaukee**

Among the land use categories, the highest tree densities occur in Single Strata followed by  and . The overall tree density in Milwaukee is 54.6 trees / acre (see Appendix III for comparable values from other cities).

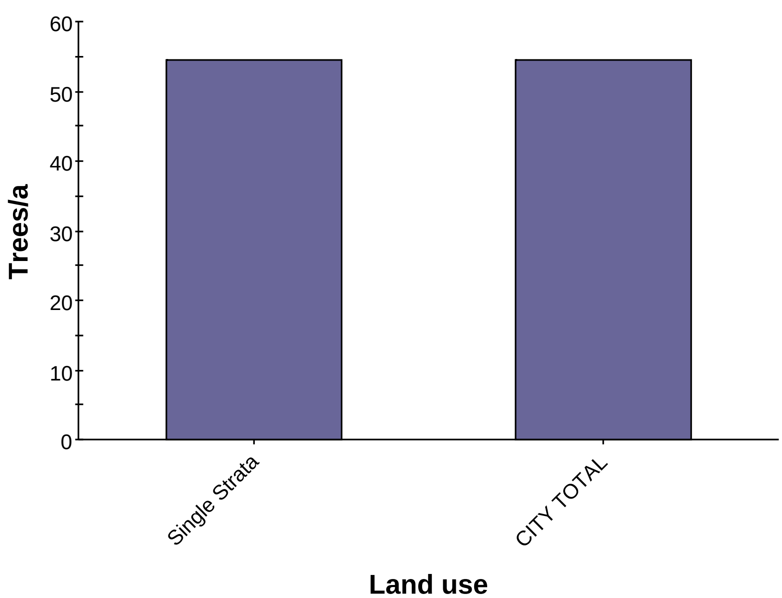



**Figure 2. Number of trees/a in Milwaukee by land use**

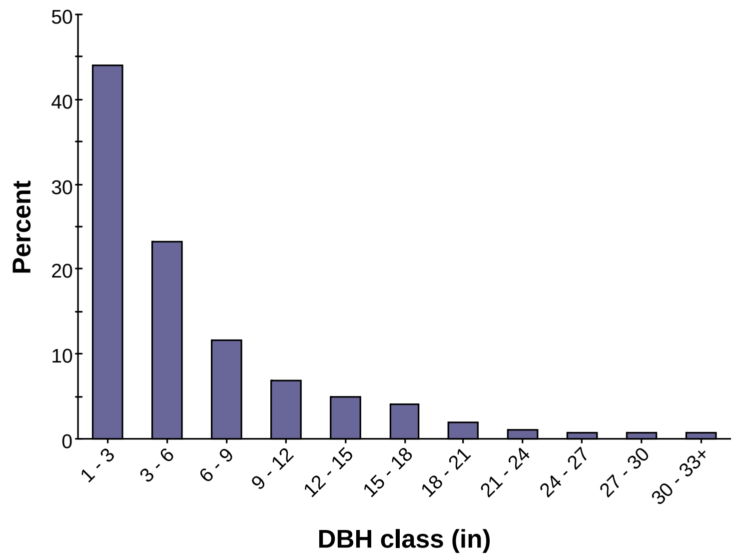



**Figure 3. Percent of tree population by diameter class (DBH=stem diameter at 4.5 feet)**

Urban forests are composed of a mix of native and exotic tree species. 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 it 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 Milwaukee, about 60 percent of the trees are from species native to North America, while 51 percent are native to the state or district. Species exotic to Wisconsin make up 39 percent of the population. Most exotic tree species have an origin from Eurasia (33.4 percent of the species).

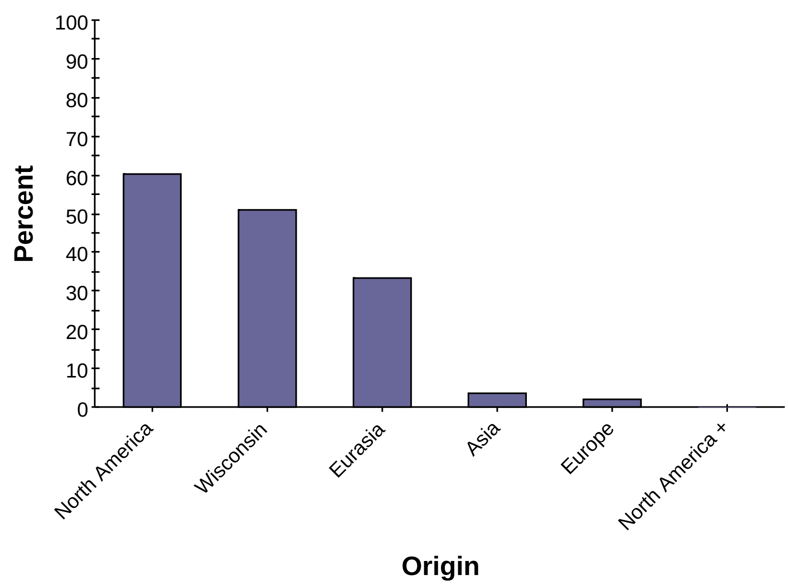



**Figure 4. Percent of live trees by species origin**

*"North America +" = native to North America and at least one other continent except South America*

# II. Urban Forest Cover and Leaf Area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. In Milwaukee, the three most dominant species in terms of leaf area are Norway maple, Boxelder, and Green ash. Trees cover about 21.6 percent of Milwaukee, and shrubs cover 9.1 percent.

The 10 most important species are listed in the table below. Importance values (IV) are calculated as the sum of relative leaf area and relative composition.

**Table 1. Most important species in Milwaukee**

| *Common Name* | *Percent Population* | *Percent Leaf Area* | *IV* |
|---|---|---|---|
| European buckthorn | 23.3 | 5.5 | 28.7 |
| Norway maple | 6.0 | 21.2 | 27.2 |
| Boxelder | 11.0 | 12.1 | 23.1 |
| Green ash | 12.7 | 8.8 | 21.5 |
| White ash | 4.7 | 4.9 | 9.6 |
| American elm | 6.1 | 2.9 | 9.0 |
| Honeylocust | 5.9 | 2.9 | 8.8 |
| American basswood | 2.5 | 4.2 | 6.7 |
| Silver maple | 0.9 | 5.0 | 6.0 |
| Sugar maple | 1.6 | 3.0 | 4.6 |

The two most dominant ground cover types are Grass (28.5 percent) and Cement (20.4 percent).

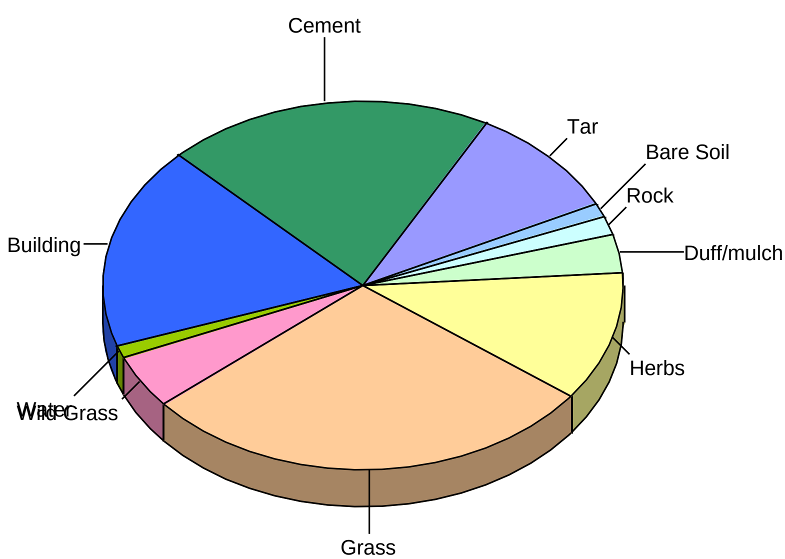



**Figure 5. Percent ground cover in Milwaukee**

# III. Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, 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 reduces 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[1].

Pollution removal by trees and shrubs in Milwaukee was estimated using field data and recent pollution and weather data available. Pollution removal was greatest for ozone. It is estimated that trees and shrubs remove 496 tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns (PM10), and sulfur dioxide (SO2)) per year with an associated value of $2.59 million (based on estimated national median externality costs associated with pollutants[2]).

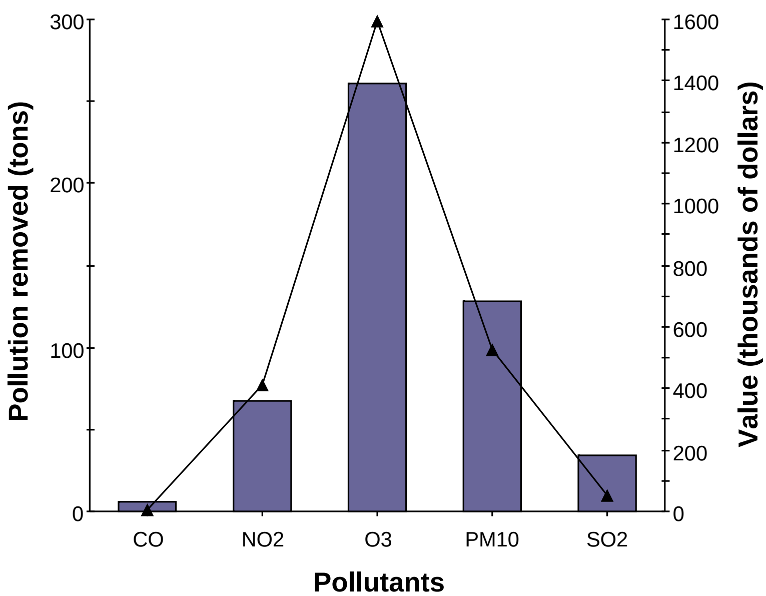



**Figure 6. Pollution removal and associated value for trees in Milwaukee (line graph is value)**

# IV. 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 altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants[3].

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Milwaukee trees is about 15,500 tons of carbon per year with an associated value of $321 thousand. Net carbon sequestration in the urban forest is about 10,400 tons.

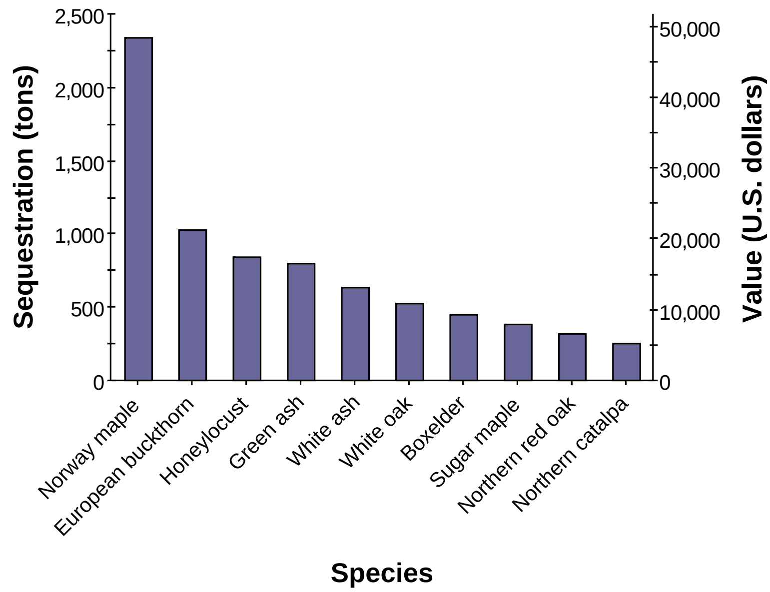



**Figure 7. Carbon sequestration and value for species with greatest overall carbon sequestration in Milwaukee**

As trees grow they store more carbon as wood. 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 lost if trees are allowed to die and decompose. Trees in Milwaukee are estimated to store 434,000 tons of carbon ($8.97 million). Of all the species sampled, Norway maple stores and sequesters the most carbon (approximately 15.0% of the total carbon stored and 22.4% of all sequestered carbon.)

# V. Trees and Building Energy Use

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[4].

Based on 2002 prices, trees in Milwaukee are estimated to reduce energy-related costs from residential buildings by $864 thousand annually. Trees also provide an additional $39,093 in value[5] by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 1,890 tons of carbon emissions).

**Table 2. Annual energy savings due to trees near residential buildings. Note: negative numbers indicate an increased energy use or carbon emission.**

| | *Heating* | *Cooling* | *Total* |
|---|---|---|---|
| MBTU[1] | -17,080 | n/a | -17,080 |
| MWH[2] | -21 | 11,896 | 11,875 |
| Carbon avoided (t) | -290 | 2,180 | 1,890 |

[1]One million British Thermal Units
[2]Megawatt-hour

**Table 3. Annual savings[1] (US $) in residential energy expenditure during heating and cooling seasons. Note: negative numbers indicate a cost due to increased energy use or carbon emission.**

| | *Heating* | *Cooling* | *Total* |
|---|---|---|---|
| MBTU[2] | -122,736 | n/a | -122,736 |
| MWH[3] | -1,745 | 988,415 | 986,670 |
| Carbon avoided (t) | -5,998 | 45,091 | 39,093 |

[1]Based on state-wide energy costs for Wisconsin.
[2]One million British Thermal Units
[3]Megawatt-hour

# VI. Structural and Functional Values

Urban forests have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree); they also have functional values (either positive or negative) based on the functions the trees perform.

The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees [6]. 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. 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: $1.43 billion
- Carbon storage: $8.97 million

Annual functional values:

- Carbon sequestration: $321 thousand
- Pollution removal: $2.59 million
- Lower energy costs and carbon emission reductions: $903 thousand (Note: negative value indicates increased energy cost and carbon emission value)

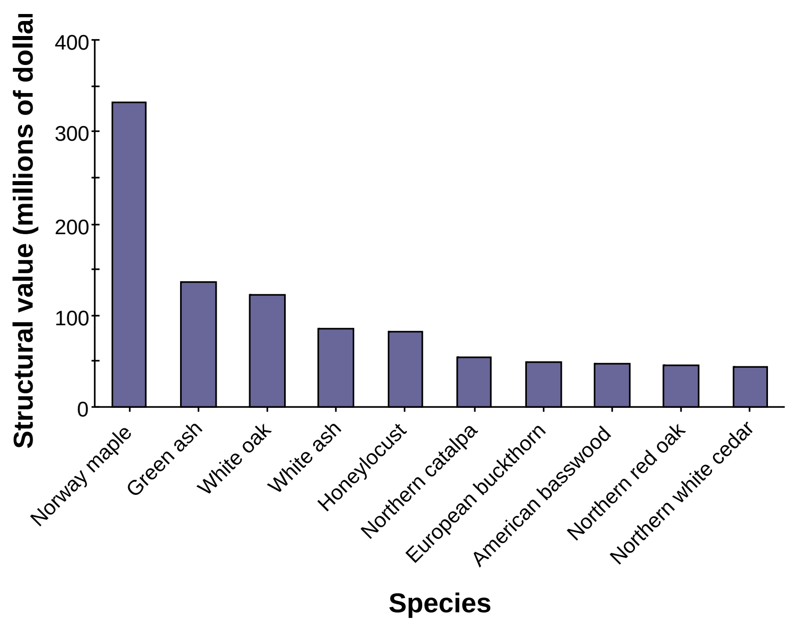



**Figure 8. Structural value of the 10 most valuable tree species in Milwaukee**

# VII. Potential Pest Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As pests tend to 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 (ALB), gypsy moth (GM), emerald ash borer (EAB), and Dutch elm disease (DED).

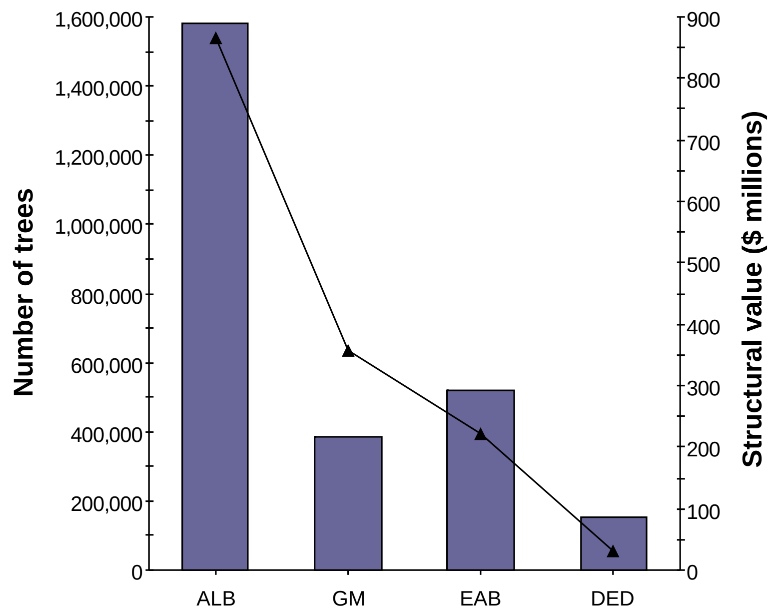



**Figure 9. Number of susceptible Milwaukee trees and structural value by pest (line graph is structural value)**

The Asian longhorned beetle (ALB) [7] is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 46.9 percent of the Milwaukee urban forest, which represents a loss of $865 million in damage to the structure.

The gypsy moth (GM)[8] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest threatens 11.5 percent of the population, which represents a loss of $357 million in structural value.

Emerald ash borer (EAB)[9] has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 15.4 percent of the population ($221 million in structural damage).

American elm, one of the most important street trees in the twentieth century, has been devastated by the Dutch elm disease (DED)[10]. Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States. Although some elm species have shown varying degrees of resistance, Milwaukee could possibly lose 4.6 percent of its trees to this pest ($30.1 million in structural value).

# Appendix I. UFORE Model and Field Measurements

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 [5], including:

- Urban forest structure (e.g., species composition, tree health, leaf area, 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.
- Structural 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.

In the field -2.5 acre plots were randomly distributed. Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Within each plot, typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings[11].

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[12]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was 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[13,14]. 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[15,16] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[17].

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described the literature[4] using distance and direction of trees from residential structures, tree height and tree condition data.

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers[8], which uses tree species, diameter, condition and location information[18].

# Appendix II. Relative Tree Effects

The urban forest in Milwaukee provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions[19], average passenger automobile emissions[20], and average household emissions[21].

Carbon storage is equivalent to:
- Amount of carbon emitted in Milwaukee in 43 days
- Annual carbon (C) emissions from 260,000 automobiles
- Annual C emissions from 131,000 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 21 automobiles
- Annual carbon monoxide emissions from 89 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 4,250 automobiles
- Annual nitrogen dioxide emissions from 2,830 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 49,800 automobiles
- Annual sulfur dioxide emissions from 834 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:
- Annual PM10 emissions from 342,000 automobiles
- Annual PM10 emissions from 33,000 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Milwaukee in 1.6 days
- Annual C emissions from 9,300 automobiles
- Annual C emissions from 4,700 single-family houses

Note: estimates above are partially based on the user-supplied information on human population total for study area

# Appendix III. Comparison of Urban Forests

A common question asked 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 for trees

| *City* | *% Tree Cover* | *Number of trees* | *Carbon storage (tons)* | *Carbon Sequestration (tons/yr)* | *Pollution removal (tons/yr)* | *Pollution Value ($US)* |
|---|---|---|---|---|---|---|
| Calgary, Canada | 7.2 | 11,889,000 | 445,000 | 21,422 | 326 | 1,611,000 |
| Atlanta, GA | 36.8 | 9,415,000 | 1,345,000 | 46,433 | 1,662 | 2,534,000 |
| Toronto, Canada | 20.5 | 7,542,000 | 992,000 | 40,345 | 1,212 | 6,105,000 |
| New York, NY | 21.0 | 5,212,000 | 1,351,000 | 42,283 | 1,677 | 8,071,000 |
| Baltimore, MD | 21.0 | 2,627,000 | 596,000 | 16,127 | 430 | 2,129,000 |
| Philadelphia, PA | 15.7 | 2,113,000 | 530,000 | 16,115 | 576 | 2,826,000 |
| Washington, DC | 28.6 | 1,928,000 | 523,000 | 16,148 | 418 | 1,956,000 |
| Boston, MA | 22.3 | 1,183,000 | 319,000 | 10,509 | 284 | 1,426,000 |
| Woodbridge, NJ | 29.5 | 986,000 | 160,000 | 5561.00 | 210 | 1,037,000 |
| Minneapolis, MN | 26.5 | 979,000 | 250,000 | 8,895 | 305 | 1,527,000 |
| Syracuse, NY | 23.1 | 876,000 | 173,000 | 5,425 | 109 | 268,000 |
| Morgantown, WV | 35.9 | 661,000 | 94,000 | 2,940 | 66 | 311,000 |
| Moorestown, NJ | 28.0 | 583,000 | 117,000 | 3,758 | 118 | 576,000 |
| Jersey City, NJ | 11.5 | 136,000 | 21,000 | 890 | 41 | 196,000 |
| Freehold, NJ | 34.4 | 48,000 | 20,000 | 545 | 21 | 133,000 |

## II. Per acre values of tree effects

| *City* | *No. of trees* | *Carbon storage (tons)* | *Carbon sequestration (lbs/yr)* | *Pollution removal (lbs/yr)* | *Pollution Value ($US)* |
|---|---|---|---|---|---|
| Calgary, Canada | 66.7 | 2.5 | 0.120 | 3.6 | 9.0 |
| Atlanta, GA | 111.6 | 15.9 | 0.550 | 39.4 | 30.0 |
| Toronto, Canada | 48.3 | 6.4 | 0.258 | 15.6 | 39.1 |
| New York, NY | 26.4 | 6.8 | 0.214 | 17.0 | 40.9 |
| Baltimore, MD | 50.8 | 11.5 | 0.312 | 16.6 | 41.2 |
| Philadelphia, PA | 25.0 | 6.3 | 0.190 | 13.6 | 33.5 |
| Washington, DC | 49.0 | 13.3 | 0.410 | 21.2 | 49.7 |
| Boston, MA | 33.5 | 9.0 | 0.297 | 16.0 | 40.4 |
| Woodbridge, NJ | 66.5 | 10.8 | 0.375 | 28.4 | 70.0 |
| Minneapolis, MN | 26.2 | 6.7 | 0.238 | 16.4 | 40.9 |
| Syracuse, NY | 54.5 | 10.8 | 0.338 | 13.6 | 16.7 |
| Morgantown, WV | 119.7 | 17.0 | 0.532 | 23.8 | 56.3 |
| Moorestown, NJ | 62.0 | 12.5 | 0.400 | 25.2 | 61.3 |
| Jersey City, NJ | 14.3 | 2.2 | 0.094 | 8.6 | 20.7 |
| Freehold, NJ | 38.5 | 16.0 | 0.437 | 33.6 | 106.6 |

# Appendix IV. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are[22]:

- Temperature reduction and other microclimate effects
- Removal of air pollutants
- Emission of volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the 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[23]. Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include[24]:

| ***Strategy*** | ***Result*** |
|---|---|
| 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 |

## References


1. Nowak D.J. and Dwyer J.F. ""Understanding the Benefits and Costs of Urban Forest Ecosystems."" Handbook of Urban and Community Forestry in the Northeast. Ed. John E. Kuser. Kluwer Academics/Plenum Pub., New York. 2000. 11-22.

2. Murray, F.J.; Marsh L.; Bradford, P.A. 1994. New York State Energy Plan, vol. II: issue reports. Albany, NY: New York State Energy Office.

3. Abdollahi, K.K.; Z.H. Ning; and A. Appeaning (eds). 2000. Global climate change and the urban forest. Baton Rouge, LA: GCRCC and Franklin Press. 77p.

4. McPherson, E.G. and J. R. Simpson 1999. Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research station 237 p. http://wcufre.ucdavis.edu/products/cufr_43.pdf

5. Nowak, D.J., and D.E. Crane. 2000. The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions. In: Hansen, M. and T. Burk (Eds.) Integrated Tools for Natural Resources Inventories in the 21st Century. Proc. Of the IUFRO Conference. USDA Forest Service General Technical Report NC-212. North Central Research Station, St. Paul, MN. pp. 714-720. See also http://www.ufore.org.

6. Nowak, D.J.; Crane, D.E.; Dwyer, J.F. 2002. Compensatory value of urban trees in the United States. Journal of Arboriculture. 28(4): 194 - 199.

7. Northeastern Area State and Private Forestry. 2005. Asian Longhorned Beetle. Newtown Square, PA: U.S. Department of Agriculture, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/alb/

8. Northeastern Area State and Private Forestry. 2005. Gypsy moth digest. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://na.fs.fed.us/fhp/gm

9. Northeastern Area State and Private Forestry. 2005. Forest health protection emerald ash borer home. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/eab/index.html

10. Northeastern Area State and Private Forestry. 1998. HOW to identify and manage Dutch Elm Disease. NA-PR-07-98. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/pubs/howtos/ht_ded/ht_ded.htm

11. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R.E. 2005. The urban forest effects (UFORE) model: field data collection manual. V1b. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station, 34 p. http://www.fs.fed.us/ne/syracuse/Tools/downloads/UFORE_Manual.pdf

12. Nowak, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's urban forest. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 83-94.

13. Baldocchi, D. 1988. A multi-layer model for estimating sulfur dioxide deposition to a deciduous oak forest canopy. Atmospheric Environment. 22: 869-884.

14. Baldocchi, D.D.; Hicks, B.B.; Camara, P. 1987. A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. Atmospheric Environment. 21: 91-101.

15. Bidwell, R.G.S.; Fraser, D.E. 1972. Carbon monoxide uptake and metabolism by leaves. Canadian Journal of Botany. 50: 1435-1439.

16. Lovett, G.M. 1994. Atmospheric deposition of nutrients and pollutants in North America: an ecological perspective. Ecological Applications. 4: 629-650.

17. Zinke, P.J. 1967. Forest interception studies in the United States. In: Sopper, W.E.; Lull, H.W., eds. Forest Hydrology. Oxford, UK: Pergamon Press: 137-161.

18. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Ibarra, M. 2002. Brooklyn's Urban Forest. Gen. Tech. Rep. NE-290. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 107 p. Council of Tree and Landscape Appraisers guidelines. For more information, see Nowak, D.J., D.E. Crane, and J.F. Dwyer. 2002. Compensatory value of urban trees in the United States. J. Arboric. 28(4): 194-199.

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/ggrpt/) divided by 2003 U.S. total population (www.census.gov). Per capita emissions were multiplied by city 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) divided 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 automobile assumed six pounds of carbon per gallon of gasoline if energy costs of refinement and transportation are included (Graham, R.L., Wright, L.L., and Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO2 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: Energy Information Administration. Total Energy Consumption in U.S. Households by Type of

Housing Unit, 2001 http://www.eia.doe.gov/emeu/recs/contents.html.

CO2, SO2, 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 1/3 of one percent of C emissions is CO based on: Energy Information Administration. 1994 Energy Use and Carbon Emissions: Non-OECD Countries DOE/EIA-0579.

PM10 emission per kWh from: Layton, M. 2004. 2005 Electricity Environmental Performance Report: Electricity Generation and Air Emissions. California Energy Commission. http://www.energy.ca.gov/2005_energypolicy/documents/2004-11-15_workshop/2004-11-15_03-A_LAYTON.PDF

CO2, NOx, SO2, PM10, 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/

CO2 and fine particle emissions per Btu of wood from: Houck, J.E. Tiegs, P.E, McCrillis, R.C. Keithley, C. and Crouch, J. 1998. Air emissions from residential heating: the wood heating option put into environmental perspective. In: Proceedings of U.S. EPA and Air Waste Management Association Conference: Living in a Global Environment, V.1: 373-384.

CO, NOx and SOx emission per Btu based on total emissions and wood burning (tonnes) from: Residential Wood Burning Emissions in British Columbia, 2005. http://www.env.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: Heating with Wood I. Species characteristics and volumes. http://ianrpubs.unl.edu/forestry/g881.htm

22. Nowak, D.J. 1995. Trees pollute? A "TREE" explains it all. In: Proceedings of the 7th National Urban Forestry Conference. Washington, DC: American Forests. Pp. 28-30

23. Nowak, D.J. and J.F. Dwyer. 2007. Understanding the benefits and costs of urban forest ecosystems. In: Kuser, J. (ed.) Urban and Community Forestry in the Northeast. New York: Springer. Pp. 25-46.

24. Nowak, D.J. 2000. The interactions between urban forests and global climate change. In: Abdollahi, K.K., Z.H. Ning, and A. Appeaning (Eds). Global Climate Change and the Urban Forest. Baton Rouge: GCRCC and Franklin Press. Pp. 31-44.