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## **Assessing Environmental Functions and Values of Veteran Trees**

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### **Introduction**

Urban trees can provide many benefits to society. These benefits include improvements in air and water quality, building energy conservation, cooler air temperatures, reductions in ultraviolet (UV) radiation, enhanced property values, and many other environmental and social benefits (Nowak and Dwyer, 2000). These multiple benefits combine to improve urban environmental conditions and associated human health and well-being.

However, not all trees are equal in the benefits that they provide for society. Selection of proper species and locations can enhance desired benefits. Another important factor is tree size. Veteran trees – trees that have lived a long time and are significant elements of the landscape – often contribute substantially more benefits to society relative to other (smaller) trees in the landscape.

Not only do veteran trees contribute the most cumulative benefits due to their relatively long life span, but if healthy, these trees will also typically contribute the greatest annual benefits per tree. The purpose of this paper is to illustrate, based on field data and modeling from various cities, how the environmental benefits and values of veteran trees differ from smaller, more typical urban trees. The benefits discussed in this paper are:

- Air temperature cooling and UV radiation reduction
- Building energy conservation
- Carbon storage and sequestration
- Air pollution removal

Though the focus of this paper will be on the environmental benefits of veteran trees, it must be recognized that these trees also often have significant social benefits relative to smaller trees (Dwyer et al., 1991; Barro et al., 1997; Nowak and Dwyer, 2000).

### **Urban Forests**

Urban forests include the assemblage of all trees and other vegetation within an urban area. To understand the structure and functions of these forests, data were collected on trees throughout all land uses in selected cities. In the late 1990's, approximately 200 randomly located 0.04 hectare field plots were measured in Atlanta, GA; Baltimore, MD; Boston, MA; Jersey City, NJ; New York, NY; Philadelphia, PA; Syracuse, NY; and Toronto, Ontario. These field data were

combined with local hourly meteorological and pollution concentration data within the Urban Forest Effects (UFORE) model (Nowak and Crane, 2000) to quantify urban tree structure, functions, and values in each city. Results from these analyses were summarized by diameter class to illustrate the difference in benefits by tree size. Detailed methods and field sampling techniques can be found in Nowak et al. (1998, 2000, 2002), Nowak and Crane (2002) and [www.fs.fed.us/ne/syracuse](http://www.fs.fed.us/ne/syracuse). For this paper, veteran trees are defined as trees greater than 76.2 cm in diameter at breast height (1.37 m) (dbh).

Results from the cities reveal that typically the majority of trees are less than 15.2 cm in dbh, and less than 3% of the population is veteran trees greater than 76.2 cm in dbh (Table 1). Even though there are relative few veteran trees, these trees averaged between 35 to 65 times more leaf surface area than small trees less than 7.6 cm in dbh in the cities analyzed.

**Table 1.** Percent of total tree population in selected dbh ranges.

City	% less than 15.2 cm dbh	% greater than 76.2 cm dbh
Atlanta, GA	68.5	1.0
Baltimore, MD	62.8	2.3
Boston, MA	47.2	1.8
Jersey City, NY	67.9	0.8
New York, NY	42.8	1.4
Philadelphia, PA	57.4	2.6
Syracuse, NY	58.4	2.1
Toronto, ON	57.8	0.9

### Temperature and UV Effects

Leaf area is a critical factor in determining many environmental benefits of trees. Typically the more healthy functional leaf surface area on a tree, the greater the environmental benefits. Assuming a tree has ample soil moisture and all other factors are equal, trees with a greater leaf surface area will typically transpire more water, thereby leading to greater evaporative cooling (e.g., University of California Cooperative Extension, 2000). Increased canopy cover can help reduce air temperatures, with reported reductions of maximum mid-day air temperatures ranging from 0.04°C to 0.2°C per percent increase in canopy cover (Simpson, 1998).

In 1995, a heat wave in Chicago caused 514 heat-related deaths, and a heat wave in London caused a 15% increase in all-cause mortality. Excess mortality during heat waves is greatest with the elderly and people with preexisting illness. Much of this excess mortality from heat waves is related to cardiovascular, cerebrovascular, and respiratory disease (IPCC, 2001). Increased urban canopy cover and leaf area, and its consequent reduction in urban area temperature can have a significant human health impact.

Increased leaf area and canopy size will also typically lead to greater shading effects, which consequently can affect the amount of ultraviolet radiation (UV) received by humans. Rates of skin cancer have increased greatly in recent years, and increased ultraviolet B radiation caused

by reductions in stratospheric ozone may be responsible for this increase. Epidemiological considerations suggest that routine exposure to UV in urban areas can produce adverse health effects (Heisler and Grant, 2000). As tree leaves typically absorb greater than 90% of ultraviolet radiation reaching its surface, larger tree canopies can lead to greater reductions in UV rays reaching urban inhabitants.

### **Building Energy Conservation**

Trees affect local building heating and cooling energy needs by shading buildings and reducing air temperatures in the summer, and by blocking winds in winter. However, trees that shade buildings in winter also can increase heating needs. Energy conservation from trees varies by regional climate, the size and amount of tree foliage, and the location of trees around buildings. Tree arrangements that save energy provide shade primarily on east and west walls and roofs, and wind protection from the direction of prevailing winter winds. Energy use in a house with trees can be 20 to 25% lower per year than that for the same house in an open area (Heisler, 1986).

Based on results of energy simulations for 11 different climate zones in the United States (McPherson and Simpson, 1999), large (> 15 m tall) deciduous trees adjacent to buildings have an average effect on building energy use 4 to 27 greater than small deciduous trees (6-10 m tall) in the same position (median value = 9 fold difference between large and small trees). This range is based on the average difference between large and small trees, with one tree at each of the 8 cardinal directions around a post-1980 vintage building. Model results of these trees revealed energy reductions in the cooling season and increased energy use in the heating season in all climate zones analyzed.

### **Carbon Storage and Sequestration**

Increasing levels of atmospheric carbon dioxide (CO<sub>2</sub>) and other "greenhouse" gases (e.g., methane, chlorofluorocarbons, nitrous oxide) are thought by many to be contributing to an increase in atmospheric temperatures by trapping certain wavelengths of heat in the atmosphere. Globally averaged air temperature at the Earth's surface has increased between 0.3 and 0.6°C since the late 1800's. A current estimate of the expected rise in average surface air temperature globally is between 1 to 3.5°C by the year 2100 (Hamburg et al., 1997). Global warming is implicated in the recent discovery that floating ice over the Arctic Ocean has thinned from an average thickness of 10 feet in 1950 to less than 6 feet in the late 1990's, and a large expanse of ice-free water that has opened up at the North Pole in 2000 (Appenzeller, 2000; BBC News, 2000).

By storing carbon through their growth process, trees act as a sink for atmospheric CO<sub>2</sub>, a dominant greenhouse gas. Larger trees, due to their increased size, will store larger amounts of carbon in their tissue as approximately half of the dry-weight of a tree is carbon. In addition, large healthy trees will typically be able to sequester more carbon annually than trees with smaller diameters. To estimate monetary value associated with urban tree carbon storage and sequestration, carbon values were multiplied by \$20.3/tC based on the estimated marginal social costs of carbon dioxide emissions (Fankhauser, 1994).

Based on data from various cities, veteran trees store between 600 to 1,000 times more carbon within their biomass than trees less than 7.6 cm dbh (Table 2). In addition, veteran trees continue to store additional carbon and annually sequester between 30 to 80 times more carbon than small trees less than 7.6 cm dbh (Table 3).

**Table 2.** Differences in estimated carbon storage and value between small (< 7.6 cm dbh) and veteran (> 76.2 cm dbh) trees in various cities.

City	<u>&lt; 7.6 cm dbh</u>		<u>&gt; 76.2 cm dbh</u>	
	Storage (kgC)	Value (USD)	Storage (kgC)	Value (USD)
Atlanta, GA	4.2	\$0.09	2,834	\$57.54
Baltimore, MD	3.4	\$0.07	3,210	\$65.16
Boston, MA	5.7	\$0.12	3,446	\$69.96
Jersey City, NY	2.3	\$0.05	2,342	\$47.54
New York, NY	4.8	\$0.10	2,965	\$60.19
Philadelphia, PA	3.8	\$0.08	2,791	\$56.65
Syracuse, NY	3.2	\$0.06	2,665	\$54.10
Toronto, ON	3.8	\$0.08	2,487	\$50.48

**Table 3.** Differences in estimated annual carbon sequestration and value between small (< 7.6 cm dbh) and veteran (> 76.2 cm dbh) trees in various cities.

City	<u>&lt; 7.6 cm dbh</u>		<u>&gt; 76.2 cm dbh</u>	
	Sequest. (kgC/yr)	Value (USD/yr)	Sequest. (kgC/yr)	Value (USD/yr)
Atlanta, GA	0.7	\$0.01	58	\$1.18
Baltimore, MD	0.6	\$0.01	42	\$0.84
Boston, MA	1.3	\$0.03	43	\$0.86
Jersey City, NY	0.7	\$0.01	52	\$1.06
New York, NY	1.0	\$0.02	44	\$0.89
Philadelphia, PA	0.9	\$0.02	42	\$0.85
Syracuse, NY	0.7	\$0.01	43	\$0.87
Toronto, ON	0.9	\$0.02	53	\$1.08

### **Air Pollution Removal**

Air pollution is a multibillion dollar problem that affects many major cities worldwide. Air pollution is a significant human health concern as it can cause coughing, headaches, lung, throat, and eye irritation, respiratory and heart disease, and cancer. It is estimated that about 60,000 people die annually in the United States from the effects of particulate pollution (Franchine 1991). In addition, air pollution damages vegetation and various anthropogenic materials.

Major air pollutants in urban areas are carbon monoxide (CO), predominantly from automobiles; nitrogen oxides (NO<sub>x</sub>), mainly from automobiles and stationary combustion sources; ozone (O<sub>3</sub>),

formed through chemical reactions involving the principal precursors of NO<sub>x</sub> and volatile organic compounds; sulfur dioxide (SO<sub>2</sub>), emissions mostly from stationary combustion sources and smelting of ores; and particulate matter. Small particulate matter results from local soils, industrial processes, combustion products, and chemical reactions involving gaseous pollutants.

Gaseous pollution removal by trees occurs predominantly through the leaf stomata, though some deposition occurs on the plant surface (e.g., Smith 1990; Fowler 1985; Murphy and Sigmon 1990). During daylight hours when plant leaves are transpiring water and taking up CO<sub>2</sub>, other gases including pollutants are taken up into the leaf. Once inside the leaf, these gases diffuse into intercellular spaces and can be absorbed by water films on inner-leaf surfaces. Pollutant uptake by plants is highly variable as it is regulated by numerous plant, pollutant, and environmental forces (e.g., plant water deficit, light intensity, windspeed, gas solubility in water, leaf size and geometry, etc.) (Smith 1990).

Particles can be dry deposited on plant surfaces through sedimentation under the influence of gravity or through impaction resulting from wind. Particles hitting the tree may be retained on the surface, rebound off it, or be retained temporarily and subsequently removed (resuspended into air or transported to soil or other surface) (Smith 1990). Thus, vegetation generally is only a temporary retention site for atmospheric particles as particles can be resuspended to the atmosphere, be washed off by rain, or drop to the ground through leaf and twig fall.

Trees can also emit volatile organic compounds such as isoprene and monoterpenes into the atmosphere. These compounds are natural chemicals that make up essential oils, resins, and other plant products, and may be useful in attracting pollinators or repelling predators (Kramer and Kozlowski 1979). These compounds can also contribute to ozone formation (Brasseur and Chatfield, 1991). Even though trees may emit VOCs, other attributes of trees (air temperature reduction, pollution removal) can lead to reductions in ozone. Comprehensive ozone studies are revealing that increased urban tree canopy cover leads to reduced ozone concentrations (Cardelino and Chameides, 1990; Taha, 1996; Nowak et al., 2000; Luley and Bond, 2002).

A significant factor affecting the influence of trees on air pollution is the amount of functional leaf surface area. Veteran trees remove 30 to 65 times more air pollution annually than small trees less than 7.6 cm in diameter in selected cities (Table 4).

**Table 4.** Differences in estimated annual average air pollution removal and value between small (< 7.6 cm dbh) and veteran (> 76.2 cm dbh) trees in selected cities. Pollution removal is the total for carbon monoxide, nitrogen dioxide, ozone, particulate matter less than 10 microns, and sulfur dioxide. Values are based on median U.S. externality values for each pollutant (Murray, 1994).

City	< 7.6 cm dbh		> 76.2 cm dbh	
	Removal (kg/yr)	Value (USD/yr)	Removal (kg/yr)	Value (USD/yr)
Atlanta, GA	0.04	\$0.19	1.6	\$8.90
Baltimore, MD	0.03	\$0.18	1.4	\$7.66
Boston, MA	0.03	\$0.14	1.1	\$6.05
Jersey City, NY	0.04	\$0.21	2.6	\$13.81

New York, NY	0.05	\$0.24	1.3	\$6.94
Philadelphia, PA	0.04	\$0.19	1.4	\$7.36
Syracuse, NY	0.01	\$0.08	0.6	\$3.64
Toronto, ON	0.03	\$0.16	1.0	\$5.46

## Conclusion

On a per tree basis, veteran trees typically contribute significantly more environmental benefits and value to society than smaller trees. These beneficial functions provided by veteran trees require that these trees be healthy, functioning elements in the urban landscape. By being healthy, veteran trees offer significantly more leaf surface area to interact with the surrounding environment. The gas exchange exhibited by large, functioning veteran trees can provide significant environmental benefits such as air pollution removal, carbon sequestration, and air temperature reduction. In addition, the relative large leaf surface area of veteran trees often provides more shade than smaller trees, leading to increased potential benefits from reduced building energy use (if trees are located in the proper position around buildings) and reduced exposure to ultraviolet radiation. As veteran trees produce some of the greatest environmental values, these trees can offer the greatest single tree effects to improve human health and well-being in urban areas.

## References

- Appenzeller, T., 2000. Plying a fabled waterway. U.S. News Online. <http://www.usnews.com/usnews/issue/000828/passage.htm> (last accessed June, 2001)
- Barro, S.C., P.H. Gobster, H.W. Schroeder, and S.M. Bartram. 1997. What makes a big tree special? Insights from the Chicagoland tremendous trees program. *J. Arboric.* 23(6): 239-249.
- BBC News. 2000. North Pole ice 'turns to water'. BBC News Online. [News.bbc.co.uk/english/world/americas/newsid\\_888000/888235.stm](http://www.bbc.co.uk/english/world/americas/newsid_888000/888235.stm) (last accessed June, 2001).
- Brasseur, G.P. and R.B. Chatfield. 1991. The fate of biogenic trace gases in the atmosphere. In: Sharkey, T.D.; Holland, E.A.; Mooney, H.A., eds. *Trace gas emissions by plants*: Academic Press, New York. pp. 1-27.
- Cardelino, C.A. and Chameides, W.L. 1990. Natural hydrocarbons, urbanization, and urban ozone. *J. Geophys. Res.* 95(D9):13,971-13,979.
- Dwyer, J.F., H.W. Schroeder, and P.H. Gobster. 1991. The significance of urban trees and forests: Toward a deeper understanding of values. *J. Arboric.* 17(10): 276-284.
- Fankhauser, S., 1994. The social costs of greenhouse gas emissions: an expected value approach. *The Energy Journal* 15(2), 157-184.
- Fowler, D. 1985. Deposition of SO<sub>2</sub> onto plant canopies. In: Winner, W.E.; Mooney, H.A.; Goldstein, R.A. eds. *Sulfur dioxide and vegetation*. Stanford, CA: Stanford University Press: 389-402.
- Franchine, P. 1991. Soot kills 60,000 a year in U.S., survey shows. *Chicago Sun-Times*. June 30.
- Hamburg, S.P., N. Harris, J. Jaeger, T.R. Karl, M. McFarland, J.F.B. Mitchell, M. Oppenheimer, S. Santer, S. Schneider, K.E. Trenberth, and T.M.L. Wigley. c. 1997. *Common questions*

- about climate change. United Nation Environment Programme, World Meteorology Organization.
- Heisler, G.M. 1986. Energy savings with trees. *J. Arboric.* 12(5):113-125.
- Heisler, G.M. and Grant, R.H. 2000. Ultraviolet radiation in urban ecosystems with consideration of effects on human health. *Urban Ecosystems* 4: 193-229.
- Intergovernmental Panel on Climate Change. 2001. Climate change 2001: Working group II: Impacts, adaptation, and vulnerability. Chapter 9: Human health. [http://www.grida.no/climate/ipcc\\_tar/wg2/353.htm](http://www.grida.no/climate/ipcc_tar/wg2/353.htm) (last accessed February, 2004)
- Kramer, P.J. and T.T. Kozlowski. 1979. *Physiology of woody plants*. Academic Press, New York.
- Luley, C.J. and Bond, J. 2002. A plan to integrate management of urban trees into air quality planning. Report to Northeast State Foresters Association. Davey Resource Group, Kent, OH. 73 p.
- McPherson, E.G. and J.R. Simpson. 1999. Carbon dioxide reduction through urban forestry: Guidelines for professional and volunteer tree planters. USDA Forest Service, Pacific Southwest Research Station, Gen. Tech. Rep. 171. Berkeley, CA.
- Murray, F.J., L. Marsh. and P.A. Bradford. 1994. New York State energy plan, vol. II: issue reports. New York State Energy Office, Albany, NY.
- Murphy, C. E. and J.T. Sigmon. 1990. Dry deposition of sulfur and nitrogen oxide gases to forest vegetation. In: Lindberg, S. E.; Page, A. L.; Norton, S. A. eds. *Acid precipitation. Volume 3: sources, deposition, and canopy interactions*. Springer-Verlag, New York. 217-240.
- Nowak, D.J., K.L. Civerolo, S.T. Rao, G. Sistla, C.J. Luley, and D.E. Crane. 2000. A modeling study of the impact of urban trees on ozone. *Atmos. Environ.* 34: 1601-1613.
- 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 21<sup>st</sup> Century*. Proc. of the IUFRO Conference. USDA Forest Service General Technical Report NC-212. North Central Research Station, St. Paul, MN. pp. 714-720.
- Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the United States. *Environ. Poll.* 116(3): 381-389.
- Nowak, D.J., D.E. Crane, J.C. Stevens, and M. Ibarra. 2002. Brooklyn's Urban Forest. USDA Forest Service, Northeastern Research Station, Gen. Tech. Rep. 290. Newtown Square, PA.
- 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.
- Nowak, D.J. and J.F. Dwyer. 2000. Understanding the benefits and costs of urban forest ecosystems. In: Kuser, J. (ed.) *Urban and Community Forestry in the Northeast*. Plenum Publ. New York. pp. 11-25.
- Nowak, D.J., P.J. McHale, M. Ibarra, D. Crane, J. Stevens, and C. Luley. 1998. Modeling the effects of urban vegetation on air pollution. In: Gryning, S.E. and N. Chaumerliac (eds.) *Air Pollution Modeling and Its Application XII*. Plenum Press, New York. pp. 399-407.
- Smith, W. H. 1990. *Air pollution and forests*. Springer-Verlag, New York.
- Taha, H. 1996. Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. *Atmos. Environ.* 30(20):3423-3430.

Simpson, J.R. 1998. Urban forest impacts on regional cooling and heating energy use: Sacramento County case study. *J. Arboric.* 24(4):201-214.

University of California Cooperative Extension. 2000. A guide to estimating irrigation water needs of landscape plantings in California. California Department of Water Resources, Sacramento, CA.