FOREST SCIENCE
Newsletter

ISSUE NUMBER 3
WINTER 2005

NORTHEASTERN
RESEARCH STATION
USDA FOREST SERVICE

ENVIRONMENTAL RESEARCH, TECHNOLOGY & LEADERSHIP

Trees in the City

Measuring and Valuing the Urban Forest

NE scientist David Nowak's research confirms what Frederick Law Olmsted, the designer of Central Park in New York City, said a century ago: parks and their trees are "the lungs of the city"

As odd or contradictory as it sounds, there is indeed an urban forest. That is what scientists and foresters call community trees—the street trees, park and cemetery trees, and yard trees in cities, towns, and suburbs. They even include invasives such as ailanthus (tree-of-heaven) and paulownia (princess tree), that grow along highways and railroads and in junk yards and abandoned factories.

City people especially appreciate their urban forest, for although trees in downtown areas are often dwarfed by office towers and skyscrapers, they add life to the concrete canyons and make parks beautiful refuges. In neighborhoods, suburbs, and towns, trees can arch gracefully over residential streets and fill yards with shade and provide homes for birds and small creatures. Old trees give us a sense of history, for they have lived many human lifetimes. For example, tuliptrees (often referred to as yellow-poplar) planted by George Washington still live on at Mount Vernon. New trees give us a sense of hope and remembrance, for they will live on after us into the future. Trees have been one of the most common memorials to those who died in the September 11, 2001, terrorist attacks.

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NE Forest Science Review is dedicated to presenting clear and concise information on current problems and issues relating to forests and forestry in the Northeast and the role of the nearly 100 scientists in the USDA Forest Service's Northeastern (NE) Research Station in exploring these topics and finding solutions for problems.

We hope that land managers, policymakers, science communicators, extension specialists, environmental advocates, and educators, as well as conservationists and all others interested in the health and productivity of forests in the Northeast, will find our quarterly newsletter useful and informative.

The NE Research Station is part of the USDA Forest Service's Research & Development national network of 6 regional research stations, the Forest Products Laboratory, and the International Institute of Tropical Forestry. NE scientists work at research sites in 13 states—Hamden/Ansonia, CT; Newark, DE; Amherst, MA; Baltimore, MD; Bradley, ME; Durham, NH; Burlington Co., NJ; Syracuse, NY; Delaware, OH; Warren and Newtown Square, PA; Burlington, VT; and Morgantown, Parsons, and Princeton, WV.

NE scientists work in laboratories and a wide variety of field sites, including eight experimental forests (several of these maintain long-term data sets that are unique to science) and six research natural areas, sited on National Forest System lands. Two important research locations are the Forest Service's only primary quarantine laboratory on the continental United States (Hamden/Ansonia, CT), a facility certified for biological control research on non-native forest pests and their natural enemies as well as the Baltimore (MD) Long Term Ecological Research Site, where NE scientists and other cooperators study the ecology of an urban forest.

Contact the USDA Forest Service's Northeastern Research Station:

11 Campus Boulevard #200
Newtown Square, PA 19073-3200
www.fs.fed.us/ne

Michael T. Rains
Station Director
610-557-4017
mrains@fs.fed.us

Lynn Campbell Wingert
Communications Director
610-557-4253
lwingert@fs.fed.us

Rebecca G. Nisley
Newsletter Writer & Editor
203-230-4338
rnisley@fs.fed.us

For additional copies or to be included in the mailing list, contact ne_pubs@fs.fed.us or call 740-368-0123.

Trees do more than just provide aesthetic benefits, they provide important cooling effects, reduce the urban heat-island effect, reduce incident UV rays and help keep pavement and parked cars cooler. In addition, in properly planted barriers, they can reduce wind and traffic sounds. They can actually reduce air pollution and absorb carbon dioxide (CO_2), the predominant greenhouse gas. Given current concerns about global climate change increasing temperatures, anything that helps to ameliorate the urban heat-island effect and reduce atmospheric CO_2 levels certainly merits attention and action. However, for the greatest benefits to occur from planting trees, two important details need to be right: species choice and location.

But Gee, It's Common Sense—After All, Trees Are Nice

Growing more trees in the city sounds like a great idea—it's "common sense," right? But sometimes common sense may not be true (consider the recent discovery that ulcers are caused by a bacterium, *Helicobacter pylori*, and can be treated with the right antibiotics!). Many cities and towns have arborists, urban foresters, or tree wardens as part of their government; often these people work in parks and recreation or public works departments. There are many volunteer groups also concerned about urban trees. Because urban forests are not only "public trees" growing along streets, parkways, and public buildings and in parks and cemeteries, but also include private trees, urban residents can affect the overall health and magnitude of the urban forest. Municipal urban foresters and land managers, as well as urban residents, need to base their tree decisions on science, not just common sense.

Although the urban forest offers a wide range of potential benefits to society and the environment (see TREE, page 5), there is a wide range of potential costs and numerous interactions that must be understood. Inadequate understanding of these costs and interactions can drastically reduce the contribution of the urban forest towards improving urban life and the environment. Though trees can provide multiple benefits at one site, not all benefits can be realized in each location. Individual management plans need to focus on optimizing the mix of benefits that are most important to a particular area.

To provide these facts, there are scientists who study urban environments, including urban trees. Since 1978, the USDA Forest Service's Northeastern Research Station (NE) has had an urban forestry unit located at the State University of New York's College of Environmental Science and Forestry (SUNY–ESF) in Syracuse, New York, and more recently at the University of Maryland's Baltimore Campus (UMBC). Five scientists, led by Dr. David J. Nowak, are leading researchers in this relatively new scientific discipline. These scientists and their staff members (1) research the functions and benefits of urban trees; (2) are an integral part of the National Science Foundation's Long-Term Ecological Research (LTER) Program's Baltimore Ecosystem Study; and (3) are developing computer models to help others inventory, monitor, and evaluate their urban forests. They have used these models to measure urban forests and determine their value in many cities.

Urban Forest Effects Computer Model

The Urban Forest Effects (UFORE) model is designed to use standardized vegetation data taken from randomly located plots and hourly local air pollution and weather data to quantify urban forest structure and numerous urban forest effects for cities around the world. Currently, 22 cities in the United States and 9 in other countries have been studied. The NE urban foresters assist local users in locating field plots, setting up data-collection procedures, and analyzing their data.

The standardized plots are randomly located 0.04-hectare (one-tenth acre) circular areas. Within each plot, data are collected on land use, ground and tree cover, and shrub characteristics, as well as details on trees, including species, stem diameter at breast height (dbh), tree height, height to crown, crown width, and distance and direction from buildings. Digital hourly weather and pollution data in the United States have already been obtained by the Forest Service for the year 2000, so users only need to collect the field data to conduct a basic analysis.

With the UFORE model and local field data, urban foresters are able to calculate many useful results. These include an overall description of the entire urban forest (for example, numbers of individual trees and species), the economic and environmental value of trees, and susceptibility to selected invasive insects (Asian longhorned beetle, gypsy moth, and emerald ash borer) and diseases (sudden oak death).

Data on tree numbers and biomass allow calculation of carbon sequestration for a city. For example, in New York City, existing trees store about 1.2 million metric tons of carbon. This amount, which took years to store, is equivalent to the amount emitted from New York's population in about 10 days based on average per person carbon emissions. New York's trees sequester about 39,000 tons of carbon annually. But tree death and associated decomposition of wood may make annual sequestration a negative number. However, through proper planting strategies, urban trees can reduce atmospheric carbon by reducing the energy use in buildings and consequent emission of carbon from fossil fuel-based power plants. This avoidance of carbon emissions has the potential to be four times greater than direct carbon storage over the life of a mature tree.

Frederick Law Olmsted, the designer of Central Park in New York City, considered parks and their trees "the lungs of the city." Dr. Nowak's data show that this

indeed is true. For example, in 1994, he found that trees in New York City removed an estimated 1,821 metric tons (about 14 grams per square meter of leaf canopy) of air pollution, at an estimated value to society of $9.5 million. Air quality improvement in New York City due to pollution removal by trees during daytime hours of the in-leaf season averaged 0.47 percent for particulate matter, 0.45 percent for ozone (O_3), 0.43 percent for sulfur dioxide (SO_2), 0.30 percent for nitrogen dioxide (NO_2), and 0.002 percent for carbon monoxide (CO). Air quality improvement increases with increased canopy cover. Thus, improvement values for urban areas with 100 percent canopy cover can have hourly improvements as high as 15 percent for O_3, 14 percent for SO_2, 13 percent for particulate matter, 8 percent for NO_2, and 0.05 percent for CO. Urban trees also remove particulate pollution by intercepting airborne particles, such as soot on their leaves. Some of the particles are absorbed into the trees, but most are retained on the leaf surface and later resuspended into the atmosphere, washed onto the ground by rain, or carried along in leaf-fall. Thus, vegetation is often only a temporary retention site for particles.

The NE urban forestry unit continues its work to improve and extend the usefulness of the UFORE program, with new modules (for example, effects of urban forests on stream flow and water quality) under development. The UFORE program thus is an important tool for urban foresters, architects, and planners in our cities, suburbs, and towns. For example, UFORE analysis has shown that the number of trees in Baltimore has declined by 4 percent annually from 1999 to 2001.

Given the knowledge that we now have, that trees do more than just look pretty and support bird populations (which are good things in themselves!), it behooves us to use science as the basis for making better management decisions to enhance healthy urban forests. In doing so, we can help improve our planet, our home.

Web Resources

US Department of Agriculture, Forest Service, Northeastern Research Station's Urban Forestry unit
www.fs.fed.us/ne/syracuse
US Department of Energy information
www.eere.energy.gov/consumerinfo/energy_savers/landscaping.html
US Environmental Protection Agency information
www.epa.gov/region6/6xa/trees_heat.htm
New York City urban forestry group
www.oasisnyc.net/resources/street_trees
Heat island effect research at Lawrence-Berkeley Laboratory
http://eande.lbl.gov/HeatIsland/vegetation/Planting.html
Tree planting & placement tips
www.treesaregood.com
Information on the founder of Central Park, NYC
www.fredericklawolmsted.com
Information on historic trees and seedling sources
www.historictrees.org

T·R·E·E — Specific Atmospheric Benefits Provided by the Urban Forest

It's easy to remember the four interactive ways that trees affect air quality in the urban/suburban environment by using the word TREE (you can read more details on the web at www.fs.fed.us/ne/syracuse):

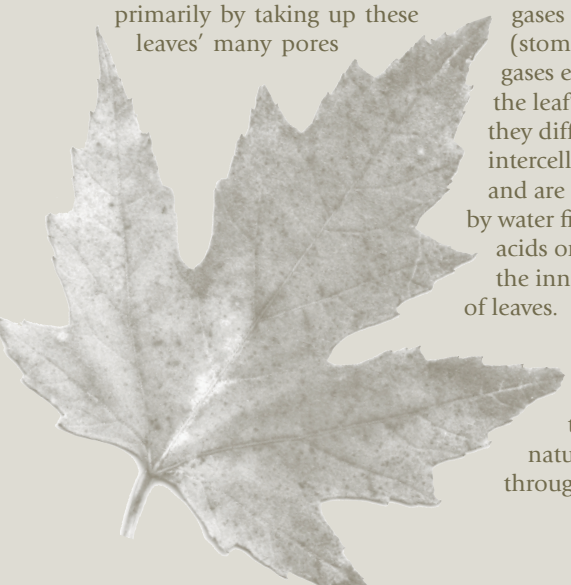
- **T**emperature and microclimate effects
- **R**emoval of air pollutants
- **E**mission of volatile organic compounds by trees and emissions due to tree maintenance
- **E**nergy conservation in buildings and consequent effects on emissions from power plants

Temperature and microclimate efffects — Urban trees provide important cooling effects (cooling from shade and evapotranspiration) that can moderate climate and reduce urban heat-island temperatures by much as 5 °C and also reduce UV rays, help keep pavement and parked cars cooler, and lower rainfall runoff and flooding. In addition, properly planted tree barriers can reduce wind and traffic sounds.

Trees influence temperature and climate, both as individual trees and as urban forests covering entire metropolitan areas. By altering wind speeds, water transpiration, and surface shading, trees affect local climate, thus influencing thermal comfort and air quality. Groups of trees with dense crowns can significantly affect wind. Dr. Gordon Heisler (Forest Service meteorologist) found that wind speeds at 2 meters above ground level were reduced by 60 percent in winter and 67 percent in summer for a residential neighborhood in central Pennsylvania with 67 percent tree cover when compared to speeds in a comparable neighborhood with no trees.

Tree canopies also dramatically influence incoming solar radiation, absorbing as much as 90 percent. Some of the radiation leads to the evaporation and transpiration (evapotranspiration) of water from leaves, cooling both tree leaves and air. Air movement rapidly disperses this cooled air, reducing the overall cooling effect. However, the shade cast by tree canopies reduces solar heating of the ground below, especially street and sidewalk pavements and building which tend to hold heat. Still, these effects can reduce air temperatures by as much as 5 °C.

Removal of pollutants — Trees remove gaseous air pollution, primarily by taking up these gases through their leaves' many pores (stomata). Once gases enter into the leaf's interior, they diffuse into intercellular spaces and are absorbed by water films to form acids or react with the inner surfaces of leaves.



Pollution removal by trees in a city naturally varies throughout the year. Factors that affect pollution removal by trees include seasons, amount of healthy leaf-surface area, local concentrations of pollutants, and weather. Computer simulations using the Urban Forest Effects (UFORE) model developed by Dr. Nowak revealed that average standardized pollution removal by trees in 1994 in northeast corridor cities, as measured in grams (g) removed per square meter (m^2) of tree canopy, ranged from 13.7 g/m^2 (New York City) to 10.5 g/m^2 (Boston).

Trees also remove carbon dioxide (CO_2) from the air. In photosynthesis, the chemical reaction that is the foundation of virtually all life on earth, green plants use the energy of sunlight to detach carbon atoms from the CO_2 molecule and make the structural molecules such as lignin (woody fiber), cellulose (cell walls), and polysaccharides (food storage). This removal of carbon dioxide from the air is termed carbon sequestration. Dr. Nowak has found that large trees store about 3 tons of carbon (1,000 times more than that stored by small trees) and that healthy trees continue to sequester additional carbon each year.

Emission of chemicals — Some trees emit volatile organic compounds (VOCs), natural chemicals that make up essential oils, resins, and other plant products. These can be useful to the tree in attracting pollinators, repelling predators, or providing thermal protection to plants. They can contribute to the formation of ozone (O_3) and CO and their emission is temperature dependent. Because trees generally lower air temperatures, it is believed that increased tree cover lowers overall VOC emissions and, consequently, reduces O_3 levels in urban areas. A computer simulation of ozone conditions in Atlanta revealed that a 20 percent loss in the area's forest could lead to a 14% increase in O_3 concentrations. Although there were fewer trees to emit VOCs, the increase in city air temperatures due to the urban heat island effect from tree loss increased VOC emissions from the remaining trees and anthropogenic sources and altered O_3 photochemistry so that O_3 concentrations increased.

Tree management and maintenance equipment also affect pollutant emissions. Thus, when evaluating the overall net change in air quality due to trees, managers and planners must consider the amount of pollution resulting from maintenance and management activities.

Energy conservation — By shading buildings and reducing air temperatures in the summer and by blocking winds in winter, properly sited trees can reduce heating and cooling needs, thus reducing energy costs and consequent emissions of air pollutants and CO_2 by power plants. 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. Dr. Heisler found that energy use in a house with trees can be 20 to 25 percent lower per year than that for the same house in an open area. Establishing 100 million mature trees around residences in the United States could save an estimated $2 billion dollars annually in reduced energy costs.

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11 Campus Boulevard, Suite 200
Newtown Square, PA 19073-3200

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Dr. David J. Nowak received his B.S. and M.S. degrees from the State University of New York, College of Environmental Science and Forestry, and his Ph.D. from the University of California, Berkeley in 1991. He was a principal scientist on the Chicago Urban Forest Climate Project and is a recipient of American Forests' Urban Forest Medal, recognizing outstanding national contributions in urban forest research, and the Distinguished Science Award of the Northeastern Research Station. He has authored over 115 publications and given over 200 presentations. He is a project leader with the USDA Forest Service's Northeastern Research Station in Syracuse, New York, investigating urban forest structure, health, and change, and its effect on air quality and greenhouse gases.

Drs. Nowak and Heisler's address is USDA Forest Service, Northeastern Research Station, c/o SUNY College of Environmental Science and Forestry, 1100 Irving Avenue, 5 Moon Library, Syracuse, NY 13210; tel: 315-448-3200; e-mail: dnowak@fs.fed.us and gheisler@fs.fed.us.

Dr. Gordon M. Heisler received a B.S. in general forestry from Pennsylvania State University, an M.S. in silviculture from Yale University, and a Ph.D. in forest influences from the State University of New York, College of Environmental Science and Forestry in 1970. He moved from teaching meteorology and ecology at Talcott Mountain Science Center in Avon, CT, to working for the USDA Forest Service's Northeastern Research Station as a meteorologist at various locations, joining Dr. Nowak's unit at the Syracuse laboratory in 1991. He evaluates the influence of trees in urban areas on the physical environment, including wind, air temperature, solar and thermal radiation, outdoor sound, energy use in houses and comfort and health of people outdoors. Currently, he is emphasizing the indirect effects that trees have on human health by modifying ultraviolet radiation. He also participates in the Baltimore Ecosystem Study. He has written numerous research publications and is active in conservation and forestry activities in his local community.