THE EFFECTS OF URBAN TREES ON AIR QUALITY

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

Temperature reduction and other microclimatic effects
Removal of air pollutants
Emission of volatile organic compounds and tree maintenance emissions
Energy effects on buildings

Temperature Reduction: Tree transpiration and tree canopies affect air temperature, radiation absorption and heat storage, wind speed, relative humidity, turbulence, surface albedo, surface roughness and consequently the evolution of the mixing-layer height. These changes in local meteorology can alter pollution concentrations in urban areas[b]. Although trees usually contribute to cooler summer air temperatures, their presence can increase air temperatures in some instances[c]. In areas with scattered tree canopies, radiation can reach and heat ground surfaces; at the same time, the canopy may reduce atmospheric mixing such that cooler air is prevented from reaching the area. In this case, tree shade and transpiration may not compensate for the increased air temperatures due to reduced mixing[d]. Maximum mid-day air temperature reductions due to trees are in the range of 0.04°C to 0.2°C per percent canopy cover increase[e]. Below individual and small groups of trees over grass, mid-day air temperatures at 1.5 m above ground are 0.7°C to 1.3°C cooler than in an open area[f]. Reduced air temperature due to trees can improve air quality because the emission of many pollutants and/or ozone-forming chemicals are temperature dependent. Decreased air temperature can also reduce ozone formation.

Removal of Air Pollutants: Trees remove gaseous air pollution primarily by uptake via leaf stomata, though some gases are removed by the plant surface. Once inside the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids or react with inner-leaf surfaces[g]. Trees also remove pollution by intercepting airborne particles. Some particles can be absorbed into the tree, though most particles that are intercepted are retained on the plant surface. The intercepted particle often is resuspended to the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall[g]. Consequently, vegetation is only a temporary retention site for many atmospheric particles.

In 1994, trees in New York City removed an estimated 1,821 metric tons of air pollution at an estimated value to society of $9.5 million. Air pollution removal by urban forests in New York was greater than in Atlanta (1,196 t; $6.5 million) and Baltimore (499 t; $2.7 million), but pollution removal per m^2 of canopy cover was fairly similar among these cities (New York: 13.7 $g/m^2/yr$; Baltimore: 12.2 $g/m^2/yr$; Atlanta: 10.6 $g/m^2/yr$)[h]. These standardized pollution removal rates differ among cities according to the amount of air pollution, length of in-leaf season, precipitation, and other meteorological variables. Large healthy trees greater than 77 cm in diameter remove approximately 70 times more air pollution annually (1.4 kg/yr) than small healthy trees less than 8 cm in diameter (0.02 kg/yr)[k].

Air quality improvement in New York City due to pollution removal by trees during daytime of the in-leaf season averaged 0.47% for particulate matter, 0.45% for ozone, 0.43% for sulfur dioxide, 0.30% for nitrogen dioxide, and 0.002% for carbon monoxide. Air quality improves with increased percent tree cover and decreased mixing-layer heights. In urban areas with 100% tree cover (i.e., contiguous forest stands), short-term improvements in air quality (one hour) from pollution removal by trees were as high as 15% for ozone, 14% for sulfur dioxide, 13% for particulate matter, 8% for nitrogen dioxide, and 0.05% for carbon monoxide[h].

Emission of Volatile Organic Compounds (VOCs): Emissions of volatile organic compounds by trees can contribute to the formation of ozone and carbon monoxide. However, in atmospheres with low nitrogen oxide concentrations (e.g., some rural environments), VOCs may actually remove ozone[i,j]. Because VOC emissions are temperature dependent and trees generally lower air temperatures, increased tree cover can lower overall VOC emissions and, consequently, ozone levels in urban areas[l].

VOC emission rates also vary by species. Nine genera that have the highest standardized isoprene emission rate[m,n], and therefore the greatest relative effect among genera on increasing ozone, are: beefwood (*Casuarina* spp.), *Eucalyptus* spp., sweetgum (*Liquidambar* spp.), black gum (*Nyssa* spp.), sycamore (*Platanus* spp.), poplar (*Populus* spp.), oak (*Quercus* spp.), black locust (*Robinia* spp.), and willow (*Salix* spp.). However, due to the high degree of uncertainty in atmospheric modeling, results are currently inconclusive as to whether these genera will contribute to an overall net formation of ozone in cities (i.e., ozone formation from VOC emissions are greater than ozone removal). Some common genera in Brooklyn, NY, with the greatest relative effect on lowering ozone were mulberry (*Morus* spp.), cherry (*Prunus* spp.), linden (*Tilia* spp.) and honey locust (*Gleditsia* sp.)[n].

Because urban trees often receive relatively large inputs of energy, primarily from fossil fuels, to maintain vegetation structure, the emissions from these maintenance activities need to be considered in determining the ultimate net effect of urban forests on air quality. Various types of equipment are used to plant, maintain, and remove vegetation in cities. These equipment include various vehicles for transport or maintenance, chain saws, back hoes, leaf blowers, chippers, and shredders. The use and combustion of fossil fuels to power this equipment leads to the emission of carbon dioxide (approximately 0.7 kg/l of gasoline, including manufacturing emissions[o]) and other chemicals such as VOCs, carbon monoxide, nitrogen and sulfur oxides, and particulate matter[p].

Trees in parking lots can also affect evaporative emissions from vehicles, particularly through tree shade. Increasing parking lot tree cover from 8% to 50% could reduce Sacramento County, CA, light duty vehicle VOC evaporative emission rates by 2% and nitrogen oxide start emissions by less than 1%[q].

Energy Effects on Buildings: Trees reduce building energy use by lowering temperatures and shading buildings during the summer, and blocking winds in winter[r]. However, they also can increase energy use by shading buildings in winter, and may increase or decrease energy use by blocking summer breezes. Thus, proper tree placement near buildings is critical to achieve maximum building energy conservation benefits.

When building energy use is lowered, pollutant emissions from power plants are also lowered. While lower pollutant emissions generally improve air quality, lower nitrogen oxide emissions, particularly ground-level emissions, may lead to a local increase in ozone concentrations under certain conditions due to nitrogen oxide scavenging of ozone[s]. The cumulative and interactive effects of trees on meteorology, pollution removal, and VOC and power plant emissions determine the overall impact of trees on air pollution.

Combined Effects: Changes in urban microclimate can affect pollution emission and formation, particularly the formation of ozone. A model simulation of a 20 percent loss in the Atlanta area forest due to urbanization led to a 14 percent increase in ozone concentrations for a modeled day[l]. Although there were fewer trees to emit VOCs, an increase in Atlanta's air temperatures due to the urban heat island, which occurred concomitantly with tree loss, increased VOC emissions from the remaining trees and anthropogenic sources, and altered ozone chemistry such that concentrations of ozone increased.

A model simulation of California's South Coast Air Basin suggests that the air quality impacts of increased urban tree cover may be locally positive or negative with respect to ozone. The net basin-wide effect of increased urban vegetation is a decrease in ozone concentrations if the additional trees are low VOC emitters[t].

Modeling the effects of increased urban tree cover on ozone concentrations from Washington, DC to central Massachusetts reveals that urban trees generally reduce ozone concentrations in cities, but tend to slightly increase average ozone concentrations in the overall modeling domain. Interactions of the effects of trees on the physical and chemical environment demonstrate that trees can cause changes in pollution removal rates and meteorology, particularly air temperatures, wind fields, and mixing-layer heights, which, in turn, affect ozone concentrations. Changes in urban tree species composition had no detectable effect on ozone concentrations[u]. Modeling of the New York City metropolitan area also reveal that increasing tree cover 10% within urban areas reduced maximum ozone levels by about 4 ppb, which was about 37% of the amount needed for attainment[v].

Urban Forest Management: Urban forest management strategies to help improve air quality include[w]:

- Increase the number of healthy trees (increases pollution removal).
- Sustain existing tree cover (maintains 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 (reduces long-term pollutant emissions from planting and removal).
- Use low maintenance trees (reduces pollutants emissions from maintenance activities).
- Reduce fossil fuel use in maintaining vegetation (reduces pollutant emissions).
- Plant trees in energy conserving locations (reduces pollutant emissions from power plants).
- Plant trees to shade parked cars (reduces vehicular VOC emissions).
- Supply ample water to vegetation (enhances pollution removal and temperature reduction).
- Plant trees in polluted areas or heavily populated areas (maximizes tree air quality benefits).
- Avoid pollutant sensitive species (increases tree health).
- Utilize evergreen trees for particulate matter reduction (year-round removal of particles).

[a]Nowak, D.J.. 1995. Trees pollute? A "TREE" explains it all, in: Proc. 7th Natl. Urban For. Conf., (C. Kollin and M. Barratt, eds.), American Forests, Washington, DC, pp. 28-30.

[b]Nowak, D.J., McHale P.J., Ibarra, M., Crane, D., Stevens, J., and Luley, C. 1998. Modeling the effects of urban vegetation on air pollution, In: Air Pollution Modeling and Its Application XII. (S. Gryning amd N. Chaumerliac, eds.) Plenum Press, New York, pp. 399-407.

[c]Myrup, L.O., McGinn, C.E., and Flocchini, R.G. 1991. An analysis of microclimate variation in a suburban environment, in: Seventh Conference of Applied Climatology, American Meteorological Society, Boston, MA, pp. 172-179.

[d]Heisler, G. M., Grant, R. H., Grimmond, S., and Souch, C. 1995. Urban forests--cooling our communities? In: Inside Urban Ecosystems, Proc. 7th Nat. Urban Forest Conf., American Forests, Washington, DC. pp. 31-34.

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

[f]Souch, C.A. and Souch, C. 1993. The effect of trees on summertime below canopy urban climates: a case study, Bloomington, Indiana. *J. Arboric*. 19(5):303-312.

[g]Smith, W. H. 1990. Air pollution and forests. New York: Springer-Verlag. 618 p.

[h]Nowak, D.J. and Crane, D.E. 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. USDA Forest Service General Technical Report NC-212. St. Paul, MN. pp. 714-720.

[i]Crutzen, P.J., Delany, A.C., Greenberg, J. Haagenson, P., Heidt, L. Lueb, R., Pollock, W., Seiler, W., Wartburg, A., and Zimmerman, P. 1985. Tropospheric chemical composition measurements in Brazil during the dry season. *J. Atmos. Chem*. 2: 233-256

[j]Jacob, D.J. and Wofsy, S.C. 1988. Photochemistry of biogenic emissions over the Amazon forest. *J. Geophys. Res*. 93(D2): 1477-1486.

[k]Nowak, D.J. 1994d. Air pollution removal by Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service General Technical Report NE-186. pp. 63-81.

[l]Cardelino, C.A. and Chameides, W.L. 1990. Natural hydrocarbons, urbanization, and urban ozone. *J. Geophys. Res.* 95(D9):13,971-13,979.

[m]Geron, C.D., Guenther, A.B., and Pierce, T.E. 1994. An improved model for estimating emissions of volatile organic compounds from forests in the eastern United States. *J. Geophys. Res*. 99(D6):12,773-12,791.

[n]Nowak, D.J., Crane, D.E., Stevens, J.C., and Ibarra, M. 2002. Brooklyn's Urban Forest. USDA Forest Service Gen. Tech. Rep. NE-290. 107 p.

[o]Graham, R.L., Wright, L.L., and Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO_2 emissions. *Climatic Change*. 22: 223-238.

[p]U.S. Environmental Protection Agency. 1991. Nonroad engine and vehicle emission study -- report. USEPA Office of Air and Radiation ANR-43. EPA-21A-2001. Washington, DC.

[q]Scott, K.I., Simpson, J.R., and McPherson, E.G. 1999. Effects of tree cover on parking lot microclimate and vehicle emissions. *J. Arboric*. 25(3):129-142.

[r]Heisler, G.M. 1986. Energy savings with trees. *J. Arboric*. 12(5):113-125.

[s]Rao, S. T. and Sistla, G. 1993. Efficacy of nitrogen oxides and hydrocarbons emissions control in ozone attainment strategies as predicted by the Urban Airshed Model. *Water, Air, and Soil Pollution*. 67:95-116.

[t]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.

[u]Nowak, D.J., Civerolo, K.L., Rao, S.T., Sistla, S., Luley, C.J., and Crane, D.E. 2000. A modeling study of the impact of urban trees on ozone. *Atmos. Environ*. 34:1601-1613.

[v]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.

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

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